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Environmental Policies and Firm Behavior with Endogenous Investment in R & D

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Abstract

This paper investigates upon the optimal amount of oil usage in an economy characterized by competitive firms and by a monopolistic innovator. It is close in spirit to Denicolo 1999 and Parry 2003. There are two alternative oil saving technologies: the conventional one is promptly available to firms while the advanced one, providing more efficiency in oil saving, must be paid to the monopolistic innovator. By assuming that innovation follows a Poisson process, whose arrival rate depends on the amount of resources invested in R & D, we show that central authority provides higher level of social welfare than market instruments.

Keywords: Environmental Policies, Technological Change, Energy Saving, Welfare Analysis

1. Introduction

During the last years, several authors have included R & D into the analysis of environmental policy incentives, giving life to a new research branch. This literature can be divided in two strands. The first one is characterized by the microeconomic approach, making use of the game theory in order to study the strategic behavior in equilibrium. The major parts of these models are characterized by a partial equilibrium approach, which can be static [1] or quasidynamic, where each actor-firm, regulator and innovator-chooses in a sequential way [2]. This literature captures several aspect, such as market conditions, uncertainty about the R & D success and the environmental damage. The second research strand follows the endogenous growth approach [3,4]. We concentrate the attention on the first case, where innovation is mainly firm specific and depends on the total amount of R & D needed to developing energy saving technologies.

In this kind of models, where innovation is a private good, the literature investigates upon the optimal policy instrument to develop and diffuse the new technology. There are two alternative strategies to do so: the ex ante and the ex post policy. Several authors assume that in the former there is only one innovator [5,6] or several identical firms, engaging in a patent race: in the latter just one innovator prevails in the market, gaining market power. This innovator can sell or license to the other firms which choose for adoption or not. For this reason it becomes crucial the commitment and the timing of policies, which can make the difference in terms of welfare results [7].

Denicolo was the first at explicitly comparing ex ante and ex post regulation both for emission taxes and tradable permits in a model with an upstream monopolistic R & D firm and many polluting downstream firms [4]. In this model the degree of emissions reduction depends on R & D investment and he finds that taxes and permits give the same results for ex post regulation. However, if the regulator adopts the ex ante policy, the first best equilibrium doesn't exist, since both the instruments lead to underinvestment in R & D. The author shows an alternative solution, where the regulator can commit to the second-best optimal level of the instruments, but the choice depends on the social cost of pollution and there is no certainty about the effectiveness of taxes and permits.

Unlike most of other contributions, in Parry [8] there is free entry on both markets, and he shows that a higher tax rate produces a double effect: it involves a smaller number of polluting firms but we know that the firms with the highest willingness to pay for the new technology stay in the market, so a higher tax also induces a higher license fee. Parry [7] introduced some variations to his model and he investigated upon the magnitude of welfare gain coming from abatement cost reducing innovation, relative to the welfare gain induced by optimal pollution control over time. He found that this magnitude depends on three factors: the initially optimal abatement level, the speed at which innovation reduces future abatement costs (on the optimal innovation path) and the social discount rate. This factor plays a key role in the determinants controlling the welfare gain from innovation and pollution control. Parry shows that there are several scenarios where the welfare gains from innovation are smaller than those which come from the pollution control. In many cases the R & D investment decided by regulator does not coincide with the market decision. This result seems to contradict the earlier assertion by economist who supported the welfare gain from innovation.

Our paper is close in spirit to Denicolo [5] and Parry [6] and represents a further refinement of Gaeta [2], which analyzes how market instruments are able to mimic optimal social choice in driving the adoption of advanced oil saving technologies. In that paper the advanced technology was exogenously available to investing firms. This paper analyzes the case where the advanced technology comes from an innovating monopolistic firm investing in R & D. Main result is that, with endogenous R & D, the social planner provides Pareto optimal solution that market is not able to mimic. These results are in line with the cited literature, although our analysis involves a different microeconomic setup. Under this point of view our results confirm that market instruments provide sub-optimal oil usage amount in the economy. Even when we want to measure social welfare by means of the amount of R & D, as some authors point out, the central policy provides always higher level of investment than the free market.

2. The Model: Firms Behaviour and Market Instruments

We are going to assume an economy characterized by two sectors: manufacturing and R & D. In the manufacturing sector there are n firms acting in a competitive way. Production uses oil only. Oil is costly and polluting. Government wants to reduce oil usage in the economy by means of suitable policies. As in [1], there are two alternative oil saving technologies; conventional and advanced. The first one is promptly available free of charge; the second one involves a lump sum cost. Firms act by choosing optimal oil using; in a free market, without central policy, firms choose the maximum amount of oil, O_{Max}. With centralized policies, firms change their optimal plan; we are going to take into account how alternative oil saving policies (tax, permits and command and control) affect firms behaviour.

2.1. Taxation

When firms are charged with a tax on the amount of oil usage O, profits are given by:

$$\pi_0 = Q(O_0) - (P_0 + \tau)O_0 - C_0(O_0) \quad (1)$$

$$\pi_1 = Q(O_1) - (P_0 + \tau)O_1 - C_1(O_1) - P_R \quad (2)$$

where 0 means that the firm is not adopting the advanced technology and 1 the opposite. Functional assumptions are as usual: $Q(O) > 0,\ Q'(O) > 0, Q''(O) < 0$ and $O \in [0, O_{Max}]$. C is the oil saving cost related to the chosen technology. As usual we are going to assume convexity in $C, C(O) > 0,\ C'(O) > 0, C''(O) > 0$. P_O is the exogenous oil price and τ the tax rate. Moreover we assume that the advanced technology is more efficient in oil saving, thanks to research and development *m.* Efficiency is given by the *r* coefficient that depends on *m*, *i.e.* $C_1 = (1 - r(m))C_0$ with $r(m) \in [0,1],\ r'(m) > 0$. P_R is the patent price paid by firms adopting the advanced technology.

Firms maximize profits (Equations (1) and (2)) with respect to the oil usage O_0 and O_1, given τ , P_R and m. The optimal oil usage is implicitly given by the following first order conditions.

$$Max\ \pi \rightarrow O_0^*(\tau \mid P_0) \quad O_1^*(\tau, P_R, m \mid P_0)$$

Whenever $\pi_1 > \pi_0$ all firms are induced to adopt the advanced technology and so $n_1 = n$ Otherwise if $\pi_1 = \pi_0,\ n_1$ is not determined.

A single firm must choose which technology is going to adopt. This is done by comparing profits in both situations:

$$\Delta\pi = \pi_1 - \pi_0 \rightarrow \Delta\pi(\tau, P_R, m \middle| P_0, k) \quad (3)$$

R & D is performed by a single monopolistic firm. It invests *m* in R & D and obtains the new technology with probability *p*(*m*), that follows a Poisson process with cumulative distribution function $(1 - e^{-\phi m})$. The R & D cost for unit of research is *k* so that the innovating firm produces a quantity of R & D that makes equal the expected profit to the actual cost of investing in R & D (this is standard in the neo-shumpeterian approach). The arbitrage equation is

$$p(m)n_1P_R = km \quad (4)$$

We can solve this equation in order to get P_R $(m, n_1 \mid k)$ and then we substitute in the Equation (3). By doing so, we have $\Delta\pi(\tau, m, n_1 \mid P_0, k, P_0)$.

In the decentralized economy τ and n_1 are exogenous to the firm, so firm behaviour in adopting or not the advanced technology depends on $\Delta\pi(m, \mid \tau, n_1, P_0, k, P_0)$, where *m* depends on the R & D firm.

With partial adoption $\Delta\pi = 0$ and this leads to $m(n_1 \mid \tau, P_0, k, P_0)$. The main goal is to investigate upon this relationship and on the general equilibrium of the economy.

With full adoption $n_1 = 1$ and $\Delta\pi > 0$. In such a case the R & D firm chooses m in order to induce $\Delta\pi > 0$ but, once more, nothing assures that such equilibrium does exist and more analytical work must be developed.

2.2. Partial Adoption

Let us assume that the cost reduction function follows:

$$C_0 = \frac{\alpha}{2}(O_M - O_0)^2$$

$$C_1 = (1 - r(m))\frac{\alpha}{2}(O_M - O_1)^2$$

Profit maximization leads to:

$$O_0^*(\tau) = Q'^{-1}\left(P_0 + \tau + C_0'(O_0)\right)$$

$$O_1^*(\tau, m) = Q'^{-1}\left(P_0 + \tau + C_1'(O_1) + P_R\right)$$

where Q'^{-1} is the inverse first order derivative. When partial adoption is at work we have $\Delta\pi(\tau, P_R, m \mid k, P_0) = 0$. Equilibrium is determined by closing the model through the R & D equation $p(m)n_1 P_R(\tau, m) = km$. Nonetheless the left hand side is characterized by a strong non-linearity and in general not much can be said on the amount of R & D $m(\tau, n_1)$ characterizing the equilibrium. For further investigation, we are going to assume homothetic production function, $Q = \log(O)$ and that probabilities of new discovery follows a Poisson law $p(m) = 1 - e^{-\phi m}$. At the same time we are going to assume $r(m) = 1 - e^{-\lambda m}$.

Let us investigate upon the first order conditions. Profit maximization leads to:

$$\frac{1}{O_0} - P_0 + \alpha(O_M - O_0) = \tau \tag{5}$$

$$\frac{1}{O_1} - P_0 + \alpha(1 - r(m))(O_M - O_1) = \tau \tag{6}$$

First order conditions mean that firms uses oil until marginal profit is equal to the usage cost given by the tax rate. Solving Equations (5) and (6) provides optimal oil usage conditioned on the tax rate. Following lemma holds:

Lemma 1 *First order conditions imply*

$$O_1^* < O_0^* \in (0, O_{Max}).$$

Proof. When $O = O_{Max}$ we have $O_1^* = O_0^* = O_{Max} = \frac{1}{P_o + \tau}$. Being $(1 - r(m)) < 1$ Equation (6) lies everywhere under Equation (5). (end of proof).

Equation (6) links O_1 to the amount of R & D via $r(m)$. The relationship is linear-concave in r, being O_1 a quadratic function. Following lemma holds:

Lemma 2 O_1^* *is decreasing in m.*

Proof. By normalizing $\alpha = 1$, from Equation (6) we have:

$\lim_{r \to 0} O_1^* = \chi$ with

$$\chi = 5 + 0.5\left(\sqrt{(P_0 + \tau)^2 - 20(P_0 + \tau) + 104} - (P_0 + \tau)\right) > 0$$

$\lim_{r \to 1} O_1^* = \chi_2$ with

$$\chi_2 = 5 + 50\left(\sqrt{(P_0 + \tau)^2 - 0.20(P_0 + \tau) + 0.05} - (P_0 + \tau)\right) < \chi$$

Given the linear concavity of O_1 w.r.t. r and being $\frac{\partial r}{\partial m} > 0$ the lemma holds. (end of proof).

The lemma underlines the oil saving feature of R & D; more investment in new technologies has a positive effect in the economy as reduces the optimal amount of oil usage per firm.

Once the optimal oil usage $O_1^*(\tau)\, O_0^*(\tau)$ is carried out, Equation (2) provides the patent price P_R given the perfect market condition $\pi_1 = \pi_0$.

$$P_R(m|\tau) = \log(O_1) - (P_0 + \tau)O_1 - \frac{\alpha}{2}(1 - r(m))(O_M - O_1)^2 - [\log(O_0) - (P_0 + \tau)O_0 - \frac{\alpha}{2}(O_M - O_1)^2] \tag{7}$$

The Equation (7) sets the patent price that firms are allowed to pay for using the new technology. It depends on the optimal amount of R & D that the monopolistic firm is investing. The relationship is strongly non linear in m. The equation can be rearranged in the following way:

$$P_R(m|\tau) = a(O_0^*) + b(m) + c(m) \tag{8}$$

with $a(O_0^*) = \left[\log(O_0) - (P_0 + \tau)O_0 - \frac{\alpha}{2}(O_M - O_0)^2\right]$,

$$b(m) = \log(O_1) - (P_0 + \tau)O_1 - \frac{\alpha}{2}(O_M - O_1)^2$$

and

$$c(m) = \frac{\alpha}{2} r(m)(O_M - O_1(m))^2.$$

Following lemma holds:

Lemma 3 P_R *is increasing in m. Nevertheless second order derivative can not be signed unambiguously.*

Proof. By deriving Equation (8) with respect to m we obtain:

$$\frac{\partial b(m)}{\partial m} = \left(\frac{1}{O_1} + \alpha(O_M - O_1) - (P_0 + \tau)\right)\frac{\partial O_1}{\partial m}.$$

We are going to assume that the term in brackets is negative and so, by Lemma 2, $\frac{\partial b(m)}{\partial m} > 0$. Moreover:

$$\frac{\partial c(m)}{\partial m} = \frac{\alpha}{2}\frac{\partial r}{m}(O_M - O_1(m))^2 - \alpha r(m)(O_M - O_1(m))^2$$

$$\frac{\partial O_1}{\partial m} = \alpha(O_M - O_1(m))^2\left[\frac{1}{2}\frac{\partial r}{\partial m} - r(m)\frac{\partial O_1}{\partial m}\right] > 0$$

However, second order derivatives are not unambiguously determined and so convexity and concavity of the function can alternatively be viable. (end of proof).

The model is closed by analyzing how the monopolistic firm chooses the price P_R according to Equation (4).

Following lemma holds:

Lemma 4 *The supply curve for* P_R *is monotonically increasing in m.*

Proof. Let us rewrite Equation (4) in the following way:

$$P_R = \frac{k}{n_1}\frac{m}{(1-e^{-\phi m})}$$

In a decentralized economy, n_1 does not depend on m. Hence:

$$\frac{\partial P_R}{\partial m} = \frac{k}{n_1}\frac{((1-e^{-\phi m}) - m\phi e^{-\phi m})}{(1-e^{-\phi m})^2}$$

and so:

$$\lim_{m\to 0}\frac{\partial P_R}{\partial m} = \frac{1}{2}\frac{k}{n_1} > 0$$

$$\lim_{m\to \infty}\frac{\partial P_R}{\partial m} = \infty$$

Moreover first derivative is zero only when $m = 0$. (end of proof).

General equilibrium comes from comparing P_R by Lemmas 3 and 4, *i.e.* by crossing supply and demand for *m*. By Lemma 3, multiple equilibria are viable results. Nevertheless stable equilibrium requires that Brouwer's assumptions for fixed point are satisfied. In general, number and stability of equilibrium depend on parameters. Moreover, the general equilibrium depends on τ and is not possible to asses how taxation affects market equilibrium. For such a reason the model will be numerically analyzed by normalizing $\alpha = \phi = \lambda = 1$.

Following **Figure 1** shows the equilibrium relationship in such a case.

Although we are working in a static context, some equilibria are unstable and so not robust at the bargaining process involved by P_R. Stability of Brouwer fixed point theorem requires that first derivative be less than one in the neighborhood of the crossing point between demand and supply; this leaves just one single stable equilibrium. Since we are going to analyze the model by through some numerical investigations the unstable equilibria are ruled out from the analysis.

Table 1 sums up some numerical exercises (deep parameters $\alpha = \phi = \lambda = 1$).

Main findings are the strict non linearity of the functions; τ is defined on a subset only of the feasible domain $[0,1]$ according to the number of adopting firms. What is relevant is the monotonicity of m w.r.t. τ; an increase in taxation, all other things equal, leads firms to reduce remarkably the oil usage in both technology. This induces the R & D firm to invest more and to charge a higher price (or conversely). This means that taxation matters for the amount of R & D in the economy. However it is hard to establish a hierarchy of equilibrium. With n_1 = 0.25 the tax rate is high; this drives firms to reduce remarkably oil usage; nonetheless the maximum investment in R & D is obtained with n_1 = 0.75. This warns us on the government objective function: as the literature remarks, by adopting the maximum investment in R & D or the lowest level of oil usage as the government objective function is not neutral for results. The first target involves lower level of taxation and conversely.

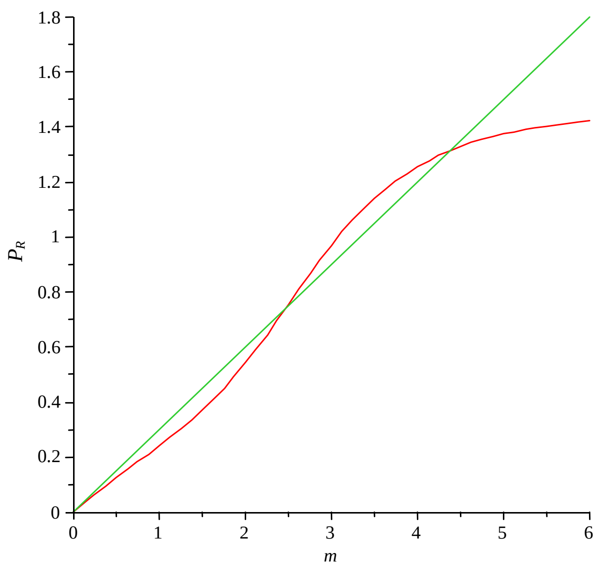

Figure 1. Multiple equilibria.

Table 1. Taxation outcome.

τ	0.80	0.9	τ	0.2	0.3	0.4	τ	0.2	0.30	0.4
O_0	9.25	9.15	O_0	9.64	9.55	9.21	O_0	9.65	9.12	9.55
O_1	1.44	1.17	O_1	9.17	8.83	7.89	O_1	8.15	4.11	2.36
m	4.38	5.30	m	1.57	1.84	2.04	m	2.95	4.83	8.65
P_R	5.32	6.4	P_R	2.16	2.32	4.41	P_R	1.34	1.86	3.66

$n_1 = 0.25, \tau \in (0.8,1)$ $n_1 = 0.50, \tau \in (0.2,0.4)$ $n_1 = 0.75, \tau \in (0.1,0.5)$

2.3. Full Adoption

When $\Delta\pi(\tau, P_R, m \mid k, P_0) > 0$ every firm invests in the advanced technology and $n_1 = 1$. Profits are:

$$\pi_1 = Q(O_1) - (P_0 + \tau)O_1 - C_1(O_1) - P_R$$

maximization leads to $O_1^*(\tau, P_R, m \mid P_0)$. In such a case the solution is quite simple; once solved for O_1^*, the optimal amount of R & D can be carried out by Equation (4).

3. Permits

Before analyzing the social planner problem, it is useful to compare results obtained in the tax case with alternative market based instruments. Let us start from permits. In such a case firms are permitted to use oil in a given amount. According to literature, we are going to distinguish between costly, auctioned and free permits (grandfathering). When firms are charged with a price P_p per unit of oil usage, results are not different from taxation. In fact, each firm acts in a price-taker environment, taking P_p as the tax rate, *i.e.* $P_p = \tau$ and Equations (1) and (2) are unchanged.

$$\pi_0 = Q(O_0) - (P_0 + P_p)O_0 - C_0(O_0) \quad (9)$$

$$\pi_1 = Q(O_1) - (P_0 + P_p)O_1 - C_1(O_1) - P_R \quad (10)$$

With auctioned permits results are different. Let us assume that L permits are exogenously issued by central authority and P_p be the market clearing price. Unlike costly permits, when partial adoption is at work, the following constraint must be satisfied:

$$L = n_1 O_1 + (n - n_1) O_0$$

where oil usage comes from firm first order conditions. This means that n_1 is not a free parameter but depends on L:

$$n_1 = \frac{nO_0 - L}{O_0 - O_1}$$

By replying simulations by taking into account such a constraint leads to **Table 2**.

By comparing results with the ones obtained with the tax rate, we can conclude that auctioned permits confirm the monotonicity of m w.r.t. the cost of oil usage related to permits; an increase in P_p, all other things equal, leads firms to reduce remarkably the oil usage in both technologies and to increase the investment in R & D, m. Nevertheless, auctioned permits allow less oil saving than non-auctioned permits (or taxation) and involve consequently a lower level of investment in R & D. As literature shows, taxation provides more incentive to firm in reducing oil usage.

Table 2. Permits outcome.

P_p	0.75	0.80	0.95	P_p	0.2	0.30	0.50	P_p	0.2	0.30	0.45
O_0	9.30	9.25	9.1	O_0	9.85	9.75	9.55	O_0	9.85	9.75	9.60
O_1	1.96	1.44	1.08	O_1	9.57	9.03	2.14	O_1	8.55	4.31	2.24
m	3.51	4.38	5.7	m	1.51	1.63	5.50	m	2.86	4.43	7.63
P_R	4.34	5.32	6.86	P_R	1.16	1.21	3.31	P_R	1.21	1.79	3.05
L	7.46	7.30	7.10	L	9.71	9.39	5.84	L	8.87	5.67	4.08

$n_1 = 0.25$ $n_1 = 0.50$ $n_1 = 0.75$

The last case we are going to analyze is free permits (grandfathering); in such a case each firm is endowed with the permits of using a given oil quantity O_p. However, since advanced technology allows firms to save out of oil, investor firms can trade their permits to not-adopting ones. Partial adoption means that firms are indifferent and the following constraint must hold:

$$Q(O_0) - (P_0)O_0 - C_0(O_0) - P_p(O_0 - O_P)$$
$$= Q(O_1) - (P_0)O_1 - C_1(O_1) - P_R + P_p(O_P - O_1)$$

given that $P_p O_P$ cancels out in both sides we obtain Equations (9) and (10). So incentive to adopt the new technology is the same under free or costly permits.

We can sum up results in the following proposition:

Proposition 5 *Non auctioned and free permits allows same results in terms of oil saving and investment in R & D than auctioned permits.*

4. Command and Control

This last section is devoted to the so called "command and control" policy; in such a case a firm is not allowed to use more than O^* units of oil. Firms are indifferent when the following condition is satisfied:

$$Q(O^*) - C_0(O^*) = Q(O^*) - C_1(O^*) - P_R$$

since $C_0(O^*) > C_1(O^*)$ the above equation is decreasing in O^*; in other words, the relaxing of the constraint on oil usage reduces the incentive to adopt the new technology. This means that for $O > O^*$ no firms will adopt the new technology and vice versa.

5. The Centralized Economy

In this section we are going to compare market equilibrium with the one chosen by a central authority. The central planner has to maximize the social welfare given by the private firm profit net of environmental damage,

$$D(O_o, O_1) = (n_1 O_1 + (n - n_1) O_0)^2 \ :$$

$$V = \underset{n_1}{Max}[n_1 \pi_1 + (n - n_1)\pi_0 - (n_1 O_1 + (n - n_1) O_0)^2] \quad (11)$$
$$s.t: O_1, O_0 \in [0, O_{Max}]$$

The government chooses the optimal oil usage, the optimal number of adopting firms and leaves the optimal size of R & D to the monopolistic firm. The lagrangian function does not allow a closed form solution. We have to solve for:

$$O_0^*: \frac{\partial \pi_0}{\partial O_0} = 2(n_1 O_1 + (n - n_1) O_0) \quad (12)$$

$$O_1^*: \frac{\partial \pi_1}{\partial O_1} = 2(n_1 O_1 + (n - n_1) O_0) \quad (13)$$

Equations (12) and (13) mean that the private marginal profit must be equal to the marginal social cost; in the decentralized economy these must be equal to the tax rate.

The model is closed by:

$$n_1^*: \pi_1 - \pi_0 = 2(n_1 O_1 + (n - n_1) O_0)(O_1 - O_0) \quad (14)$$

with:

$$\pi_1 - \pi_0 > 0 \rightarrow n_1 = 1$$
$$\pi_1 - \pi_0 < 0 \rightarrow n_1 = 0$$
$$\pi_1 - \pi_0 = 0 \rightarrow n_1 O_1 = (n - n_1) O_0$$

The R & D is still determined by Equation (4) once that oil usage and market size are optimally chosen.

Basically the model uses a fixed point argument to find social optimum; Equations (12) and (13) provide $O_0(n_1, \Pr, m)$ and $O_1(n_1, \Pr, m)$. These results plugged in 14 provide solution for n_1 and finally Equation (4) provides the optimal R & D.

Unfortunately the algebra can not be managed in an easy way. However, assumptions on functional form assure that an equilibrium do exist. **Figure 2** shows Equation (14); as can be seen, it does exist $n_1 \in [0,1]$ that satisfies the $\Delta\pi = 0$ constraint.

For analyzing the model, a numerical routine in Maple V has been written down. The routine follows a fixed point algorithm with a backward induction; by starting from a prior on m and P_R the optimal values for n_1, O_1 and O_0 are calculated through Equations (12), (13) and (14). Then the prior is updated with Equation (4) and the routine goes on, until the fixed point is achieved.

By using $\alpha = \phi = \lambda = 1$, the numerical simulation brings to this optimal value for oil usage and the consequent size of R & D.

The optimal number of adopting firms is $n_1 = 0.6$; what is striking is the very low level of oil usage chosen by the central authority. The relative high demand for advanced technology pushes up the price of patents, which in turn induces the R & D firm to invest more. By comparing this solution to the ones obtained in the market analysis with $n_1 = 0.6$, the social planner chooses always the lowest level of oil. This is summarized in the following proposition.

Proposition 6 *In the centralized economy, 60% of manufacturing firms uses the advanced technology for oil saving. This induces a very low level of oil usage per firm. By comparing such a result with market based instruments, the central economy provides the lowest level of oil usage with respect to the market equilibrium.*

The difference between social and market equilibrium comes from the more complex relationship entailed by the social question. By comparing first order conditions in both situations, we have that, in the decentralized economy, the marginal profit is equal to the market instrument (tax or permits) which is exogenously given by the government. In the decentralized economy, first order conditions lead to:

$$Q'(O_i(m, P_R)) - P_0 - C''(O_i(m, P_R)) = \tau \qquad i = 0, 1 \quad (15)$$

while in the centralized economy we have:

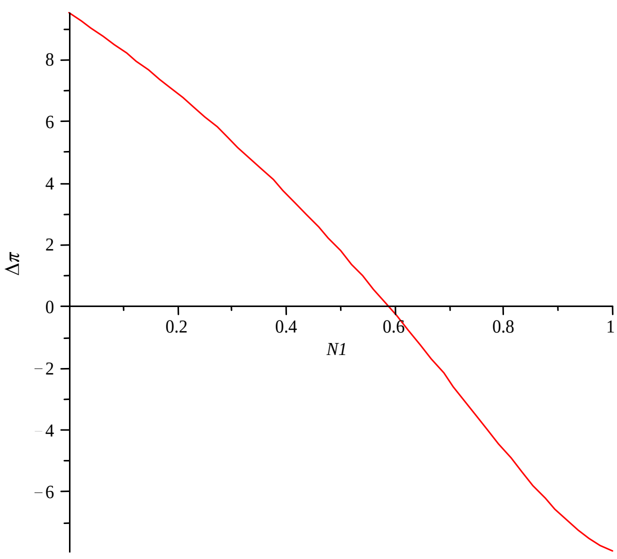

Figure 2. Partial adoption.

Table 3. Centralized economy.

O_0	5.03
O_1	0.20
m	11.5
P_R	14
n_1	0.6

$$Q'(O_i(m,P_R)) - P_o - C'(O_i(m,P_R))$$
$$= 2(n_1O_1(m,P_R) + (n-n_1)O_0(m,P_R)) \quad i = 0,1$$

In the last equation both sides depend on the amount of R & D which responds to the amount of oil usage in the economy. Such a situation is completely different from the decentralized solution where tax can be exogenously adjusted in order to satisfy Equation (15).

This result is new in the literature; Parry 2003 achieves the opposite result in the context of pollution control. He finds that market based instrument provides higher pollution abatement than the social planner and in general the positive effect on the amount of R & D is small. In our case there is a strong effect on the optimal amount of investment in new technology. Had we assumed technological spillover, we would have added a positive effect to the development of economy, as in [9].

Similar result are instead shown in Denicolo, where tax and permits are not able to reach the first best optimal solution in an economy very close to the one we assumed. In his paper, the author makes a rank market instruments according to the incentive to innovate. Following Denicolo, we compute the welfare function W by using the different oil usage quantity arisen from different policies. **Tables 4-6** sum up the previous findings adding the calculated welfare function V in the three policies: taxation, auctioned permits and social planner.

Table 4. Taxation.

τ	0.80	0.9	τ	0.2	0.3	0.4	τ	0.2	0.30	0.4
O_0	9.25	9.15	O_0	9.85	9.75	9.65	O_0	9.85	9.75	9.65
O_1	1.44	1.17	O_1	9.57	9.03	7.89	O_1	8.55	4.31	2.56
m	4.38	5.30	m	1.51	1.63	2.04	m	2.86	4.43	6.65
P_R	5.32	6.4	P_R	1.16	1.21	1.41	P_R	1.21	1.79	2.66
V	50	52	V	10	16	25	V	27	40	87

$n_1 = 0.25$ $n_1 = 0.50$ $n_1 = 0.75$

Table 5. Auctioned Permits.

P_p	0.75	0.80	0.95	P_p	0.2	0.30	0.50	P_p	0.2	0.30	0.45
O_0	9.30	9.25	9.1	O_0	9.85	9.75	9.55	O_0	9.85	9.75	9.60
O_1	1.96	1.44	1.08	O_1	9.57	9.03	2.14	O_1	8.55	4.31	2.24
m	3.51	4.38	5.7	m	1.51	1.63	5.50	m	2.86	4.43	7.63
P_R	4.34	5.32	6.86	P_R	1.16	1.21	3.31	P_R	1.21	1.79	3.05
L	7.46	7.30	7.10	L	9.71	9.39	5.84	L	8.87	5.67	4.08

$n_1 = 0.25$ $n_1 = 0.50$ $n_1 = 0.75$

Table 6. Social Planner.

O_0	5.03
O_1	0.20
m	11.5
P_R	14
n_1	0.6
V	91

As results show, the highest value for V is obtained with the centralized solution. The picture is more fuzzy when we compare taxation and auctioned permits; it is not possible to find a strict hierarchy; V depends both on n_1 and tax rate or permits price.

Finally, a last word on the number of adopting firm. Being the optimal number of adopting firm less than one (0.61 in our simulation) one can wonder how central authority can effectively implement this number in the economy. The same question arose in Gaeta [1], and it can be managed in same way, *i.e.* adopting a "multistage game with observed actions in a perfect information context" [10]. Nevertheless, this case can easily be managed by a command a control policy, where central authority commits both on the number of adopting firms (*e.g.* throughout permissions) and on the amount of oil usage. Results confirm that such a policy is successfully when R & D is endogenous.

6. Conclusions and Further Refinements

This paper analyzes the strong interplay between investment in R & D and firm behaviour in reducing oil usage. We show that market instruments are not able to mimic central authority. This is basically induced by the endogeneity of the R & D process. The result is similar to Denicolo, although under different assumptions. However, unlike this author, it is not possible to rank instruments on a Pareto ladder. There is a strong non-linearity in the behavioral equation and this reduces the relevant domain of existence. In general it is not possible to establish which instrument performs better. However it is true that higher taxation induces more investment in R & D, as in Parry and Denicolo.

This paper must be considered a first approach to the problem; however several refinements are possible. First of all, numerical simulations should call for some calibration to "stylized fact". Unfortunately is very hard to find microdata on such phenomena; despite our efforts to get in touch with international agency we were not able to fill the gap. Second, we should analyze the case where central authority chooses the optimal amount of R & D, instead of leaving such decision to an external firm. This would be very close to Parry 1998.

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Strategic Orientations: Multiple Ways for Implementing Sustainable Performance

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Abstract

The Four Phase Model®, created by prof. dr. Teun W. Hardjono [1] in 1995, distinguishes four ideal type strategic orientations and shows that these strategies brighten and dim in a specific sequence, adding the most required competences to the organization, and creating a natural rhythm to corporate dynamics. By applying this theory one can understand the nature and whereabouts of the organization's systemic constraints, revealing the basic features for creating a roadmap towards sustainable performance improvement and competence development. The model generates the top priorities, selects the most adequate (ideal type) interventions and key performance indicators. Combining strategic "situations" as indicated by the Four Phase Model and phase-wise "contexts" as introduced by Spiral Dynamics [2], provides a conceptual synergy with four innovative outcomes: Firstly, aligned with specific contexts, the strategic interventions and KPI's can be made more specific and practical, thus creating a roadmap for performance improvement and organizational development. Secondly, it structures change management into four distinctive hierarchical complexity levels: 1) enhancing fundamental skills, structures and procedures (vitalizing); 2) improving contemporary levels, aligned with the dominant value system (optimizing); 3) new re-orientations while continuing within current systems (shifting) and 4) a transformation to a more complex context or emerging value system (transforming). Thirdly, powered with the combined understanding of above concepts, one can deduct the specific context and situation for each intervention, instrument or approach to be applied effectively. Fourthly, the combination provided the bases for the so-called Strategy Scan and Strategic Sustainability Scan.

Keywords: Spiral Dynamics, Four Phase Model, Hardjono, Flexibility, Creativity, Effectiveness, Efficiency, Sustainability Scan, CSR, Corporate Sustainability

1. Introduction

The rising public expectations, the increasing social and environmental problems both locally and globally and the continuous strive for quality improvements and innovations are challenging corporations to choose new ambitions and aspire for higher performance levels with respect to corporate sustainability. They need to chart a course with respect to corporate sustainability and responsibility (CS/CR) within an increasing complex and dynamic environment.

In other publications, Van Marrewijk [3,4] presented a set of definitions of CS/CR differentiated for various development phases (or contexts, or levels of existence). Companies can initiate activities or approaches supporting sustainability, which aligns their institutional structure, values systems and ambition levels. True, traditional capitalist structures hardly enhance sustainable development, but these first small steps are essential in – eventually-moving into a worldwide transition towards structures which support a sustainable way of living, working, producing and consuming.

The more corporations recognize that CS/CR activities might increase their success, support their branding and reduce theirs risks, the more they will invest in these activities. Stated in another "worldview": the more companies accept their role in contributing to solving societal problems, to bridging the gaps between rich and poor and stop environmental degradation which are jeopardizing ecosystems, the more companies will create new product concepts and processes which include improvements to all objectives, for people, planet and profits. [5]

Each company needs to position itself within the CS/CR debate. What definition aligns their context and situation best? Which CS activities-among the numerous CS-initiatives already taken-make sense with respect to their fundamental objectives? What rate of progress do they need to take in order to stay ahead of competition? In the Journal of Business Ethics, Van Marrewijk and Hardjono [6] listed a set of the basic questions that stemmed from their SqEME approach: What does the organization want? Who are allowed to take part in this decision process? Which factors will influence the new ambitions? Which actions are most effective? And how can the espoused progress be measured and shown to the stakeholders?

This paper can support companies formulating strategies towards implementing corporate sustainability and responsibility by introducing the factors that influence the most adequate strategic orientation and the factors that indicate the developmental level at which companies need to act. Combining these outcomes will result in a sequence of strategic steps, which are placed in a context aligning the organization' value systems and institutional structures. Depending the company's ambition, the sequence of strategic steps can lead to performance improvement, a shift to new corporate orientations or set out a transition to new ways of doing business in a more sustainable way.

Paragraph two summarizes the Four Phase Model®, created in 1995 by Dr. Teun W. Hardjono, professor on Quality Management at the Erasmus University Rotterdam [1]. Paragraph three focuses on the integration of the Four Phase Model and Spiral Dynamics [2], combining the two dimensions mentioned above. Paragraph four will briefly summarize the possible sustainability interventions that can be implemented at different combinations. Paragraph five elaborates on the consequences with regard to corporate dynamics and the final chapter introduces an online strategy scan which is able to support a strategic dialogue.

2. Four Phase Model

Teun W. Hardjono presented his Four Phase Model® as a PhD thesis in 1995 [1], capturing 20 years of experiences in corporate strategy and organizational change as a senior consultant at one of the Netherlands' most renowned management consultancies. In practice, the Four Phase Model® has appeared an effective model for managers and management consultants to analyze the present state of organizations and to determine the most likely strategy to further improve their organizations. The model structures various organizational performance indicators and possible interventions and is able to provide guidelines for a program of organizational change.

2.1. Core Assets

The Four Phase Model's basic assumption is the recognition that organizations are striving to increase the sum of four essential assets, in a continuous process of exchanging one asset for another. These assets relate to basic organizational competences. These assets/competences are the:

- <u>Material asset</u>: the ability to increase, maintain and optimally utilize the tangible resources of an organization. Its worth is reflected-more or less-in the balance sheet.
- <u>Commercial asset</u>: the ability to have access to and to act on markets and the skills to execute commercial transactions.
- <u>Socialization asset</u>: the ability to inspire people and create supporting structures in order to achieve the common, corporate objectives.
- <u>Intellectual asset:</u> the learning capability of organizations, the ability to (pro-actively) adapt to changing circumstances and the creative capacity, which is based on the collective intellect and creativity of the members of organizations.

These core assets or basic competences also relate psychologically to the core drivers and professional ambitions of people and therefore also organizations. See **Table 1.**

Employees bring their best talents, skills, relationships and personality to the workplace and in return expect fair rewards, not only in financial terms, but also career opportunities, chances to grow their professional skills, challenging tasks to boost their experience, et cetera. Companies could make use of the relationships between corporate and personal drivers by for instance linking their reward schemes and employees' personal developments plans in line with their core strategies. But first, lets elaborate some more on the core assets.

Tabel 1. Basic assets at organizational and individual level (Hardjono), [1].

	Organizational level		Individual level	
	Cost	**Revenue**	**Input**	**Output**
Material asset	Money, products	Revenue, profits	P.M.	Wage
Commercial asset	Relations	Market share	Network	Customers
Socialisation asset	Workplace	Commitment	Behaviour	Colleagues
Intellectual asset	Talent development	Knowledge	Intelligence	Experience

Maximizing, for instance, the material assets at the expense of the other assets will ultimately lead to poor results. It is a myth that doing business is only focused at making profits. We all know what happened when a business unit manager shows double-digit growth figures, shortly after the CEO passionately requested for performance improvement on the shortest term possible. Having stripped research and development, postponed marketing campaigns, cut back conference trips and training possibilities, cancelled the annual day out while demanding overtime from his workers producing stocks, of course his financial figures improved. Soon his unit will be in dismay and he ought to be fired for that.

Healthy, sustainable organizations have learned to optimize the mix of the four essential competences: the abilities to create wealth, engage in transactions, enhance employee commitment, dedication and trust and the ability to adapt or proactively respond to changing circumstances.

Creating an optimal mix of the assets, companies exchange one asset for the other; For instance, invest money/ material assets for increasing the company's commercial abilities. As long as the marginal revenues exceed the marginal costs, companies will invest in enhancing their assets in order to meet their corporate objectives. In creating an optimal mix, the organization is gaining more ability to protect and improve its future.

For creating an optimal mix of basic assets, organizations need adequate strategies. The following questions are relevant: What is the constraint in increasing corporate performance? What single factor will impact performance improvement most? What extra competences should be prioritized? What is the organization's greatest risk? What kind of needs do our customers have? What are the needs of the other stakeholders? Is our organization fit to meet these requests? Although these questions seem to have different natures, the answers tend to come together nicely, as abundant case studies based upon the Four Phase Model have shown.

The Four Phase Model suggests organizations to focus on either internal or external issues and-at the same time-focus on control or change. Both pairs are dichotomies: although each side of these dichotomies are relevant, in a specific situation only one site contains the whereabouts of the constraint (inside or outside) or the key to the solution (via control or allowing change). The result can be presented in a so-called Harvard Diagram, presented in **Figure 1**. The diagram shows four concentric circles, representing the core assets, the diagram, representing the basic dichotomies, and the resulting four ideal type strategies, or strategic orientations.

These strategic orientations are:

- Effectiveness: A market-driven orientation which is directed towards increasing the effectiveness of an organization;
- Efficiency: A productivity orientation in order to enhance the efficiency of an organization;
- Flexibility: A people oriented strategy to increase the flexibility of an organization;
- Creativity: An innovation (and adaptedness)-driven orientation in order to increase the creativity of an organization.

Each strategic orientation contributes to all assets, but enhances one basic competence in particular. Effectiveness primarily boosts the commercial abilities; Efficiency focuses mainly on increasing the material assets; a strategy aimed at Flexibility has its most impact on the socialization competence and Creativity improves the intellectual capacity and the company's adaptedness to changes in the environment.

The next paragraph will elaborate on the basic interventions, structured according the Four Phase Model.

2.2. The Basic Orientations

Ideal type interventions can be plotted in the basic graph of the Four Phase Model: four assets, four quadrants (result areas) and two dichotomies (orientations) makes 32 interventions.

We will now demonstrate the Effectiveness Quadrant, (top left) in **Table 2**:

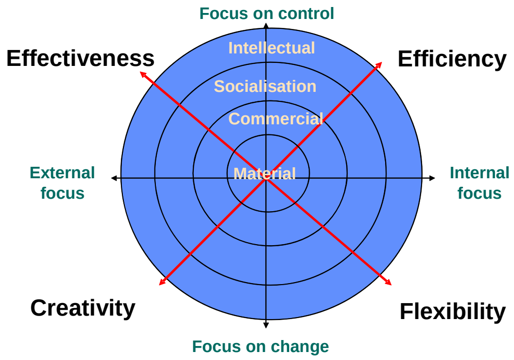

Figure 1. The core assets, dichotomies, and strategic orientations (source: T.W. Hardjono) [1].

Table 2. The Effectiveness Quadrant (Hardjono) [1].

	External Focus	**Result: Effectiveness**	**Focus on Control**
Material asset	Produce	Cash flow	Be profitable
Commercial asset	Generate supply and demand	Market share	Plan and order
Socialisation asset	Anticipate the social environment	Direction	Structure
Intellectual asset	Anticipate the societal environment	Plans	Explain and predict

It reads as follows:

- Production, or adding value in general, generates products and services. These are positively appreciated on the balance sheets, but once sold to customers it delivers a cash flow and, given its cost structure, it might be profitable.
- By carefully planning and organizing marketing, sales, supply chain and distribution, thus generating supply and demand, and competing on the market, resulting in a specific market share.
- By structuring the organisation and setting targets to all employees, organisations proved a sense of direction and a specific customer orientation. Employees engage into social networks thus stimulating the organisation's effectiveness.
- By anticipating and grasping the changing life conditions and societal circumstances, generating intelligence and understanding which will be used as inputs in new plans.

The appendix includes the full matrix of ideal type interventions.

The items in the overview are fairly basic-no rocket science here-stocks turn to revenues, to cash flow, to profits etcetera. It is the elegancy of the model providing a coherent image of complex organisations summarized in 32 activities. The model needed a fourth layer to acquire a level of sophistication in order to better meet the complexity of real life. Having defined the four basic assets, the diagram with the four quadrants based on the two dichotomies, and the four strategic orientations, the fourth level is formed by the various aspects of dynamics, which brought a specific sequence and rhythm to the model.

3. The Dynamics of the Four Phase Model

3.1. Balancing Reverse Effects

The model offers a few arguments that bring balance, sequence and rhythm to the model. The first one introduced here is "too much of anything will inevitably have a reverse effect". Too much Efficiency results in a rigid bureaucratic organisation. Too much focus on Change and Flexibility will end up in chaos and anarchy. Too much room for Creativity leads to amateurism and too much focus on the market Effectiveness causes an oversensitive, segregated organisation.

One may conclude that balance needs a temporarily focus, as a continuous focus ultimately results in adverse effects. **Figure 2** could therefore be read as follows: *"Our main focus is on Efficiency, there we can make our biggest impact on our organisation and achieve our goals, but in order to prevent our largest risk to occur—rigidness and bureaucratic tendencies—management must already prepare the roads for our next strategy and focus on Flexibility."*

To prevent reverse effects to happen, organizations should turn to the "next" strategy that happens to include the competency that can prevent this effect to occur. More Flexibility will lift the fear for bureaucracies and Effectiveness soon turns hobbyism into successful marketing and sales campaigns. Taken from a risk perspective, having invested in improving creativity the largest risk is developing new products the market doesn't want. Having successfully boosted marketing and sales, the organization needs to improve corporate efficiency to see to it that gained market shares leads to profits. Efficiency activities can turn organizations into control-driven bureaucracies and "lean and mean" entities that have lost employees' commitment to give something extra at customers' requests. Having successfully created supporting structures and gained employees' dedication and trust, companies intend to expect creative and adaptive achievements, which ought to meet the customers' perceptions, etcetera.

3.2. Prioritising Interventions

A second argument supporting balance is the fact that all four quadrants, and all 32 basic interventions are important, but not at the same time. Suppose an organisation has a focus internally and a focus on control, as **Figure 2** presents. Its strategic orientation is thus aimed at Efficiency. The more impact-in both time, efforts and means-is spend on this strategy the more powers are building up on the other end of the dichotomies. Reverse effects will occur, forcing the system to move on to the next strategy.

A metaphor can explain this in more detail: a top indoor cyclist engaged in a sprint duel can be forced to a stand still—sur place—*as he does not want to take lead position. In cycling this is a strategic option. It takes great skills to remain on one spot, but he cannot stay*

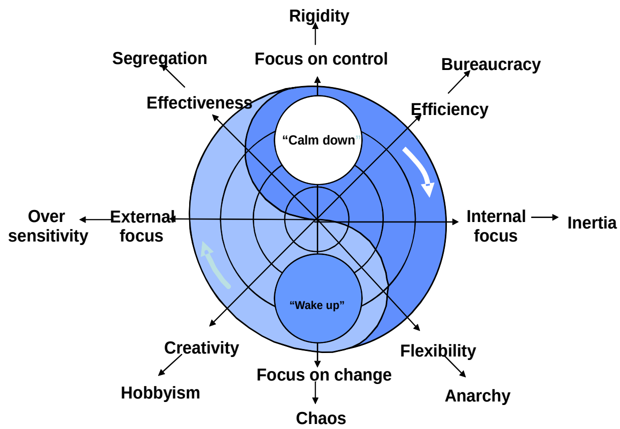

Figure 2. Dynamics of the Four Phase Model© (Hardjono) [1].

there forever. Inevitably, in order to prevent from tumbling when his skills are fading or when his adversary was finally forced to take the lead, he moves his cycle downward while building up speed, heading for the finish line.

The next quadrant represents the organisation's greatest challenge. For instance: Becoming more efficient while maintaining flexibility. If you fail, the organisation turns rigid and bureaucratic. Or, creating innovations, which promise a boost in sales. Without this market orientation creativity might lead to hobbyism. **Figure 2** therefore shows a "wake up", a position currently out of focus, but it needs extra attention in the near future to prevent large risks to occur.

As said before, all interventions are relevant but-strategically-not at the same time. Ideally, half the number of basic interventions can be adequately addressed. As **Figure 2** shows, "half" does not represent just two quadrants: the intellectual asset moves ahead, as represented in the outer circle, creating a yin-yang shape. In total 16 interventions are relevant. The dark shades in **Figure 2**: Three times four interventions aligned with internal focus, Efficiency and focus on control, three lagging interventions on Effectiveness (material, commercial and socialisation) and a leading one on Flexibility (intellectual). In the shaded area there are no conflicting interventions.

In conducting surveys among clients, we have often applied this model while structuring the employee answers to open questions such as "what can be improved in order to become a *great place to work* or a *high performance organisation*". All employee arguments can be counted and represented in **Figure 3**. Collectively employees suggest to focus internally and especially on Flexibility. The best suggestion however would be to focus first on Efficiency and implement all improvement that will have impact within short notice. Then move on to focus on Flexibility. After a while management should start preparing the issues in Creativity that needs (strategic) attention.

3.3. System Constraints

Implementing strategic interventions covered in the dark

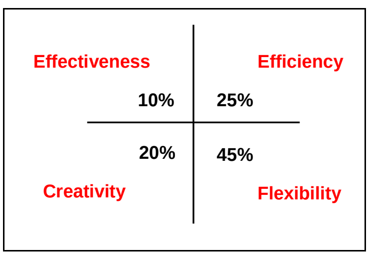

Figure 3. Results of an empirical analyses on employee arguments by Van Marrewijk

shape is supposed to enhance the necessary competences and ultimately contribute to obtaining the espoused performance results. The "yin-yang" shape indicates a dynamic process. Indeed, the Four Phase Model is a dynamic model suggesting a specific rhythm of shifting from one strategic orientation to the next, adding, each time, new improvements and competences. Ahead always lie new objectives to be met and new competences to be gained. The previous section discussed strategic risk management, with the organisation's largest challenge represented in the next phase or quadrant, and reverse effects that occur when organisations become rigid. Trying to prevent them to occur was presented as the first factor that causes dynamic effects within organisations.

This paragraph will elaborate on the system constraint, the organisation's bottleneck in improving corporate performance. Eli Goldratt elegantly proved in 'the Goal' (1984), his introduction to his Theory of Constraints, that in the end one factor obstructs the performance of an entire system. The investments that are able to lift this constraint by improving its quality or capacity will yield the highest productivity. The question is: where lies the constraint? On what factor should we target?

In terms of the Four Phase Model: 1) The constraint lies internally or externally and 2) the competences needed to lift the constraint are the material, commercial, socialisation or intellectual assets. In a strategic dialogue-within the board of directors, among experts, deep within the organisation or with various stakeholders-one must find out the whereabouts of the constraint. The following strategic issues might deliver the final clue:

Customer profile

Strategies developed with the Four Phase model apply to product/market combinations. Therefore market saturation levels, customer profiles, rate of progress et cetera are highly relevant. Our model distinguishes four ideal type profiles for customer needs. The organisation should focus on:

- Latent needs of customers. Surprise them with new, innovative products and services that where unheard off but are recognizes has attractive (Creativity).
- The customer must choose among a wide range of products, he does not fully comprehend. The traditional portfolio of marketing techniques is developed for this type of customer needs (Effectiveness).
- The customer is fully aware of all alternatives and seeks the lowest price (Efficiency).
- The customer is sensitive for the quality of services, which requires a flexible approach of the organisation (Flexibility).

Each specific customer profile can be serviced best by one of the strategic orientations mentioned between brackets. Customer needs can change over time, forcing the organisation to respond likewise. In many maturity models and life cycle approaches one can observe a sequence of these consumer types.

Although important, the strategic orientation will be influenced by more aspects than customer profile alone. We will provide an extra example:

Major risk

What is the major risk of your organisation?

- We have to prevent growing into an over-bureaucratic, inert organisation, no longer able to respond adequately to customer needs for dedicated services.
- Myopia due to conflicting kingdoms existing in the organisation, and the unbalance between customer focus and cost control might bring us in jeopardy.
- In offering ample room and insufficient focus, our employees invest too much time in their hobby's and personal interests.
- Our continuous attention for employee needs might turn into informalities and anarchy. Further more our service oriented, customer friendliness attitude might cost more than it generates.

Suppose the first option is recognised as the largest risk within the organisation, forcing it to shift to Flexibility in order to meet the needs for dedicated services while allowing human relations and corresponding socialisation ample room to balance existing rules and procedures.

With a wide spectrum of strategic aspects raised it is possible that not all answers align, but in practise these outcomes tend to match one other nicely, thus reinforcing a specific strategic orientation.

3.3. Maturity

Hardjono also dealt with the concept of maturity within his Four Phase model, especially the start up situation. See **Figure 4**. Any company starts with a good idea (Creativity). The pioneer enters the market, quickly turning to Efficiency in order to collect financial means, attracting employees and integrating them into the core processes. They need to respond to customers' remarks thus adapting the products and services and probably expanding the

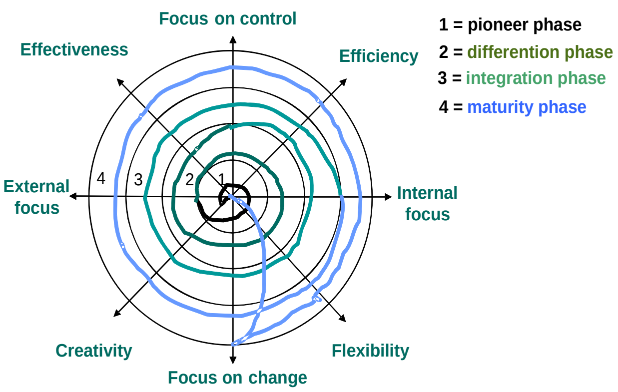

Figure 4. A start up situation gaining maturity.

scale and internal procedures (again Creativity). A new cycle starts. As a start up cycles pass quickly, and with gaining maturity they slow down. The best rhythm is a matter of flow: a balance between external and internal developments. Whenever an organisation fails to meet this flow it jeopardizes its existence.

My criticisms lies in the fact that being on the path of gaining maturity most organisations enter new levels of existence which influence the way strategies are implemented. Each level of existence is characterised by specific institutional arrangements: the dominant leadership style, the policies according which people and processes are managed, the way the organisation is structured, how decision making takes place, the relationship with partners et cetera. All these aspects relate with one and other and reinforce each other.

The nature of the interventions-as suggested by the Four Phase model-remain the same, however the context or value system that appear to be dominant highly impacts the way a specific intervention is implemented. I therefore prefer to apply strategic orientations as situations shifting from one to the next phase within a specific context, or "level of existence" as Clare Graves has put it. The next chapter will reveal an attractive effect once the Four Phase model is combined with Spiral Dynamics.

4. Combining Four Phase Model with Spiral Dynamics

4.1. Spiral Dynamics

Van Marrewijk introduced Spiral Dynamics in several previous publications [3,4,6-8]. Readers, not familiar with Spiral Dynamics, should first turn to this text before continuing with this chapter. We now summarize its features.

Clare W. Graves is the founder of the Emergent Cyclical Levels of Existence Theory. His successors, Don Beck and Chris Cowan, renamed it "Spiral Dynamics" and successfully introduced Graves' academic achievements to a wider audience [2]. Based on extensive empirical research Graves, who was professor in psychology and a contemporary of Maslow, concluded that mankind has gradually developed eight core value systems so far. Each level of existence-constructed around such a core value system-provides its own hierarchy of needs. Values are considered as coping mechanisms to meet specific challenges and to structure institutions in order to influence behaviour. A value system is a way of conceptualizing reality and encompasses a consistent set of values, beliefs and corresponding behaviour and can be found in individual persons, as well as in companies and societies. The core question that summarises this theory is: *how does the mind process reality*? Spiral Dynamics does not "label" people and organisations, but it structures thinking systems within entities. It reveals the fundaments of our behaviour that are covered below the surface.

A value system develops mainly as a reaction to specific environmental challenges and threats: the systems brighten or dim as life conditions (consisting of historic Times, geographic Place, existential Problems and societal Circumstances) change.

All entities-including organizations-will eventually have to meet the challenges their situation provides or risk the danger of oblivion or even extinction. If for instance societal circumstances change, inviting corporations to respond and consequently reconsider their role within society, it implies that corporations have to realign their value systems and all their business institutions (such as mission, vision, policy deployment, decision-making, reporting, corporate affairs, etcetera) to these new circumstances. The quest to create an adequate response to specific life conditions results in a wide variety of survival strategies, each founded on a specific set of value assumptions and demonstrated in related institutions and behaviour. Evidently, the strategies introduced above also adopt the influence of specific value systems and show different approaches and alternative interventions.

The development of value systems occurs in a fixed order: Survival; Security; Energy and Power; Order; Success; Community, Synergy and Holistic life system. Each new value system includes and transcends the previous ones, thus forming a natural hierarchy (or holarchy) [9, 10]. Despite the recognition of specific levels, reality is a continuum of developments including transition zones between the levels. These transition phases are highly interesting but are left out in these analyses, leaving ideal type development phases or contexts.

4.2. Dominant Challenges

In determining the strategic orientation we also elaborate on the major challenges that occur within the organisation. We distinguish the following options:

- We need to manage all our operations efficiently in order to protect our margins (Efficiency).
- We need to transform good ideas and innovations into saleable products and services (Effectiveness).
- We need to enhance the dedication and resilience of our people, which are crucial to the success of our organisation, especially since customers demand dedicated services with respect to speed, flexibility and quality (Flexibility).
- We need to gain a better understanding of under surroundings, *i.e.* the life conditions that impact our organisation, such as the market and technological developments, trends in society and changes in people's needs. We have to improve our ability to change along with these trends or-better-cause the changes to occur through the impact of our breakthroughs, innovations and new approach to design, produce and market our products and services (Creativity).

These options have been linked to strategic situations - as indicated between the brackets-but they also relate to contexts: Efficiency can be best implemented in Order, Effectiveness in Success, Flexibility in Community and Creativity in Synergy. However, in practice *and* theory one can observe all four strategic options in each context. In each context one strategic option can be considered dominant with all other options in a more supportive role.

The issue now arising is that for instance Effectiveness can take different appearances in various contexts. Depending how an organisation interprets one's business environment and its ambition, values and capabilities, it will adopt the characteristic way of a particular context while implementing a specific set of interventions, associated to a selected strategic orientation.

We here summarize the core appearances of Effectiveness for the various contexts:

- *Order*: Organisations produce for stock and sell what is available against well-calculated prices;
- *Success*: A wide spectrum of marketing tools and communication techniques (including packaging) is applied to inform and influence customers to buy products;
- *Community*: Customers are recognised as human beings, with particular needs. Product qualities align with customer needs. Mass production systems are adapted to small batches with diversified products;
- *Synergy*: Customers are involved in the early stages of product design. People oriented marketing approaches change the industry. Product qualities align with societal needs.

The effects of contexts on implementing strategic orientations can be acquired via Van Marrewijk, since it can not be dealt within the context of this paper. One can observe that the interventions suggested in the Four Phase model have gained practical use when combined with Spiral Dynamics: the strategic interventions and KPI's can be made more specific and practical.

In some industries you can see organisations shifting their strategies in a rapid sequence. More often one can observe particular strategies being quite persistent over time, such as a focus on low costs and Efficiency. Here we can see the mixed effects of contexts and situations. Suppose a particular industry can function adequately in Order. Rules and procedures would influence all strategies implemented within Order: Efficiency would be executed in a "blue" way, as well as Flexibility, Creativity and Effectiveness. Companies in Order cannot survive when they maintain their focus strictly on Efficiency. They have to shift their strategy to enhance the other core competences, all be it for a relative short period. Now and than, companies adapt their procedures to include new methods in order to cut costs. The challenge for these organizations remains to keep the prevailing structures from turning into rigid organizations generating reverse effects.

4.3. The Strategy Matrix

With four ideal type strategies and four selected contexts a grid can be made with sixteen combinations of specific situations and contexts. This is the Strategy Matrix, showed in **Table 3**.

This matrix offers a several distinctive benefits:

1) It expresses a basic philosophy behind the Four Phase model as well as Spiral Dynamics: all management principles, models and even hypes have their value, but often only in a certain situation/context combination. Or put differently: Due to changing circumstances both outside as well as inside organizations, models, tools and certainly hypes have limited applicability and tenability over time.
2) The matrix is therefore able to function as a framework for structuring for instance academic literature on business strategies and related policies. Also, all strategy models and tools mentioned above can be structured according this matrix.
3) The matrix implies four distinctive hierarchical complexity levels in change management: a) vitalising, b) optimising, c) shifting and d) transforming.
4) The matrix offers the conceptual basis for the Strategy Scan, which can generate the most adequate strategic situation and context of organisations, or their product/market combinations.
5) The matrix also offers a conceptual basis for performance cycle from which one can deduct a roadmap for sustainable business improvement and organisation development.

4.4. Four Dimensions of Change Management

By combining the dynamics of the Four Phase model and Spiral Dynamics, in other words: by combining strategic "situations" and phase-wise "contexts", we were able to structure change management into four distinctive hierarchical complexity levels: a) vitalising, b) optimising, c) shifting and d) transforming. These four dimensions of change management are explained below.

Vitalising

Often the performance can be improved by enhancing the fundamental skills, structures and procedures of including contexts; These interventions are relatively simple as we have a lot of experience in managing these aspects, but being involved in more complex value systems, we tend to neglect basic competences although they jeopardise current performance potential.

Optimising

Once a sound fundament has been realised, further improvement can occur when organisations enhance the effectiveness of the characteristic institutions within the dominant context. Try to find out and apply best practices, work smarter and excel in what needs to be done.

Shifting

If including and current contexts are functioning well, further improvement can be established by fine-tuning the strategic situation. Within a context, organisations must focus their business towards the most adequate situation, aligning their interventions accordingly.

Transforming

When challenged by more complex conditions, which cannot be met by prevailing work procedures, organisations have to transform into an emerging context in order to sustain their corporate performance. Organisations should adopt new ways of organising by transforming to a more complex context, adopting emerging value systems and all institutions aligned with it. Transformations are complex phenomena, especially if managed as an improvement project.

Having identified the four dimensions of change management, we adapted the Performance Cycle (**Figure 5**). It is structured according Deming's Plan-Do-Check-Improve sequence. The related activities, provided by professor Wessel Ganzevoort, are "mobilizing, appreciating, reflecting and inspiring".

Table 3. The strategy matrix (Hardjono and van Marrewijk) [6].

Contexts/Strategic	Order	Success	Community	Synergy
Effectiveness	x	**X**	x	x
Efficiency	**X**	x	x	x
Flexibility	x	x	**X**	x
Creativity	x	x	x	**X**

X = dominant
x = applicable

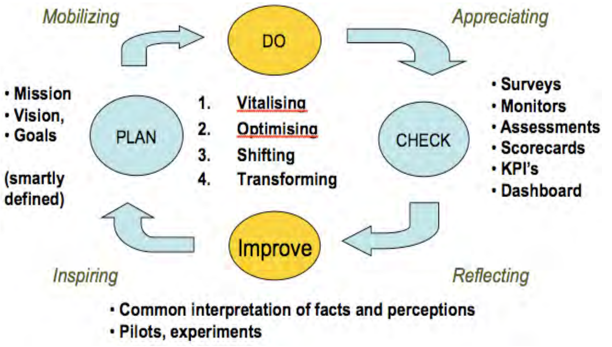

Figure 5. Performance improvement cycle, inspired by Deming and Ganzevoort.

The performance cycle suggests various ways to check the impact of the implementation process. Employee perception tools, such as surveys, monitors and assessments, as well as quality management, business operation and accounting tools generate data which via business intelligence services are provided to the board of directors, to management and professionals. Together they interpret the data and determine the progress made. Easy adaptations and fine-tuning are implemented directly, but larger alterations can be tried as experiments and pilots on a small-scale basis, or postponed until they fit the next strategic orientation.

4.5. Strategy Scan

The first step in drafting a roadmap towards sustainable performance improvement and organisation development is finding out one's position: what are the current constraints, challenges and risks; what are the dominant value systems within the organisation. In short, what (strategic) situation and context are most adequate to face current strengths and weaknesses, opportunities and threads?

In 2003 Van Marrewijk and Hardjono developed the Strategy Scan, based on the Strategy Matrix.

This online scan supports the strategic dialogue, the exchange of facts and experts opinions, and gives a direction to strategy development.

The Strategy Scan is a powerful online instrument, which takes stock of opinions, ideas and perceptions of those directly involved in the company's strategy formulation process. One can conduct the Strategic Scan in board of directors, management teams, among staff members, and as a vertical dialogue deeper into the organisation as well as outside, even with all stakeholders.

The Strategy Scan supports the strategy dialogue and gives an insight into your organisation's strategic positioning and context within which the strategy ought to be executed.

The first part of the scan focuses on strategic aspects, which ultimately determine the main direction or strategic orientation of the organisation. Examples of such aspects are the consumer needs and the current bottleneck obstructing organisational performance. The result is a focus and a set of ideal type interventions.

The second part surveys the nature and complexity of the (external) environment and the disciplinary developments (or paradigms) regarding the management criteria such as leadership, people-, resource-and process management. The Strategy Scan indicates the organisation's most dominant development phase, its favourite level of existence. Combined with the strategic orientation, the researchers and corporate experts can indicate specific interventions and sketch a roadmap for development, aligned with the dominant value systems of the organisation.

The feedback report gives an insight into shared opinions, priorities and most important differences among the responders. The first direct effect refers to the quality of the strategic dialogue with discussions focusing on the topics with a relative high level of variation. In focus groups or a workshop setting with representatives of the different views, one can try to tighten the strategy's selection and formulation. Furthermore, the Strategy Scan's result offers a solid base for an implementation plan and selecting key performance indicators.

The Strategy Scan is offered by Research to Improve. They also developed the Strategic Sustainability Scan, an extended version including additional sustainability issues. The Sustainability Scan generates an adequate meaning of corporate sustainability and-responsibility, an ideal type reference on which an organization can develop its own touch and approach. This way one can link strategy with CS/CR-policies and interventions.

5. A Roadmap towards Sustainable Performance

Deducting a roadmap for performance improvement and organizational development can be difficult as each organisation is unique. Many aspects can play a role and not all of them can be foreseen. Still it makes sense to have an idea about the path of change. What can we expect? What level of complexity? Do we have the necessary competences? The right people?

Each organisations must provide its own answers, but at least-by applying the Strategy Scan, the Strategy Matrix and the Performance Cycle-one can grasp its position, its strategic focus, a set of adequate interventions in order to lift the organisation's bottlenecks and enhance its basic competences, and its dominant context to 'colour' the interventions into fitting change activities.

Good surveys can provide management information from which one can tell if vitalisation or optimisation is most effective to enhance corporate performance. Frequently held strategic analyses can provide arguments to remain focused or shift to a next strategic orientation, prioritising a new set of interventions. Strategies can shift permanently within one context. This is relatively simple, but challenging enough.

Changing life conditions can force organisations to gain maturity by transforming into emerging value systems, thus creating new contexts. Strategies will than not only shift to a next phase, but also transform into a new context. Logically, the starting point of the transformation lies in the Creativity phase: adapting to new circumstances have forced the organisation to move its boundaries, to create adaptations "out of the box", introducing new ways of doing things. Leaving Order, a company will start adopting Effectiveness in a more entrepreneurial, profit-driven way. Marketing and leadership will be the pioneers in adopting a Success-driven approach, with People-and Process Management quickly catching up. After a while, Learning and Innovation and Communication and Decision-Making could be the two enablers, which will face the next performance constraint. When functioning within Success seems no longer adequate anymore, the need to sustain performance improvement will force the organisation to transform once more, this time into Community. It will support the need to learn, collaborate, engage and meet with society needs.

Strategic orientations (phases) as well as levels of existence (contexts) brighten and dim as responses to changing environmental circumstances and internal considerations, such as organizational structures and intrinsic motivations. We now elaborate on two developments situations: times of crises and a performance gap.

Crises

Ideally, strategies develop 'clockwise' in a natural sequence, creating additional competences and adding to the organization's total sum of assets. Especially in economic downturns, one can observe sudden shifts backwards! From for instance Efficiency back to Effectiveness, thus remaining in a control mode and ignoring the need to become more flexible and socialisation oriented. Due to such shifts specific competences are lost, expectations shattered and total sum of assets diminishes. But these shifts-for better or worse-can also support the organization's survival.

Due to changing life conditions organizations can also choose to shift to less complex value systems. The more complex ones are more vulnerable and difficult to sustain when times are hard. Eventually, tides will turn and organizations, as well as individuals and societies, will try again the more complex value systems in order to escape the limitations of the former ones.

Performance gap

Especially when centred in Success, organisations like to benchmark. Certain benchmarks such as the very best Great Places to Work® [11] and High Performance Organisations (HPO's) [12] have average scores of 85% to 90%, while ordinary organisations only score for instance 50%. These benchmarks provide a high performance level but do not provide intermediate 'stepping stones'. A target aimed at a 10% increase doesn't make much sense. The point is what should an organisation do and try to accomplish with the least effort and with maximum effect: first focus and than select the nature of the intervention and determine in what context the best contribution can be made.

In trying to bridge the performance gap, organisations often need intermediate goals. With the matrix and cycle introduced above, one is now able to design a development path with the intermediate goals as stepping goals towards the ultimate result. Both children and top athletes take the same approach in trying to establish espoused performance levels.

In designing a roadmap for change and performance improvement it is important to be aware of the complexities at hand. In a stable world one can predict the best approach and establish the expected results much easier. Prof. Ralph Stacey [13] defined this realm as 'rules'. In Spiral Dynamics it coincides best with Order. If one is uncertain of the impact of interventions, complexity increases, ultimately reaching the level of chaos. See **Figure 6**. Strategies are aimed at bringing down the level of complexity in order to be better able to predict and manage, preferably control, the outcome of one's activities.

Van Marrewijk presents Spiral Dynamics' levels of existence as 'local' equilibriums [14], offering adequate solutions to prevailing circumstances. See **Figure 7**. At each local equilibrium a specific set of values 'rules' and determines the institutional structures and patterns of behaviour, with which people and organisations are able to cope with prevailing circumstances. The moment entities become aware that current behaviour is no longer adequate to meet new challenges, periods of chaos emerge. Facing increasing complexity, people and organisations have to transform into new value systems. Each transition contains elements of chaos, due to people's resistance for the unknown, leaving behind old patters of behaviour and trying to get accustomed to new institutions, to new ways of working and new competences.

Once people and organisations feel aligned with a new context, a new level of existence, they can apply their newly acquired competences to deliver adequate solutions

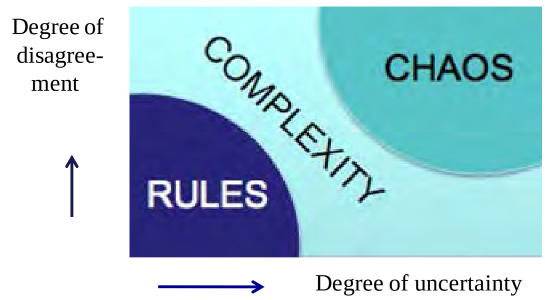

Figure 6. Reality according Prof. R. Stacey.

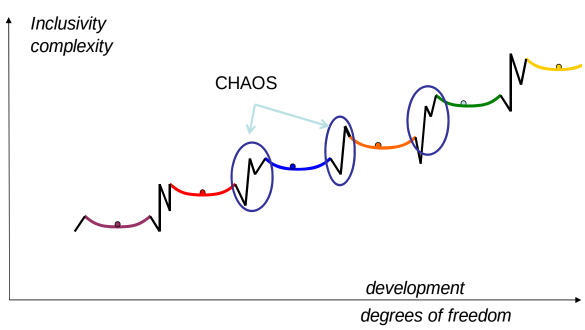

Figure 7. Phasewise orientation according Graves, (representation by van Marrewijk).

to prevailing challenges. They are able to match a higher level of complexity, as if complexity has been transformed into the realm of Stacey's rules.

Turning back to the issue of bridging performance gaps, one can observe in Western economies that successful workplaces and HPO's are often centred in Success /Community/Synergy, while the majority of organisations seem to function within Order/Success and still, quite a lot are in Power/Order.

A 40% performance gap can statistically be overcome by an average performance improvement of 4% for 10 years in a row. In practice it could imply a transition from a power-oriented organisation, via a shareholder, control- and profit-driven organisation to a stakeholder-oriented organisation. This is not an easy task, certainly not in 10 years time.

6. Corporate Sustainability (CS)

In this chapter we focus on sustainable performance, the ability to sustain organisational performance over time. Through shifting strategic orientations 'clockwise', thus building up basic competences that match the challenges and bottlenecks occurring in business operations, organisations remain fit, flexible and balanced, thus securing the best performance possible.

The philosophy behind the Four Phase model does have added value in understanding a second interpretation of corporate sustainability. One that is related to balancing people, planet and profits [5].

The Four Phase model offers specific contributions regarding the topic of sustainability, the latter interpretation. The first one relates to its philosophy: Since all organizations and individuals have the same set of basic assets, they can exchange their assets among one other as for instance happens between organizations and their customers and suppliers. In Order and Success organisations tend to emphasis shareholder value, through focusing on control and resource management. Apart from the basic exchange of assets with customers, these organisations tend to enhance their total sum of assets mainly through internal activities. Inevitably, this approach reaches its boundaries, forcing companies to seek new opportunities to grow their assets and sustain their performance. The limits of growth can be overcome by transforming into new emerging contexts, thus facing a period of change and chaos due to learning new ways of doing business (**Figure 6**).

In the process of sustaining corporate performance-thus enhancing corporate sustainability in both interpretations-organizations learn to involve their stakeholders in corporate decision-making and business practices. Organisations demonstrating Community and Synergy learn from one other, theoretically spoken they exchange intellectual assets with stakeholder inside (employees) and outside (customers, neighbourhood, etc). Involving customers in for instance product design impacts the innovation process of new product formats that include added values for various stakeholders. Therefore, Corporate Sustainability[1], ultimately, means totalling the sum of assets, not only of the company, but of a much wider group of entities, eventually including the whole planet. In this latter context, CS implies that the material assets include the planet's resources (natural capital). Depletion or exploitation of these resources is at best a zero sum game, which is no longer an attractive business objective.

Functioning in Synergy implies that organizations operate in an open system surrounded by other open systems. The interaction between these systems will lead to new and unexpected opportunities. By forming coalitions these possibilities can be explored and exploited in a way that they create added value for everyone concerned, generating added value not only in a material/financial way, but also in a commercial, social and intellectual way.

Managing the complexity of thinking and working in an environment of open systems, full of coalitions, offering great variety and diversity, opens the way to introducing "basic rules". Only when you have mastered complexity, simplicity might work. Basic rules can be understood as the principles by which complex systems function. Paradoxes and dilemmas are seen as effects and sources of inspiration, often leading to new insights, new ideas, new concepts and new learning experiences.

The second contribution of the Four Phase model lies in aligning the strategic orientations with specific sustainability activities associated with the Triple Bottom Line. In stead of implementing CS-R activities as 'add-ons' to business operations, it will generate much more impact when out of many potential CS-R activities those ones are selected which will reinforce the effect of selected strategic interventions.

The two concepts described in this chapter, the strategic phases and development contexts, are distinct notions. The contexts are broader, psychological stages in evolutionary development, while the phases are more instrumental, structuring the interventions for strategy implementations.

The Strategy Matrix-integrating both concepts-presented above can help executives and business consultants to understand organization dynamics in general and facilitate them in plotting a course for organizational change, shifts or transformation, whenever they want to implement a more ambitious approach towards CS and CR, or corporate improvement in general.

[1]Corporate responsibility, in this sense, means being accountable for working in such a way the total sum of assets will increase for direct or indirect stakeholders, now and in the future.

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Abbreviations

CEO Chief Executive Officer
CS Corporate Sustainability
CR Corporate Responsibility
CSR Corporate Social Responsibility
ECSF European Corporate Sustainability Framework
ECLET Emerging Cyclical Levels of Existence Theory
EU European Union
HPO High Performance Organizations
KPI Key Performance Indicator

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Low and Highly Skilled Labor Immigration and Wage Inequality

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Abstract

Fears of rising income inequalities loom large in recent discussions of how globalization and in particular migration are affecting economies and societies [1]. This paper addresses the question how labor immigration is related to wage inequality by using a specific-factors trade model. We show that the impact of immigration of low or highly skilled labor on wage inequality depends mainly on the capital intensity of the industry in which labor immigrates.

Keywords: Immigration, Skilled and Unskilled Labor, Wage Inequality

1. Introduction

Migration has always formed a topic of serious economic interest. However, the world appears to be on the edge of a new era in labor migration, since volume of migration has increased, more home and host countries have been added, and new types of labor migration have emerged. The global stock of migrants about 191 million doubled over the past 40 years which made migration the top of the national and international policy agenda [2].

Globalization is often claimed as being one of the driving forces behind the increasing labor migration [1,3]. Decreasing transportation costs, the emergence of transnational networks and the rapid growth of communication technologies, in addition to sustained growth in international trade as well as foreign direct investment and the trend of international outsourcing, indicating integrated world markets, all that contributes to the increasing movement of both low and highly skilled workers [4].

Although workers do not only migrate northward or into high income countries, fears of mass immigration often engross the dicussions. However, in 2005, 62 million of migrants coming from developing countries migrate to industrialized countries whereas 61 million went to developing countries [2]. Neighboring countries or countries within the region are still important destinations for low skilled migrants working abroad. The increasing size of migration goes along with more countries becoming host countries. But, seasonal workers, mine workers as well as maids belonging to the group of low skilled workers[1] seldom find a ready welcome. Host countries tend to prefer other types of migrants. The movement of highly skilled professionals towards the developed countries, widely known as brain drain[2] for the countries of departure, and seen as brain gain for the countries of arrival is highly welcomed and recently undergoes further promotion by special immi- gration schemes. Some studies already see a competition for the skilled between the developed countries due to demographic and economic challenges [4,7].

According to the International Labour Organization [8], about half of the migrants moving 2006 were economically active at all rungs of the job ladder. Labor immigration affects the economy and development in a multiplex way, depending on features of labor markets, structures of production, and number of migrants [6,4] and is often claimed to change the status of wages in general for both migrants and natives. Moreover, various studies indicate that globalization has gone along with increasing wage inequality. The increasing premiums on skills compared to constant or even decreasing wages have led to considerable public

[1]The countries of South Africa have been sending and receiving workers, especially the mining centers in the region, Namibia, South Africa Zambia and Zimbabwe. This region recently undergoes an increasing number of migrants from Asia [5].

[2] See, for example, OECD, 2008b. According to the World Bank [6], over fifty percent of college graduates from Central America and the Caribbean leave their countries and in some of them, the figure is as high as eighty percent, *i.e.* eight out of ten Haitians and Jamaicans who have college degrees live outside their home country.

and scholarly debates[3] [9]. Thus, the effect of immigration on host countries wages takes on greater significance.

The rest of the paper is organized as follows. Section 2 deals with wage inequality in developing countries. Section 3 develops a general equilibrium model with highly skilled and low skilled labor. In section 4 the main findings are derived and discussed. The final section 5 concludes.

2. Wage Inequality in Developing Countries

The scanty theoretical literature explaining the wage inequality in the Southern countries includes works of Marjit *et al*., Marjit and Acharyya [10-12]. They reveal unfavorable effects of trade liberalization and inflows of foreign capital on less developed countries, given the specific structural characteristics of developing countries, such as imperfections and distortions in the goods and labor markets and the degree of global capital mobility. More recently, Marjit and Kar [13], Yabuuchi and Chaudhuri [9] addressed the questions of wage inequalities and different types of labor. They find that emigration of low skilled workers increases the wage inequality if the capital's shares is greater in the skilled-using labor sector[4]. Whereas those studies focus on emigration, Johannsson and Weiler [14] highlight the effect of immigration on wage inequality of natives. They find evidence that growing relative inflows of unskilled workers increase wage inequalities within the USA, and that the impact on native wage inequality is even stronger as the overall effect.They estimate that a 10 percent increase of the skill-low skill ratio between immigrants and natives leads to a 0.22 percent increase in the wage inequality ratio.

This paper addresses the question how immigration of various types of workers affects the overall wage inequality within host countries in a general equilibrium model. We use the specific-factors model related to Jones [15] with two goods and three inputs. Whereas capital is mobile between the sectors, labor is specific. We interpret labor as being industry specific with skills as human capital which needs time to be acquired[5].

In the specific-factors trade model, immigration of either high or low skilled workers leads to a decline in wages and an increase in the return of capital. Because capital is mobile between the skilled and the low skilled-using sector, immigration that causes reallocation of capital will always affect the wage of the other sector. The main findings are that immigration leads to decreasing wages and increasing capital incomes which might explain the increasing income inequalities in both developing and developed countries. Moreover, this little theoretical study helps to explain how wage inequality is affected by immigration. We find that as long as the capital share in the skilled-using sector exceeds that in the low-skilled-using sector, immigration of both skilled and low skilled workers may reduce the wage-gap. On the other hand, capital income is likely to win from immigration independently on type of migration[6].

3. Specific-Factors Trade Model and Immigration

We use a specific-factors model for a small open economy on a comparative static approach, *i.e.* initially there is no international labor immigration. There are two goods, X and Y. Good X is produced by using low skilled labor, L, and good Y by using highly skilled labor, S. Highly skilled and low skilled labor are different inputs, *i.e.* labor is specific by industry. This fact points out that wages differ across industries. The production of both goods needs capital, K. Only capital is homogeneous and common to the two production functions. Therefore we have $X = F_x(K_x, L)$ and $Y = F_y(K_y, S)$. Production functions exhibit constant returns to scale and diminishing marginal productivities[7]. Goods are traded freely and prices for these goods are given exogenously in the rest of the world[8].

The following set of equations describes the market equilibrium. With perfect competition in goods and factor markets, factor markets clear and cost for each commodity is driven down to price.

$$a_{LX}(w, w_s, r)w + a_{KX}(w, w_s, r)r = p_x, \qquad (1)$$

$$a_{SY}(w, w_s, r)w_s + a_{KY}(w, w_s, r)r = p_y. \qquad (2)$$

Wages and the rental rate of capital are denoted by w, w_s and r. The cost minimizing input-output coefficients in industry X are $a_{LX}(\cdot)$, $a_{KX}(\cdot)$. The same variables are used for the Y sector, with S and Y as indices, $a_{LY}(\cdot), a_{KY}(\cdot)$. Capital and labor are fully em-

[3]For a study explaining the interaction between the wage inequality and the supply of highly skilled labor, see J. Meckl, and S. Zink, [16].

[4]Yabuuchi and Chaudhuri [9] develop a model that incorporates diverse trade pattern and the imperfection of labor markets within a general equilibrium. Although focusing on emigration they expand their findings on immigration and argue that immigration is likely to have an unfavorable effect on wage inequality independently on factor allocation.

[5]In the literature on trade and development, a developing country is seen as exporter of agricultural commodities and importer of manufacturing goods. These types of commodities completely differ in production and require two different types of capital. However, we assume immigration in either commercial agricultural sectors and non-agricultural sectors and hence justify the use of homogeneous capital in two sectors.

[6]The results have important policy implications for receiving countries. Although the immigration of low or medium skilled workers are often blamed for the increase in wage inequalities, the immigration of seasonal workers, maids and nurses seems to have no deteriorating effect on wage inequalities given those sectors are producing at a low relatively capital intensity.

[7]Sufficient conditions for an interior optimal solution, the Inada conditions, are fulfilled.

[8]The model can be used to study international trade in which talent labor form the basis for comparative advantage.

ployed. Hence we obtain

$$a_{LX}(w, w_s, r)X = L, \quad (3)$$

$$a_{SY}(w, w_s, r)Y = S, \quad (4)$$

$$a_{KX}(w, w_s, r)X + a_{KY}(w, w_s, r)Y = K. \quad (5)$$

In the specific-factors model we know even if the prices of the goods (p_x, p_y) are the same as those prevailing in the global economy, local factor prices may differ from the global ones, since factor prices are not equalized if factor endowments in the economy are different from the rest of the world[9].

In the following we assume that $w_s > w$; in particular, $w > w^*$ and $w_s > w_s^*$, where w^* and w_s^* denote wages in the foreign country. This assumption implies that the open developing economy is an immigration country. In our model, economic incentives are the key driver of immigration decisions. In the next section we explore the effect of immigration on relative income inequality. The higher value of w_s / w stands for the relative higher wage inequality in the economy. A percentage change in an endogenous factor price is denoted by $dw / w = \hat{w}$. Therefore, a decrease in the wage gap between highly skilled and low skilled labor can be described by $\hat{w}_s / \hat{w} > 1$.

4. The Immigration of Talent and Low Skilled Labor

Firstly, we examine the consequences of mobility of talent, *i.e.* immigration of skilled workers. In this case S increases and w_s decreases. Subsequent changes will follow in equilibrium:

$$\hat{r} = -\frac{\theta_{SY}}{\theta_{KY}}\hat{w}_S \text{ and } \hat{w} = \frac{\theta_{SY}}{\theta_{KY}} \cdot \frac{\theta_{KX}}{\theta_{LX}}\hat{w}_S \quad (6)$$

where θ_{KY} is the share of capital in production cost of Y, *etc*. as mentioned above. A decline in w_s, following the immigration of the talent, will increase r. Both wage rates, w and w_s, are decreasing. Therefore immigration of talent leads to a change in income distribution within the economy.

Proposition 1. (*Immigration of talent*): *As wages w, w_s fall, the rental rate of capital r increases. Wage inequality will be reduced if the wage rate w_s decreases more than w, i.e. $\frac{\hat{w}_s}{\hat{w}} > 1$. Immigration of skilled workers results in a decreasing wage inequality, if and only if the capital's share in the Y industry exceeds that in the industry X, i.e. $\theta_{KY} > \theta_{KX}$. Whenever the factor intensities are reversed, wage inequality will increase.*

Proof. Following condition (6) and using $\theta_{LX} = 1 - \theta_{KX}$ and $\theta_{SY} = 1 - \theta_{KY}$, we get $\frac{\hat{w}_s}{\hat{w}} > 1$ if and only if $\theta_{KY} > \theta_{KX}$.

Suppose that P_x and P_y remain constant, while the supply of talent increases by immigration, it follows that $\hat{r} > 0 > \hat{w} > \hat{w}_s$, if capital intensity in the immigration industry Y exceeds that of non-immigration industry X, and $\hat{r} > 0 > \hat{w}_s > \hat{w}$ if $\theta_{KX} > \theta_{KY}$.

Secondly we examine the consequences of immigration of low skilled labor. In this case L increases and w decreases. Subsequent changes will follow in equilibrium:

$$\hat{r} = -\frac{\theta_{LX}}{\theta_{KX}}\hat{w} \text{ and } \hat{w}_S = \frac{\theta_{LX}}{\theta_{KX}}\frac{\theta_{KY}}{\theta_{SY}}\hat{w}. \quad (7)$$

We obtain

Proposition 2. (*Immigration of low skilled workers*): *As wages w and w_s fall, the rental rate of capital r increases. Wage inequality will be reduced, if the wage rate w_s decreases more than w, i.e. $\frac{\hat{w}_s}{\hat{w}} > 1$, if and only if $\theta_{KY} > \theta_{KX}$. Immigration of low skilled workers results in a decreasing wage inequality if and only if the capital's share in the Y industry exceeds that in industry X. Whenever the factor intensities are reversed, wage inequality will increase.*

Proof. Following condition (7) and using $\theta_{LX} = 1 - \theta_{KX}$ and $\theta_{SY} = 1 - \theta_{KY}$, $\frac{\hat{w}_s}{\hat{w}} > 1$ if and only if $\theta_{KY} > \theta_{KX}$.

If P_x and P_y remain constant, while the supply of low skill labor increases by immigration, it follows that $\hat{r} > 0 > \hat{w} > \hat{w}_s$, if capital intensity in non-immigration industry Y exceeds that of immigration industry X and $\hat{r} > 0 > \hat{w}_s > \hat{w}$ if $\theta_{KX} > \theta_{KY}$. Therefore, capital will gain in terms of both goods, while labor will lose in terms of both goods. The results of both propositions show that the effect on income and wage inequality depends on the degree of mobility and capital intensity in the immigration industry of the economy.

5. Conclusions

Immigration affects wages and decreasing wages in both sectors following immigration make labor the loser of the race for talents. Furthermore, immigration is affecting wage

[9]For a discussion of the properties of the specific-factors model see, for example, Bhagwati *et al*., [17].

rates and the wage inequality in developing economies. This note shows that the impact of immigration of skilled or low skilled labor on the wage inequality depends on the capital intensity of the both sectors, the one in which workers immigrate and the second one on which the immigration has an downstream effect. It is often argued that immigration of low skilled workers contributes to increasing wage inequality. Taking into account the income share of capital in the different sectors we are able to show that this is true only if the low skilled labor using sector produces with relatively high capital intensity. However, agricultural sectors with a high demand for seasonal workers as well as services like domestic staff might be sectors with low capital endowment and intensity. So, seasonal workers and maids appear not to stress the wage inequality. On the contrary, using the specific-factors trade model, we find that immigration might reduce wage inequalities under rather realistic conditions.

Developing countries with often porous immigration schemes do not choose their migrants. Insofar the types of labor as well as its specific impact on wage inequalities matter in analyzing the short and medium-run effects of immigration. The results presented may shift the focus from the bounded consideration of the effect on the single wage towards the downstream effects on the other sector as well as on the wage gap. They reveal immigration being not the driving force behind the increasing wage inequality but behind the increasing income equality; further empirical studies are required.

Altogether, the winner of the race for talents are the capital holders benefiting from immigration.

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A Typology of Institutional Frameworks for Organizations

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Abstract

Inspired by Dr. Clare Graves' research on evolutionary developments in value systems and levels of existence, this paper introduces an integral business framework—a sequence of ideal type organizations—each characterized by specific institutional arrangements. A table—the transition matrix—summarizes the specific features of each type. It is an update of former version based upon an international EU-financed ECSF research project [1].

Keywords: Value Systems, Organization Types, Responsive Scorecard, Organization Framework, Order, Success, Community, Synergy, Spiral Dynamics

1. Introduction

With Spiral Dynamics, based on the research of Clare Graves [2], summarized in paragraph two, this paper presents ideal type organizations structured according the Gravesian holarchy of value systems. Each type is showing a coherent set of ambitions, relating institutional structures and corresponding business practices, demonstrating different levels of corporate performance and manifestations of for instance sustainability.

In the final paragraph the author presents the Transition Matrix, published earlier in the Journal of Business Ethics [3]. It was the first step in a development that created a more sophisticated integral management framework—coined the Cubrix [4], introduced in the previous edition of this journal.

2. Value Systems

2.1. Graves' Value Systems Model

In the 1950s through 1970s Professor Clare W. Graves performed extensive empirical research regarding values and levels of existence (value systems). The focus of his research—*how does the mind process reality*—resulted in a overall framework for "healthy adult behavior" which he coined the "Emergent, Cyclical, Double-Helix Model of Adult BioPsychoSocial Systems Development". He rarely published his findings. In 1996, his successors, Don Beck and Chris Cowan, introduced Graves' Emerging Cyclical Level of Existence Theory—the shorter title of his model—as Spiral Dynamics [2].

Based on Graves' research they concluded that mankind has gradually developed eight core value systems so far. A value system is a way of conceptualizing reality and encompasses a consistent set of values, beliefs and corresponding behavior and can be found in individual persons, as well as in companies and societies.

The development of value systems occurs in a fixed order. These can be tagged as follows: Survival; Security; Energy and Power; Order; Success; Community, Synergy and Holistic life system. Each new value system includes and transcends the previous ones, thus forming a natural hierarchy (or holarchy).

In most occasions, a value system develops in reaction to specific environmental challenges and threats: the systems brighten or dim when life conditions (consisting of historic *Times*, geographic *Place*, existential *Problems* and societal *Circumstances*) change. Transformations, that is shifts of contexts, actually occurs when life conditions (LC) have build up a sufficient level of urgency among entities to leave behind their proven patterns of behavior. Secondly, these entities must have a supportive mind capacity (MC) to be able to match the new challenges life conditions offer and generate new adequate behavior and subsequent institutional arrangements.

It is all about balancing MC and LC. Psychologically, people might not be able to match changes in the environment, so they remain "arrested" towards future needs or even "closed" to less complex value systems that, naturally—should have been included in their repertoire.

Entities such as people and organizations will eventually have to meet the challenges their situation provides or risk the danger of oblivion or even extinction. If for instance societal circumstances change, inviting corporations to respond and consequently reconsider their role within society, it implies that corporations have to re-align their value systems and all their business institutions (such as mission, vision, policy deployment, decision-making, reporting, corporate affairs, etcetera) to these new circumstances.

The quest to create an adequate response to specific life conditions results in a wide variety of survival strategies, each founded on a specific set of value assumptions and demonstrated in related institutions and behavior.

Out of the eight core Gravesian value systems, we are only taking the six most recent ones as these are most relevant in the context of corporate sustainability. The same color codes as introduced by Beck and Cowan [2] are used to label the value systems, respectively red, blue, orange, green, yellow and turquoise. In **Table 1** a short description of each value system is given, in relation to (the perceptions of) the environment (life conditions), which induce the value system.

3. Organization Types

3.1. Thinking Systems

It is absolutely essential to understand that Gravesian value systems are distinguishing types of thinking *in* people and not types *of* people. It is about the intentions and awareness of people and their actual thinking systems to match the issue at hand. *A person is not "Blue". No, a Blue way of thinking is dominant within this person.*

When the coping possibilities a value system offers are no longer sufficient to provide an appropriate response to the existing circumstances, there is an incentive to move on to the next value system. The awareness that a current pattern of behavior or a certain institution is no longer adequate to tackle a problem can propel a change in the perception of reality. Increasing complexity requires more complexity of the value systems in coping with the situation. More complex value systems allow more degrees of freedom to act in accordance with the environment.

The question is often posed: "Is a more complex value system better than a basic one? In general, the answer is no. When the life conditions are adequately dealt with in less complex value system there is no need to aim for a higher value system. However, in highly complex environments, Yellow can provide a more adequate response to outside challenges than Blue because it offers more degrees of freedom to act appropriately under varied circumstances. The real issue therefore is "adequateness", the ability to provide a balance between Life Conditions and Mind Capacity.

The gradual move to a new value system facilitates new patterns of behavior and the creation of new institutions in line with the emerging value system. In other words, challenged by changing circumstances and provoked by new opportunities, individuals, organizations and societies develop adequate solutions, creating synergy and adding value at a higher level of complexity. Since instability increases at higher complexity levels,

Tabel 1. Development of human and organizational value systems, inspired by Graves and Spiral Dynamics [2].

Main Themes-Labels	Energy & Power (Red)	Order (Blue)	Success (Orange)	Community (Green)	Synergy (Yellow)	Holistic life System (Turquoise)
Environment: Life Conditions	Limitless challenges about boundaries of the territory and to be dominant over self and others within the territory.	Ordered relationships requiring legitimization in order to ensure stability and security for the future	Many viable alternatives for progress, prosperity and material gain since change is the nature of things	The gap between people and their (material) Possibilities has become disproportionately large	Complex problems that cannot be solved within the current systems as awareness of broad interconnections grows.	The consequences of human actions threaten the planet's living systems and demand coordinated effort.
Life Force	Conquering Domination	Belief	Achievement Changeability	Belonging	Understanding	Interconnections
Main Focus	Individual/self	Group/collective	Individual/self	Group/collective	Individual/self	Group/collective
Thinking System: Mind Capacity	Egocentric/cunning	Absolutistic/linear (consequential)	Multiplistic/ calculating	Sociocentric/ affiliative	Systemic/existential	Holistic/ experimental
Typical Values	Courage, vitality, strength, respect, personal power, rivalry, territorial, intimidation, hedonism, loyalty to persons	Clarity, discipline, one truth, loyalty, duty, guilt, justice, conformity, obedience, orderliness, quality, craft-man-ship	Results, reward, entrepreneurial, image, career advancement, productivity, guts, creativity, control, satisfaction	Consensus, conflict avoidance, team-work, equality, participation, honesty and openness, being a decent person, harmony	Insight, integrity, learning, long-term orientation, ability to reflect, flexibility, tolerance for uncertainty and paradoxes	Inspiration, interdependence, future generations, ability to forgive, wisdom, sufficiency, responsible living

entities can shift to lower levels if circumstances turn unfavorable or if competences fail to meet the required specifications. Charles Darwin once concluded: "It is not the strongest of the species that survive, nor the most intelligent, but the one most responsive to change".

When one studies particular expressions (e.g. certain behavior) within an organization one should not deduct automatically that the related value system is functioning. Since a particular value system includes and transcends previous ones, a basic expression can be found in all contexts. For example rules and regulations will be found in every organization, not only in organizations with a dominant Blue value system. The key question when certain behavior is displayed is: "Why is it important for you to do this?" In the example of rules and regulations, in the case of a Blue value system, the answer to this question could be: "Because rules provide me with the desired order and stability; rules are important by themselves and must be followed". In an Orange value system the answer might be: "Because the rules we use ensure smooth functioning and lead to success and high profit; rules can be followed as long as they help us in achieving our goals (and can be bent when not)".

In presenting ideal type organizations we will focus on the institutional structures and arrangements of four core value systems, for which we use the color codes, introduced by Christopher Cowan, the co-author of Spiral Dynamics. The selected systems are Order, Success, Community and Synergy, *i.e.* blue, orange, green and yellow. The transition zones between core value systems are also not included in the analyses. Each context is introduced by the underlying value system, its dominant worldview and related, often psychological explanations, which brings forth supporting institutional arrangements and structures.

3.2. Compliance-Driven, Based on Order (Absolute Order: Blue)

Introduction of the value system

Before mankind experienced Order, it was able to function at three previous levels of existence characterized by the Survival, Security (bonding order) and 'Energy and Power (powerful self)'. Historically, loose tribes evolved to clans, seeking refuge in kinships, rituals, holy ancestors and mystical nature. The value system supporting Security can also be observed in the mother and child relationship, in feelings of pride and belonging and in the identity of organizations. Its color code is Purple.

Freeing themselves from kinships and family ties, people gradually experienced ways of expressing themselves guiltlessly and selfishly, so as to find immediate pleasure and avoid shame in a world of domination, threats and ego. Power and Energy—indicated with Red—can be easily recognized in feudal states, in perseverance when the going gets tough and in negative manifestations such as in traffic (road rage), hooliganism and "party animals". Red lacks the capacity for long-term sequential thinking. They feel no guilt, only the need to gratify impulses and senses immediately. Individual persons tend to manifest these energies especially when they are young (set limits and they will test it!) or in adverse times (CEOs, admirals). These manifestations relate to an environment with limited possibilities, with a shortage of sources, provoking entities to fight in order to gain control and get their share.

When people learn to transcend the self, experience consequential thinking, they are able to live up to "higher ideals", find pride and fulfillment in their work and accept sacrifices now so as to obtain rewards later. New values emerged that matched a quest for order, meaning and purpose. History has shown empires transcending the feudal states. Christianity, communism, armies and bureaucracies represented absolute order, providing a master plan that puts people in their proper places. Impulses are controlled through discipline, guilt and punishments. The rightful authorities seek order and stability and succeed in making their people believe to sacrifice themselves for future rewards.

People "with a lot of blue" live by the book. They try to comply with the laws, regulations, procedures and agenda's that structure their lives. Life is relatively simple: for each problem there is a proven practice and a guidebook to help them solving it, step by step.

Organizational features associated with Order

Organizations grounded in Order have a clear purpose, often explicitly or implicitly founded on principles, which often find their background in history and religion. Organization-wide there is a strong sense of moral duty.

These organizations are structured in strict bureaucracies, with the status of each individual linked to its position in the hierarchy. The archetype leadership style is "manager": formulating top-down planning schemes and policy deployment, determining control systems and budgets and designing and maintaining procedures and a clear division of tasks.

Taylorism is an approach typically linked to Order. Taylor's principles of standardization, specialization, maximization, concentration and centralization are typical features according to which business is run. Furthermore, the Deming's Quality Circle and other traditional quality tools as well as optimizing techniques and resource allocation are applied in order to economize on costs and expenditures.

Focusing on the various departments within an organization, one can observe that the production system is based on internal priorities and mainly technology-oriented in order to create economies of scale and vertical integration. They often dominate or try to include the supply chain within the hierarchy. Innovations are often of incremental nature and mainly apply to product development.

The people department is mainly an administrative unit, with employees fulfilling their tasks provided by line managers. Corporate behavior can often be characterized as authoritarian and custodial[1]. The market strategy is primarily a supply push approach, charging consumers a price based on integral costs plus a justifiable margin.

It is a goal-oriented system, with a focus on assigned tasks, not on persons.

Progress in Order is measured in terms of material wealth. The traditional scorecard format, relating to Order, is the annual financial report organizations have to show to Tax Authorities, the Chamber of Commerce or the Stock Exchange, in case the organization is publicly listed. The format is determined by law and carefully described by accountancy boards, such as the ACCA.

Organizations in Order expect governments to provide clear legislation and subsequent enforcement, which is effective and visible (law and order). Business' role in society is more or less independent and social welfare is the exclusive responsibility of the state.

The "license to operate" is applicable to organizations that are compliance-driven, thus matching Order.

Certain things are best done in the "blue way", such as maintenance, bookkeeping, chemistry, refineries, energy production and transport. The banking system, court's practices, the judge and jury, are all embedded in Absolute Order. Also private companies rely on a basic blue fundament: "a deal is a deal". Contracts are important ways to conclude arrangements between people and organizations.

Furthermore, many public services flourish within a hierarchical environment, but fail once these services are privatized and left to compete within a market environment.

With too much emphasis on linear thinking and values such as discipline, one truth, loyalty, duty, guilt, conformity, justice, obedience and orderliness the blue way attracts adverse effects such as:

- Limited problem solving capacity and reluctant creativity;
- Suffocating rules and procedures for employees and customers;
- Planning and regulation is more important than the objective;
- One truth, one right way, always categorical.

These omissions created the seeds for a new value system to emerge. It awaited the right circumstances to change paradigms once more. Instead of being what you are meant to be, more and more people longed to be who they could become. What kind of organization supports this new attitude?

[1]Davis (1967): Authoritarian refers to the authority of the CEO (or minister), and the custodial (paternalistic) on the organization as a whole securing the (basic) needs of the employees. [5]

3.3. Profit-Driven Based on Success and Entrepreneurship (the Enterprising Self: Orange)

Introduction of the Value System

In a world with plenty of viable alternatives for progress, prosperity and material gain, people and organizations with a sufficient level of Orange realize that change is in the nature of things and (personal) success within reach of anyone with talents and guts. When you are born a "dime" the "Enterprising Self" knows how to grow into something larger and gain control over its destiny. Success is the new name of the game in an environment offering plenty opportunities to compete, win and make things better and better.

In Success multiplistic thinking evolved offering many options and choices. In Order, people compared to the standard, but here they benchmark themselves against competition and the number one. People with a lot of Orange recognize change is the nature of things, creating new niches and introducing new technologies, enhancing life for many.

They work hard—preferably make others work hard for them—and risk time and money (not their life, as in Red) to achieve prosperity and material gain. They seek out the "good life" and abundance, rather than rewards hereafter. The expression "keep up with the Joneses" is typically Orange. Both people and organizations act in a calculated way while striving for autonomy and independence, seeking for progress and success with the best solutions. If they are allowed to, they try to master nature and exploit its resources.

Organizational features associated with Success and Entrepreneurship

Organizations with a dominant level of Orange make use of an active hierarchy, with informal and pragmatic lines of communication. The matrix and business unit structure are Orange varieties to open up and loosen the hierarchies, while maintaining a firm grip on business processes.

Through typically Orange values such as image, productivity, creativity, career advancement, entrepreneurship and control companies are result-oriented through (gradual and continuous) improvement, stimulating a desire to compete and to become better.

The archetype role of leaders is the Entrepreneur: discovering niches as opportunities for success, putting together new "combinations", creating the necessary means and enjoying the fruit of their labor. Burton Klein's "*Happy Warrior*" and Schumpeter's "*perennial gale of creative destruction*" are classic illustrations of the entrepreneurial drive behind capitalism.

Success in this context is primarily measured in terms of money and commercial assets. Organizations, having already established a sound-Blue-production system tend to focus on marketing efforts in trying to gain market share. Related practices such as communication, and advertising are also important activities in Success, with often pretending and "make believe" as its underlying intentions. "Window dressing" is invented in Orange!

Organizations engage with suppliers in a market environment, with contracts primarily based on prices and secondly, on specific quality requirements. Product development takes place, especially diversification, moreover Orange gained the competences to enhance process innovations and apply them in the context of quality management.

Human Resource Management treats employees as full time equivalents, as resources, and as costs, carefully selecting where each employee fits best. Employee satisfaction is the crucial standard for HR-performance measurement. HR managers might support its employees with bonuses, various benefits, training facilities and alike, when they are convinced it will lead to higher revenues, lower (turnover) costs and corporate success. In the same way, CS/CSR is accepted only as an opportunity to gain success, significantly reduce risks or enhance reputation, image, prestige and personal esteem. Thus, companies tend to embrace CS/CSR, the moment CS/CSR activities are supported with business case evidence.

A commonly applied measuring format, typically matching Success and Entrepreneurship, is the Business Balanced Scorecard, introduced by Kaplan and Norton. Its anchor point remains the financial position of the organization, but it also identifies three contributory elements: customers, people and processes and corporate lea- rning. See **Figure 1**.

Organizations expect governments to abstain from over-regulating their markets, as these are jeopardizing their profits and interfere with their sense of freedom. Governments should create and maintain "level playing fields" and allowing companies a "license to grow". According to Orange norms, the voluntary character of corporate sustainability and responsibility particularly must never be violated.

Activities best done in Success are entrepreneurship and marketing, sales and promotion activities in order to boost the commercial capacity of the organization.

People with a lot of Orange tend to be pragmatic. This attitude gives rise to ethical issues since the end is more important than the means. With profits gained at the expense of the weaker, the Entrepreneurial system generates dropouts. Tending to elitism, Orange is inattentive to a fair distribution. With a hang to quantity and profits instead of quality and durability, Success creates "consumerism" and a huge waste stream. Moreover striving for success often becomes compulsive, leaving orangists no time to enjoy their fruits.

The spillover of the entrepreneurial successes gave rise to a new value system, shortly introduced in the next section.

3.4. Care-Driven, Based on Community (the Egalitarian Order: Green)

<u>Introduction of the Value System</u>

The Purple reciprocity and Orange accumulation of material wealth paved the way for Green redistribution of society's resources among all. The self is once more being sacrificed, but this time in a world where compassion and belonging are paramount, where everything is relative and "truth" is a matter of context and the group's needs. Community liberates humans from dogma and greed, promoting a sense of community and unity. Solidarity is felt with the weaker and dropouts, victims of a system exploiting resources and causing an unequal distribution of material wealth.

People and organizations with a lot of Community-sense try to explore the inner beings of themselves or others. They refresh spirituality and seek to bring New Harmony. Generally Community is anti-dogmatic, and since everyone is unique, anti-labeling and anti-hierarchy, but highly tolerant.

<u>Organizational features associated with Community</u>

In Community, the process of organizing has become an end in itself. Not the organization as such matter that much, but a group of people engaged in a process of organizing. It implies the involvement of all others, within and outside the organization. Community values support competences enhancing the ability to involve everyone (engagement) and listen carefully (dialogue). In Community one tend to recognize the human being "behind" the employee and the customer. As Peter Drucker already noticed in 1952 "when hiring a worker, one gets a whole man": along with the muscles and brainpower comes the emotional and spiritual dimension. These capacities allow persons to better understand one other, to create a two-way flow of information, turning conversations into dialogues. Teamwork improves, as people are better able to work together.

Persons and organizations with a lot of Green are convinced that individual achievements alone are not sufficient to adequately confront the challenges Community Organizations are facing. In Community one believes that cooperation beats competition: "together we stand strong". Fairness is a highly regarded value, both in the supply chain, especially when suppliers come from emerging economies, and in the pricing policy towards customers.

Success organizations mainly exploit their own resources and existing competences in trying to become better and better, while Community organizations learn to collaborate first internally and secondly by engaging with outside stakeholders. Examples for increasing internal coherence are quality orientations shifting from process to organization-wide, a people-driven philosophy and significantly improving workplace culture and practices. The newly acquired skills in dialogues and teamwork, support the engagement with outside stakeholders such as customers, suppliers, and neighborhood representatives. The engagement primarily commences as a consequence of corporate responsibility, expressing that the organization is accountable for its impact on others. By effectively working together with internal and external stakeholders, thus tapping into their competences and capacities, organizations find new opportunities to boost their performance. This time with respect to the triple bottom line: people, planet and profits.

The archetype leadership style in Community is "coaching"—the servant leader. The servant leader, a term coined by Robert Greenleaf, implies a state of being, not doing: the first and important choice a leader can make is the choice to serve, without which one's capacity to lead is profoundly limited [6]. Hierarchies are replaced by supportive structures. A typical expression is: "We take care of the people, the people take care of the business."

Instead of providing solutions, managers should allow the group to create the answers. With typical values such as consensus, conflict avoidance, teamwork, equality, participation, honesty, openness, being a decent person and harmony, decision making in the context of Community is an-often time consuming-group process. Once the decision is reached, the buy-in is guaranteed and implementation can be done quickly. This type of consensus-oriented decision-making implies that a new type of corporate governance structure has emerged, including a new role of management, a flat organization structure and shareholder value being balanced against the interest of other legitimate stakeholders.

In Community Organizations, the term Human Resources is no longer applicable to employees, and their satisfaction as indicator is surpassed by the level of trust which (ought to) exist between management and employees, between employees and among stakeholders such as customers, suppliers, shareholders and neighborurs. Human Talent Management is more appropriate, indicating its emphasis on the development of individual employees and the recognition of employees being assets instead of costs.

The traditional focus on the material and commercial organizational competences are fading somewhat in favor for the socialization [7] among employees and other stakeholder groups: the ability to engage with people and uniting them in an attempt to achieve common goals. Previous organization types were resource oriented, but organizations applying engagement and collaboration as key concepts in Community strategies are stakeholder oriented. Stakeholders have become co-makers and co-creators. Strategic partnerships are common and institutional arrangements on sector level emerge.

The bulk of management tools supports Order and Success. Community related tooling is still rare. The ECSF project created an innovative measurement format: the Responsive Business Scorecard. This format includes four stakeholder groups, each with an interactive relationship with a fifth entity, the organizations itself. See **Figure 1**. The box in the middle—Corporate Performance Improvements—functions as an anchor point linking Community with Success, as much as Financiers and Owners linked the Balanced Business Scorecard with the Financial Report (Order).

The word "responsive" emphasize the Communion principle [8] and represents its willingness to interact with stakeholders and be accountable for their actions and impact to others. The Responsive Business Scorecard emphasizes the relationships with the main stakeholder groups and the extent to which these outcomes contribute to the improvement of the corporate goals.

The relationships with the stakeholders can be managed by applying the old Deming learning cycle Plan-Do-Check-Improve, or more appropriate to Community: Identify-Engage-Involve-Agree-Deliver-Learn and Improve.

Trying to be a decent person, nice and loving, is a highly regarded quality in Community. Conflict avoidance, how ever, also have negative consequences. With criticism smothered by love and judgments made relative to the

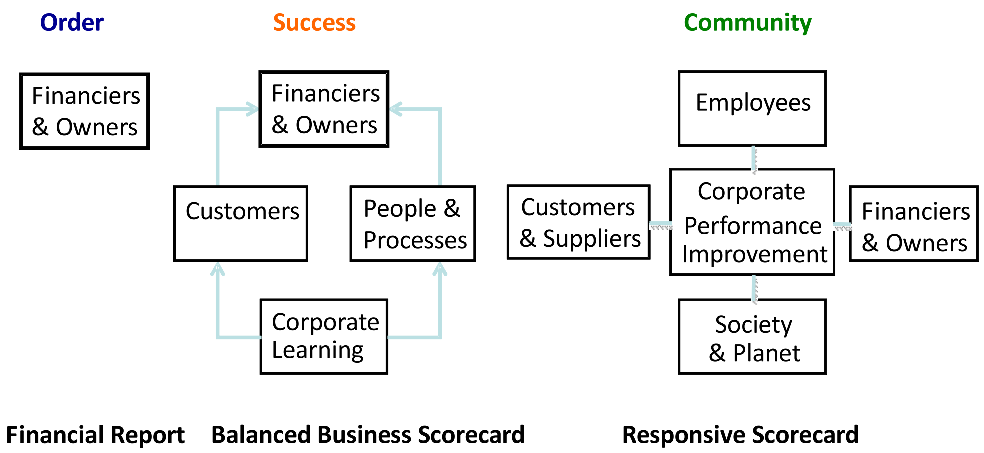

Figure 1. Three manifestations of business reporting formats aligning specific development phases.

situation at hand, decision-making risk non-functional and abstract outcomes.

Using each other's qualities for mutual growth, Community is able to create good learning conditions. However, the aura of an expert is badly regarded in Green: consensus is more important than expertise and incompetence is not a reason to be laid off. With rising complexity levels, Community does no longer provide the ultimate solutions to the problems at hand. Furthermore, equality and consensus building may lead to pooling of ignorance.

Being confronted by chaos in a world at-risk, typical Community features such as the lack of leadership and expertise and the emotional and economic cost of caring are important arguments to develop new ways to cope with more complex challenges.

3.5. Synergy (the Integrating Self: Yellow)

Introduction of the Value System

Comprehension, understanding and synergy are the buzzwords of Synergy. A person and organization with a lot of yellow, express itself, but never at the expense of others or the earth, so that all life may continue in the most natural, sustainable, and fitting ways. They recognize the inevitability of nature's flows. They understand that the complexity of today's world cannot be solved within the current systems, as their awareness of broad interconnections grows.

Synergy can find its way in a mix of conflicting "truths", for it is able to see more colors and uses more senses at the same time. By focusing on functionality and applying competencies to get buy—in from others, Synergy is able to create win-win options, seeking self-interest without doing harm to others and nature.

In discussing ideas, persons with a lot of yellow do not get personalized. They will not say: "These people can't cook", but "This food is not of good taste". Furthermore, in Yellow there is room for authenticity, since internal motivations matter a lot. Existentialism is strong.

Organizational features associated with Synergy

In order to meet its drive—to be, to learn and to discover—persons with a lot of Synergy function best in a network with a strong sense of direction: Yellow demands flexibility and open systems. Values such as insight, long-term orientation, ability to reflect and tolerance for uncertainty and paradoxes support the drive for self-development and boost people's ability to learn and apply knowledge. They are able to learn from any source. With a mind that quickly wanders, they have difficulty in maintaining focus.

Larger organizational entities transforming-or breaking up-into network structures, demonstrate the drive behind Synergy. The Hollywood movie scene is a good example of a once highly successful oligopoly, which broke up in numerous small professional clusters, who work together in a network for the duration of a project. Not far from Hollywood, in Silicon Valley, one can witnessed a network structure that emerged bottom up, independent professionals clustering into networks, creating the necessary competences to meet the challenges facing Synergy.

The archetype activity in Synergy is the "Emergence or connected Leader", who is both "visionary" and able to link the various qualities into one effective and coherent approach. The leadership style dominated by Synergy causes breakthroughs, supports transitions, directing its organisation into new innovative ways that alter business. Jim Collins' [9] "Good to Great"—concept of level five leadership fully coincides.

Real leadership is no longer confined to what people *do*, but grounded in who people *are*. An authentic choice *to serve life* increases ones capacity to lead by allowing life to unfold through you. The hierarchy between the leader and the led remains healthy: leadership is never dominating or abusing raw power. The leadership potential can be developed in everyone. It implies identifying the personal responsibility and the alignment between one's personality and ambitions with one's role within the network. Therefore, essentially, leadership is about learning how to shape the future [6].

The basic guiding principle between people and their organization is the alignment between collective and individuals needs and motives. Alignment also takes place between the various entities within the network, including the stakeholders. Corporate behavior associated with this context can be characterized as "motivational". Managers support their employees, often professionals, in order to bring them into the flow, accomplishing both their own as well as their organization's objectives and creating a feeling of self-actualization.

Employees accept career advancements only when they feel they are competent and when it is a nice job. Typical negative manifestations of synergy-driven people and organizations are the lack of commitment to organization and colleagues. They might appear aloof and uninterested or operate as loners. When they do not get enough interesting work they will abandon their position. Furthermore they are intolerant to rigidity and demands open access to information.

4. Final Remarks

4.1. Transition Matrix

The institutional structures of each ideal type can be summarized and structured according the enablers of the Global Excellence Model, one of the fundaments of the Cubrix [4]. See **Table 2**, below.

In coherent ideal type institutional structures, one can distinguish the left quadrant dimensions, introduced by

Ken Wilber [10,11], specifically the ideal type cultures and intentional values people apply while coping with the challenges the ideal type organization is facing. These two topics are summarized below (see **Table 3**).

The ideal type organizations, introduced in this paper, cannot be recognized as actual organizations. However, in studying or monitoring organization development one can distinguish various elements from these ideal types. It also supports the gap analyses between ambitions, actual behavior and policies and the structural elements of these types. When these are not coherent, one should transform towards, or adopt institutional elements from the types that align better with the intentions and challenges organizations are facing.

In practices, several challenges remain intact and groups of people often have a mix of values from various value systems, making it quite a challenge to determine which types of organization align best with the given goals. Vice versa, an actual set of institutions can jeopardize the ambitions when these ambitions cannot be met within the contemporary setting. Again, there are no simple cause relation effects in organization development.

This matrix can also be used as a framework for structuring, for instance, management literature, or all management tools, methods and theories, as these methods

Table 2. A developmental approach to corporate enablers, structured according to the GEM [4].

Development Labels	Compliance-driven Order (Blue)	Profit-driven Success (Orange)	Care-driven Community (Green)	Systemic-driven Synergy (Yellow)
1. Leadership	Manager	Entrepreneur	Servant Leader	Emergent Leader
2. Strategy	Mergers & acquisitions	Autonomous growth due to competitive qualities	Stakeholder engagement; Chain related	Industry related, seeking breakthroughs
3. People Management	Personnel & Administration	Human Resources Management	Human Talent Management	Human Capital Management
4. Communication & Decision Making	Top down, while applying the procedures from higher authorities	Top down, but valuable info from the bottom is always welcome	Bottom-up; group decides based on consensus; sociocratic	Consent principle decides who should make the decision, as understanding of the matter prevails
5. Learning & Innovation	Product innovation based on technical expertise	Process innovation, and product diversification	Social Innovations, developing supportive structures to boost learning and innovation	System innovations, based on in-depth understanding of dynamics, sustain-ability, and needs
6. Resources	Price competition	Maintenance on process indicators	Outsourcing with strong relationships, peer audits	Co-creating; together- win; Sustainable Purchasing
7. Processes	Activity Orientation	Process Orientation	(Internal) System Orientation	Chain Orientation

Table 3. A developmental approach to corporate enablers-context related (GEM).

Development Labels	Order (Blue)	Success (Orange)	Community (Green)	Systemic-driven Synergy (Yellow)
1. Culture	Bureaucratic; procedural; compliance-driven	Entrepreneurial, calculative; profit-driven	Retiree Consensus; Empathetic; care-driven	Open, flexible, transparent; network oriented; Systemic-driven
2. Values	Clarity, discipline, one truth, loyalty, duty, guilt, justice, quality, conformity, obedience, orderliness, craftmanship	Results, reward, entrepreneurial, image, career advancement, productivity, guts, creativity, control, satisfaction	Consensus, conflict avoidance, team-work, equality, participation, honesty and openness, being a decent person, harmony	Insight, integrity, learning, long-term orientation, visionary, ability to reflect, flexibility, tolerance for uncertainty and paradoxes

often align with specific contexts only. It is as if one simply opens up a specific drawer, from a wide chest of drawers, finding a full set of business institutions, management tools and concepts, whatever. Although it is a complicated framework, users only need to know the relevant aspects, the aspects related to their context only. By determining A and B, referring to an initial context and situation and a desired state, the user will get a full-management reference, indicating the various steps and sets of relevant information that will help getting them to the espoused situation. The framework can be used as an expert system, raising the right questions as well as providing the best answers.

A foundation has started—Stichting Koploperz (Leading Organizations Foundation) that will benchmark the best practices, structured according this framework.

In practice, some drawers are still empty, others are not fully filled and lacking coherence. So there is still a lot of work to do. However, we did analyze over 100 management tools, according their characteristics related to this framework, coined the Cubrix. In the near future we will create an online expert system. If you want to be involved, someway, let us know!

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Abreviations

CEO Chief Executive Officer
CS Corporate Sustainability
CSR Corporate Social Responsibility
ECSF European Corporate Sustainability Framework
ECLET Emerging Cyclical Levels of Existence Theory
GEM Global Excellence Model
LC Life Conditions
MC Mind Capacity

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Simple Differential Equations of A & H Stock Prices and Application to Analysis of Equilibrium State

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Abstract

Similar to the simplest differential equation of stock price, a set of simultaneous differential equations of stock prices of the same share in both A and H stock markets have been established. This is a set of simultaneous nonlinear differential equations, which can be solved by iteration method via a proof by g-contraction mapping theorem. Further more, the exact solution for equilibrium state and an example of checking the price prediction of "China Petroleum" (601857) at a conference held in May 2008 are given.

Keywords: A & H Stock Markets, Differential Equation, G-Contraction Mapping, Equilibrium State, Stock Value

1. Introduction

The "A-stock market" in China is a new developing market approaching to connect with the regulations of international markets. The Hong Kong stock market (H-stock market) is a district international stock market. Many Chinese companies issue their stocks in both A and H stock markets. The difference between A and H stock market makes the same share have different prices in A and H stock markets, and thus speculating on different stock prices happens frequently. The technique of evaluating the value of a stock is most important for investors. Usually, for the same share, a higher value, or PE ratio, is estimated in A-stock market than that for H-stock market due to many reasons. However, no paper concerned with quantitative analysis for stock price in A & H stock markets has been found. This paper establishes a set of simultaneous differential equations for stock prices in A & H stock markets based on a certain mathematic model developed by a serious works of the author [1-11]. The simultaneous differential equations can be solved by iteration method via the similar proof by g-contractive mapping theorem [12]. Further more, an exact solution for a usefully special case is obtained. An example of checking the predicting of stock price of "China Petroleum" (601857) at a conference held in May 2008 is given.

2. Simultaneous Differential Equations of Stock Prices of A & H Stock Markets

Similar to the establish of simplest differential equation of stock price [9], we set up:

a) Equations of Amount of Purchasing and Selling:

$$A_p(t) = p_a x^{-1}(t) + m[x(t) - ey(t)] \quad (1)$$

$$A_s(t) = s_a x(t) - m[x(t) - ey(t)] \quad (2)$$

where t represents time; A_p, A_s represent the amount of purchasing and selling respectively; x, y represent the stock price (unit by RMB) of a share in A and H stock market respectively; p_a, s_a, m, e are constants. In which we assume that the amount of purchasing A_p is inverse proportion to the stock price x, and proportion to the difference of $[ey - x]$; the amount of selling A_s is proportion to the stock price x and minus proportion to the difference of $[ey - x]$, since selling and purchasing are opposite action of trading.

b) Equation of the Changing Rate of Stock Price:

We assume that the changing rate of stock price is proportion to the difference between demand and supply, *i.e.*,

$$\dot{x}(t) = dx/dt = g[A_p(t) - A_s(t)] \quad (3)$$

where g is a constant to make sure same dimension on both sides.

c) Simultaneous Differential Aquations of Stock Prices in A & H Stock Markets

Substituting (1), (2) into (3), we have

$$y = y(t) = T_1(x) = a\dot{x}(t) + bx^{-1}(t) + cx(t) \quad (4)$$

$$a = 1/(2meg),\ b = -p_a/(2me),\quad c = -(2m - s_a)/(2me), \quad (5)$$

Similarly, for H stock market, we have

$$H_p(t) = p_h y^{-1}(t) + n[x - ey] \quad (6)$$

$$H_s(t) = s_h y(t) - n[x - ey], \quad (7)$$

$$\dot{y}(t) = g[H_p(t) - H_s(t)], \quad (8)$$

where H_p, H_s are the amount of purchasing and selling respectively; p_h, s_h, n are constants. Substituting (6), (7) into (8), we have

$$x = x(t) = T_2(y) = a_h\dot{y}(t) + b_h y^{-1}(t) + c_h y(t) \quad (9)$$

$$a_h = 1/(2ng), b_h = -p_h/(2n),\quad c_h = -(2en - s_h)/(2n), \quad (10)$$

(4), (9) are the simultaneous differential equations of stock prices. Which are a cycling nonlinear differential equations, and can be shown the existence of solutions $x^*(t)$ and $y^*(t)$, *i.e.*, the fixed points $x^*(t) = T_2[T_1(x^*(t))]$, and $y^*(t) = T_1[T_2(y^*(t))]$, via g-contractive mapping theorem [12]. We are not going to the details of the proof but focus our attention to the more useful problem, *i.e.*, where is the equilibrium point?

3. The Exact Solution of Simultaneous Differential Equations for a Special Case, the Equilibrium State $[ey - x] = 0$

We say that $[ey - x] = 0$ is an equilibrium state, at which no profit can be made from speculating the difference between the A and H stock prices, or no money moves on balance from A-stock to H-stock (or from H-stock to A-stock) for speculation. If $[ey - x] > 0$, then, A-stock price x is chipper, and thus money moves from H-stock market to A-stock market; If $[ey - x] < 0$, then money moves from A-stock market to H-stock market.

In an equilibrium state $[ey - x] = 0$, we have

$$e = e(t) = x(t)/y(t) \quad (11)$$

where e is the ratio of A and H stock prices at equilibrium state.

There are a lot of argue on the value of e. How much should e be?

If $[ey - x] = 0$, then substituting (1), (2) into (3), we have

$$\dot{x}(t) = p_a x^{-1}(t) - s_a x(t) \quad (12)$$

The solution of (12) is

$$x(t) = \left[\frac{p_a}{s_a} - \left(\frac{p_a}{s_a} + x_0^2\right)\exp(-2s_a t)\right]^{1/2} \quad (13)$$

where $x_0 = x(0)$ is the stock price at the beginning of the equilibrium state.

Similarly, for $[ey - x] = 0$, substituting (6), (7) into (8), we have

$$\dot{y}(t) = p_h y^{-1}(t) - s_h y(t) \quad (14)$$

The solution of (14) is

$$y(t) = \left[\frac{p_h}{s_h} - \left(\frac{p_h}{s_h} + y_0^2\right)\exp(-2s_h t)\right]^{1/2} \quad (15)$$

where $y_0 = y(0)$ is the stock price at the beginning of the equilibrium state.

Substituting (13), (15) into (11), we get

$$e = e(t) = \left[\frac{(p_a/s_a) - [(p_a/s_a) + x_0^2]\exp(-2s_a t)}{(p_h/s_h) - [(p_h/s_h) + y_0^2]\exp(-2s_h t)}\right]^{1/2} \quad (16)$$

Once the coefficients p_a, s_a, p_h, s_h have been found ([10] for the determination of coefficients), e can be calculated by (16).

However, how can we find an equilibrium state from the markets data?

The "equilibrium state" is an ideal concept, in which no money moves on balance from either A-stock market to H-stock market or from H-stock market to A-stock market for speculating profits. But how can we know no money moving between both stock markets from markets data? The market data only provide information of stock prices, turn-over volumes. The coefficients p_a, s_a, p_h, s_h can be calculated from the market data [10] of different time in a short time interval such that these coefficients keep unchanged. However, it is more accurate to use the information at the same time. In the following, we consider a special case of an equilibrium state, *i.e.*, $\dot{x}(t) = 0$ and $\dot{y}(t) = 0$ hold at the same time $t = t_e$, *i.e.*, both stock prices x and y are in a "stationary point" (or the so-called "Doji" in marketing term, or a "cross star" in Chinese marketing term).

$$\dot{x}(t) = 0,\ \text{and}\ \dot{y}(t) = 0, \quad (17)$$

Substituting (17) into (12) and (14), we have

$$x(t_e) = \sqrt{(p_a / s_a)} \tag{18}$$

$$y(t_e) = \sqrt{(p_h / s_h)} \tag{19}$$

Substituting (18), (19) into (11) we have

$$e = \sqrt{(p_a s_h)/(p_h s_a)} \tag{20}$$

Since at a stationary point, $x(t_e)$, $y(t_e)$ keep unchanged, then $x(t_e) = x(0) = x_0$, $y(t_e) = y(0) = y_0$, *i.e.*, let the time t_e be the starting time $t = 0$ of the equilibrium state, then (16) becomes

$$e = x_0 / y_0 \tag{21}$$

(21) and (20) are equivalent, but (21) is easier to know x_0 and y_0 from the market data.

Now we have not used the information of turn-over volumes. Notice that Substituting (3) and (8) into (17), together with (1), (2), (6), (7), we have

$$A = A_p(t_e) = A_s(t_e) = p_a x_0^{-1}(t_e) = s_a x_0(t_e), \tag{22}$$

$$H = H_p(t_e) = H_s(t_e) = p_h y_0^{-1}(t_e) = s_h y_0(t_e), \tag{23}$$

where A and H are the turn-over volumes of the stock *s* in A and H markets respectively.

Now we have three independent Equations (22) and (23) and can determine three unknown coefficients $p_a = p_h$, s_a, s_h, (let $p_a = p_h$, *i.e.*, the purchasing condition is the same for A and H stock markets)

$$p_a = Ax_0 = p_h = Hy_0,\ s_h = H / y_0,\ A / x_0 = s_a, \tag{24}$$

From (24) and (21), we have

$$e = H / A, \tag{25}$$

Substituting x_0, y_0, A, and H into (21) and (25), if both (21) and (25) are satisfied, *i.e.*,

$$x_0 / y_0 = H / A, \tag{26}$$

i.e., the turn-over volume is inverse proportion to the stock price, then, we can consider that such a state is in equilibrium.

4. An Example of Checking the Prediction on Stock Price of "China Petroleum" (601857) at a Conference Held on May 23-25, 2008 [13].

"China Petroleum" (601857) has the largest weight on Shanghai SSE Index and the tendency of the prices of both "Petroleum China" (HK0857) and "China Petroleum" (601857) become the focus of attention for A & H stock speculators and investigators. When the price of "China Petroleum" went down from 48 (Yuan of RMB) to about 20, since Oct. 2007, many analysts revised their price bottom estimations from 45, 42, 40, 35, 32, 30, 25, 20. At last, 16.7 (the issuing price) was considered as the bottom line by the market. The author analyzed the market data according to the theory of equilibrium state based on simultaneous differential equations of A, H stock prices and made a prediction that "16.7 is not the bottom" published in a "Collecting papers" of "forum on district economic cooperation and district development" held on May 23-25, 2008 [13].

From the markets data, we tried to find both "Doji" appeared at the same time 2008-04-10, the opening price 17.11, the closing price 17.35 (near "Doji"), turn-over volume 51.887 (million Yuan, RMB) of "China Petroleum" (601857); while opening price 10.20 (HKD), Closing price 9.82 (HKD) (near "Doji"), turn-over volume 172.785 (million HKD) of "Petroleum China" (HK0857). We considered that the time 2008-04-10 can be viewed as the time t_e of equilibrium state and x_0 = 17.35, y_0 = 9.82 × 0.90 = 8.838 (0.90 is the ratio of RMB to HKD). By (21), we have

$$e_1 = x_0 / y_0 = 1.963 \tag{26}$$

By (25), we have

$$e_2 = H / A = 172.785 / (0.9 \times 51.887) = 3.700, \tag{27}$$

However, $e_1 \neq e_2$, which means that 2008-04-10 is not a strict equilibrium state, in which the turn-over volume in H-stock market is 3.7 times the turn-over volume in A-stock market. This means that the same stock "Petroleum China" (HK0857) is much chipper than that of "China Petroleum" (601857), therefore the speculating money rushed into H-stock market, and made a larger turn-over volume. This also showed that the price of (601857) 17.35 had rooms for getting down, especially for the tendency of (HK0857) was going down (opening price < closing price) at 2008-04-10. Again, even if 2008-04-10 is an equilibrium state, then, 17.35 is a mean value (or the value of stock) and is not the bottom line, so that 16.7 (the so-called "political bottom", "technical bottom" *etc*.) is not a real bottom of the A stock market.

According to the above analysis, the author made a prediction that "16.7 is not the bottom" at a conference held in May 23-25, 2008 [13]. The history shows that the prediction is correct, the stock price of "China Petroleum" went down and break the issuing price 16.7 since June-July 2008, until now its price is below 13.8 (lowest 9.9).

5. Conclusion Remarks

Stock value estimation is an important evaluation to investigators. Stock value is defined herein as the stock price at the "equilibrium state". The "equilibrium state" is an ideal concept, in which no money moves on balance between A and H stock markets for gaining speculating profits from the difference of A and H markets. How to find the equilibrium state from the markets data? At first, finding both "Doji" (*i.e.*, the stationary point) at the same time t_e from the daily K-line of A and H stock markets; then, calculating the ratios e_1 and e_2 by (26) and (27), if $e_1 = e_2$, *i.e.*, the turn-over volume is inversely proportion to the stock price, then, t_e is the time at equilibrium. Usually, it is hard is find a strict equilibrium state from the markets data, and a near equilibrium state is excepted for rough estimation.

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Sub-Optimal Generation Portfolio Variance with Rate of Return Regulation

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Abstract

This paper demonstrates that continuation of traditional rate-of-return electric utility regulation of transmission and distribution assets will impede the ability of customers to optimize their generation portfolios. Under linear price regulation, with increasing (decreasing) returns to scale customers will choose a more (less) risky generation portfolio than they would with no transmission and distribution asset rate-of-return regulation. Similar problems arise under non-linear (two-part) pricing of transmission and distribution assets. When the per-unit price is set at marginal cost, with increasing (decreasing) marginal cost, customers will choose a more (less) risky generation portfolio than they would with no transmission and distribution asset regulation. With price caps the optimal generation portfolio is chosen.

Keywords: Bidding, Electric Utilities, Rate-of-Return Regulation

1. Introduction

The US electric utility industry is currently in the middle of a massive transition from being a highly regulated industry to one that is partially deregulated. In the past, companies in the industry were vertically integrated with three distinct functional sectors: generation, transmission, and distribution. Those functions are being unbundled, either by regulatory fiat, or by the actual sell-off of assets. In the future, US consumers will have a rich array of choices with regard to generation sources, while the transmission and distribution (T & D) sectors, and will still continue to be regulated by either state or federal commissions.[1]

A major reason for this restructuring is to unleash competitive forces in the generation market, so as to decrease generation prices to the ultimate consumer. Consumers would also have a broader array of choices, in terms of price, price risk, and service quality. In particular, it is important that customers be allowed to optimize their portfolio in terms of generation price risk and price level without hindrance from regulators.

Unfortunately, because T & D assets are utilized to obtain the generation product, regulatory policies can have a bearing on customers' decisions with regard to their generation portfolio mix. In particular, with traditional rate-of-return regulation customers may choose a sub-optimal level of generation risk, a result that is inconsistent with the avowed desire to allow customers the opportunity to choose an optimal generation portfolio mix.[2] Consequently, the type of regulation currently employed in T & D regulation may have to be modified significantly.

In Section II we consider the market-induced trade-off between generation price risk and generation price level, and derive the unconstrained optimizing level of variance chosen by customers. This is used as a benchmark for Sections III and IV. In Section III we consider the impact of traditional rate-of-return regulation with linear pricing when T & D asset regulation is factored in. Section IV expands upon Section III by using non-linear regulatory pricing of T & D assets.

2. Unconstrained Model of Generation Portfolio Optimization

Assume a T & D utility that provides only regulated T & D services. Consumers purchase generation services in the competitive market on their own, with the electric energy transmitted over the T & D utility's wires.

Define:

p = regulated price of T & D service;

$E(.)$ = expectations operator;

[1]See [1] and [2] for an overview of electricity restructuring issues.

[2]See [3] and [4] for discussion of the rate-of-return method.

u = stochastic disturbance term associated with the price of generation, where $E(u) = 0$;

$\sigma^2 = E(u^2)$ = variance in the price of generation;

$g_0(\sigma^2) + u$ = stochastic generation cost;

$g_0(\sigma^2) = E[g_0(\sigma^2) + u]$ = expected generation cost;

$q(p + g_0[\sigma^2] + u)$ = quantity demanded; and

$C(q)$ = cost function for providing T & D services.

Note that q is a function of the sum of T & D and generation prices.

Let the consumers' utility function, for given u, be given as $U(p + g_0[\sigma^2] + u))$. Assume this is of the Von Neuman-Morgenstern (V-M) type (see [5]). The utility function is, then, unique up to a linear transformation. In the selection of suppliers in the generation market by consumers, the expected generation price, g_0, obtainable by consumers is an inverse function of the variance, σ^2. In order to obtain a lower average generation price consumers have to accept a higher variance.[3] This function can be reflected as $g_0(\sigma^2)$ where $g' = \partial g_0/\partial(\sigma^2) < 0$, and $\partial^2 g_0/\partial(\sigma^2)^2 > 0$.[4]

We can use a Taylor series approximation to express the expected utility of consumers as[5]

$$E[U(p + g_0[\sigma^2] + u)] = U(p + g_0) + (1/2)\, \sigma^2 U'' \qquad (1)$$

where $U' = \partial U(p + g_0)/\partial p = \partial U(p + g_0)/\partial g_0 < 0$. This represents the rate of change in utility with a change in generation price. Further, $U'' = \partial^2 U(p + g_0)/\partial p^2 = \partial^2 U(p + g_0)/\partial g_0^2$. If consumers simply maximize their expected utility with respect to generation price variance, *without any consideration of regulation on T & D operations*, they would maximize (1) with respect to σ^2 producing

$$U'g' + ½U'' = 0. \qquad (2)$$

This can be re-expressed as

$$½(U''/U') = -g'. \qquad (3)$$

The Pratt-Arrow measure of absolute risk aversion with regard to price in this case is U''/U'.[6] Equation (3) implies that utility maximization requires that one-half of the degree of absolute risk aversion be equal to the rate of trade-off between the level of generation prices and the variance of generation prices. If consumers are risk averse with regard to price, then $U'' < 0$ and $U''/U' > 0$ because $U' < 0$. Since U is a V-M preference function, U''/U' is a unique measure (even with linear transformations). Let us assume constant absolute risk aversion so that $U''/U' = \varphi$ is constant, and is, consequently, independent of both the T & D price and the generation price.

As customers accept greater risk, σ^2, in their portfolio of generation sources, the expected generation price falls by an amount that is *greater* than the minimum required by customers. Without regulatory constraint, customers would optimally choose σ_1^2 of generation portfolio variance. For variance less than σ_1^2 an increase in σ^2 decreases g_0 by an amount greater than that amount required by consumers (given as $½\varphi$). For variance greater than σ_1^2 a decrease in σ^2 increases g_0 by an amount less than that consumer would have been willing to bear.

3. Generation Portfolio Optimization with Regulation of T & D Assets Using Linear Pricing

Let us now explicitly introduce regulation of T & D assets into our model. Assume that $g_0(\sigma^2) + u$ and σ^2 are exogenously determined; that is, they are not determined by the regulator, but by competitive generation market conditions. We also assume that the regulated T & D utility has profit requirements on its T & D services, given as $0 \le E[pq - C(q)]$.[7] This can be simplified to $0 \le pq_0 - C(q_0)$, where $q_0 = q(p + g_0)$.[8] In this case, the regulator's goal is to maximize $E[U(p + g_0[\sigma^2] + u])]$ with respect to p, subject to the profit constraint $0 = pq_0 - C(q_0)$. Customers maximize $E[U(p + g_0[\sigma^2] + u])]$ with respect to σ^2, subject to the same profit constraint.

The Lagrangian function is then

$$E[U(p + g_0[\sigma^2] + u])] + \lambda[(pq_0 - C[q_0])] \qquad (4)$$

where $\lambda > 0$ is the Lagrangian multiplier. Substitution from (1) into (4) yields the following Lagrangian expression

$$U[(p + g_0)] + (1/2)\ \sigma^2 U'' + \lambda[(pq_0 - C[q_0])]. \qquad (5)$$

Assuming constant absolute risk aversion the first-order conditions are:

$$U' = -\lambda[(p - C'[q_0])q_0' + q_0], \qquad (6)$$

$$U'(g' + ½\varphi) = -\lambda g'[(p - C'[q_0])q_0'], \qquad (7)$$

[3]Alternatively, we could say that in order to obtain lower price risk, market forces require the consumer to accept greater average generation prices.

[4]The positive sign of the second derivative implies that additional increments of risk reduce average generation price, in the market, by smaller and smaller amounts.

[5]A function $f(x + a)$ can be expressed in a Taylor series as $f(x) + a(\partial f/\partial x + a^2/2!(\partial^2 f/\partial x^2) + a^3/3!(\partial^3 f/\partial x^3) + \ldots$ [6]. A reasonable approximation is then $f(x + a) = f(x) + a(\partial f/\partial x) + a^2/2!\,(\partial^2 f/\partial x^2)$. Applied to this case, it implies that $E[U(p + g_0[\sigma^2] + u)]$ can be approximated as $\int [U(p + g_0[\sigma^2]) + uU'(p + g_0[\sigma^2]) + ½u^2 U''(p + g_0[\sigma^2])]\, du = U(p + g_0[\sigma^2]) + E(u)U'(p + g_0[\sigma^2]) + ½E(u^2)\, U''(p + g_0[\sigma^2])$. Since $E(u) = 0$ and $E(u^2) = \sigma^2$, this produces $U(p + g_0[\sigma^2]) + E(u)U'(p + g_0[\sigma^2]) + ½E(u^2)U''(p + g_0[\sigma^2]) = U(p + g_0[\sigma^2]) + ½\sigma^2\, U''(p + g_0[\sigma^2])$.

[6]This can be seen from [7], Equations (4a)-(6), where we substitute $p + g_0$ for x.

[7]Throughout we assume that $C(q)$ implicitly includes the cost of capital See [8] for discussion of this point.

[8]Since $q(p + g_0 + u)$ is stochastic, $pq - C(q)$ is as well. Consequently, the constraint is expressed as $0 = E[pq - C(q)]$. Using similar Taylor series expansion as discussed in footnote 5 we obtain $E[pq - C(q)] = pq_0 - C(q_0) - ½\sigma^2 pq_0'' - ½\sigma^2 C''(q_0)(q_0')^2 - ½\sigma^2\, C'(q_0)q_0''$. The latter three terms are of small order of magnitude so that we can reasonably approximate $E[pq - C(q)]$ as $pq_0 - C(q_0)$.

where $C' = \partial C(q)/\partial q$ and $q' = \partial q/\partial(p + g_0) = \partial q/\partial p = \partial q /\partial g_0$.With increasing returns to scale, the term $p - C'[q_0]$ is positive.[9] Since $\lambda > 0$, and g', q', $U' < 0$,

$$g' + ½\varphi > 0. \tag{8}$$

Consequently,

$$½\varphi > -g'. \tag{9}$$

With the regulatory profit constraint on T & D assets, customers choose to have a generation portfolio variance of $\sigma_2^2 > \sigma_1^2$ which is a riskier generation portfolio than the portfolio they would choose without regulatory constraint on T & D assets (from in Section II).[10]

An intuitive explanation for this is that consumers have a regulatory-induced incentive to seek a greater amount of generation portfolio risk. That greater σ_2^2 results in a lower value of g_0 and a corresponding greater amount of q. Given a regulatory constraint $0 < pq_0 - C(q_0)$, and since $p - C'[q_0] > 0$, consumers realize that with a larger σ_2^2, the regulator will have to lower the regulated T & D price, p, with attendant T & D pricing benefits to the consumers. Consequently, by increasing σ^2 above σ_1^2 consumers obtain the additional benefit of a correspondingly lower value of the T & D price, p.

Alternatively, with decreasing returns to scale, the term $p - C'[q_0]$ is negative, and consumers choose $\sigma_3^2 < \sigma_1^2$ for their level of generation portfolio risk. That smaller σ_3^2 results in a greater value of g_0 and a corresponding smaller amount of q. Given the regulatory constraint and since $p - C'[q_0] < 0$, consumers realize that with a smaller σ_3^2 the regulator will have to lower the regulated T & D price, p, with attendant T & D pricing benefits to the consumers. Consequently, by decreasing σ^2 below σ_1^2, consumers obtain a correspondingly lower value of the T & D price, p.

This sub-optimal behavior has effects on the size of the T & D system as well. Given the profit constraint $pq_0 - C(q_0) = 0$ we can calculate the change in p with a change in σ^2 by taking the total differential of the profit constraint:

$$(pq_0' + q_0 - C'[q_0]q_0')dp + (pq_0'g' - C'[q_0]q_0'g')d(\sigma^2) = 0, \tag{10}$$

which implies

$$dp/d(\sigma^2) = -(pq_0'g' - C'[q_0]q_0'g')/(pq_0' + q_0 - C'[q_0]q_0'). \tag{11}$$

The change in q_0 associated with a change in σ^2 is:

$$dq_0/d(\sigma^2) = (dq_0/dp)(dp/d(\sigma^2)) + dq_0/d(\sigma^2). \tag{12}$$

[9]Since under rate-of-return regulation $p = C/q$, when $C/q > C'$ we have increasing returns to scale.

[10]The average generation price is, also, lower than would be obtained without constraint. Our focus, however, in this paper is on generation portfolio variances.

Substitution from Equation (11) into Equation (12) produces

$$\begin{aligned} &dq_0/d(\sigma^2) \\ &= -q_0'(pq_0'g' - C'[q_0]q_0'g')/(pq_0' + q_0 - C'[q_0]q_0') + q_0'g' \\ &= (q_0q_0'g')/(pq_0' + q_0 - C'[q_0]q_0'). \end{aligned} \tag{13}$$

The denominator of the above expression is the change in profits with a change in price, which is greater than zero by Equation (6). Further, since q_0', $g' < 0$, $dq_0/d(\sigma^2) > 0$. As shown above, with increasing returns to scale, customers choose a riskier generation portfolio ($\sigma_2^2 > \sigma_1^2$). This implies that q_0, and the size of the T & D system is greater than it would be if customers had chosen the optimal generation portfolio variance, σ_1^2. With increasing returns to scale, and rate-of-return regulation, the T & D system is larger than optimal.[11]

The reason this sub-optimal behavior occurs is because of the responsiveness of q to $g(\sigma^2)$. We can evaluate that sensitivity by considering the impact of demand elasticity, $\varepsilon = -(\partial q_0/q_0)/(\partial p/p)$, on the amount by which σ_2^2, or σ_3^2, deviates from the optimal variance, σ_1^2. Dividing (6) by (7) and rearranging terms produces

$$-q_0(g' + ½\varphi) = ½\varphi\ (p - C'[q_0])q_0'. \tag{14}$$

Dividing both sides of (14) by $-q_0$ and p produces:

$$g' + ½\varphi = ½\varphi\ [(p - C'[q_0])/p]\varepsilon, \tag{15}$$

where $(p - C')/p$ is the price mark-up (or mark-down). For a given price mark-up (or mark-down), the greater the elasticity, the greater the deviation of the consumers' choice of sub-optimal variance from the optimal variance, σ_1^2.

However, with price caps applied in regulation of T & D assets, customers no longer have an incentive to incur greater (or smaller) generation risk than is optimal.[12] A regulatory price cap, p_c, fixes prices for an indefinite period. As profits change, there are no offsetting changes in prices, as there is in traditional rate-of-return regulation. Consequently, consumers simply maximize

$$U(p_c + g_0) + (1/2)\ \sigma^2 U''(p_c + g_0), \tag{16}$$

with respect to σ^2 to obtain the same result as in (3). Consumers will choose the optimal level of generation portfolio risk when price caps are applied to T & D regulation.

4. Generation Portfolio Optimization with Regulation of T & D Assets Using Non-Linear Pricing

Let us assume the same model as in Section III, but assume that the regulator employs non-linear pricing (two-part rates) with regard to the T & D assets.[12] Let the fixed T

[11]With decreasing returns to scale, the T & D system would be smaller than optimal.

& D charge be F and the T & D per unit price be p. The consumers' utility function is $U(F, p + g_0[\sigma^2] + u)$. Assume an income-compensated demand function of the form $q(p + g_0[\sigma^2] + u)$. Finally, assume that the regulator sets p equal to marginal cost, C', as is often the case in two-part pricing regimes.[13] The regulatory profit constraint is $0 = E(F + [C'(q_0)q_0 - C(q_0)])$, which can be simplified to $0 = F + [C'(q_0)q_0 - C(q_0)]$ [10-12]. In this case, the regulator's goal is to maximize $E[U(F, p + g_0[\sigma^2] + u)]$ with respect to F, subject to $0 = F + [C'(q_0)q_0 - C(q_0)]$. Customers maximize $E[U(F, p + g_0[\sigma^2] + u)]$ with respect to σ^2, subject to the same profit constraint.

The Lagrangian is

$$U[F, p + g_0] + (1/2)\,\sigma^2 U'' + \lambda(F + [C'(q_0)q_0 - C(q_0)]) \quad (17)$$

with $\lambda > 0$.The first-order conditions are:

$$\partial U/\partial F = -\lambda \quad (18)$$

$$U'[g' + ½\varphi] = -\lambda g' q_0'[C'(q_0) + C''(q_0)q_0 - C'(q_0)]$$

$$= -\lambda g' q_0'[C''(q_0)q_0]. \quad (19)$$

Increasing marginal cost, $C''(q_0) > 0$, implies that $g' + ½\varphi > 0$ (since $\lambda > 0$ and g', q', $U' < 0$). In that case consumers choose a level of variance that is greater than σ_1^2, such as σ_2^2. Conversely, decreasing marginal cost, $C''(q_0) < 0$, implies $g' + ½\varphi < 0$. When that occurs, consumers choose a level of variance that is less than σ_1^2, such as σ_3^2. However, imposing price caps on the fixed charge and the per-unit price lead to the same optimal generation portfolio as in the linear pricing case.[15]

5. Conclusions

This paper has demonstrated that continuation of traditional rate-of-return electric utility regulation of transmission and distribution assets will impede the ability of customers to optimize their generation portfolios. Under linear price regulation, with increasing (decreasing) returns to scale customers will choose a more (less) risky generation portfolio than they would with no transmission and distribution asset rate-of-return regulation. Further, the size of the T & D system is greater (smaller) than optimal, with increasing (decreasing) returns to scale. The degree by which the portfolio variance deviates from the unregulated optimum increases as demand elasticity increases. However, with price cap regulation of transmission and distribution assets, consumers choose the optimal generation portfolio.

Similar problems arise under non-linear (two-part) pricing of transmission and distribution assets. When the per-unit price is set at marginal cost, with increasing (decreasing) marginal cost, customers will choose a more (less) risky generation portfolio than they would with no transmission and distribution asset regulation. Setting a price cap on both the fixed charge and the per-unit price leads to the same optimal generation portfolio as in the linear pricing case.

This implies that the success of deregulation of electricity generation is closely intertwined with the type of regulatory regime employed by the regulator on those assets still under regulation. Rate-of-return regulation will cause sub-optimal results in the generation market. The regulator has to utilize alternative regulatory methods, such as price caps, so as to avoid unwanted interference in the generation market.

[12] See [2-4], and the "Symposium on Price-Cap Regulation" in [9] for discussion of price caps.

[13] See [10] and [11] for discussion of two-part tariffs.

[14] Similar to the discussion in footnote 8, $0 \le E(F + [C'(q_0)q_0 - C(q_0)])$ can be approximated as $0 \le F + [C'(q_0)q_0 - C(q_0)]$ because of the relatively small order of magnitude of several terms in a Taylor series expansion.

[15] If a price cap is set on just the fixed charge or the per-unit charge, sub-optimal results are obtained.

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Petrochemical Industry: Assessment and Planning Using Multicriteria Decision Aid Methods

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Abstract

A methodology to solve a large and complex problem is proposed. OR methods as Multilevel Planning, Network Techniques, Multicriteria Decision Aid (MCDA) and Mixed Integer Linear Programming (MILP) were used to structure the methodology. One of the principal objectives of this work is reduce the complexity of a large problem and solve it to find the better solution for the decision makers. The methodology is applied to a petrochemical industry of Mexico, which is structured in a network, having different alternative routes of production; each of them having also a different technology. This network begins from the crude oil as raw material in order to produce the basic petrochemicals until finals ones. It has been considered that basic petrochemicals will be produced through a set of Refineries with a high production of basic petrochemicals yield, searching the best configuration among it, according with the needs of basic petrochemicals coming from the final's and its best route selected.

Keywords: Multiple Criteria Analysis, Multilevel Planning, Network Flows, Linear and Integer Programming, Petrochemical Industry Assessment

1. Main Objectives and Goals: Description of the Work

The targets to be reached in this work are:

a) To reduce the complexity of a large system using a model of coordination in a framework of decentralized multilevel planning with a lot of interrelated subsystems.

b) To structure a methodology with different operational research (OR) tools, as Network Techniques, MCDA (PROMETHEE II and V methods) and MILP, according with the problem stated.

c) To apply the methodology to the Mexican petrochemical industry as a case study, with a horizon planning starting in 2003 until 2025 and taking into account the demand of each final petrochemical as an exogenous variable.

As particular objectives:

d) Considering that the model must start with the crude oil as raw material and end with the final petrochemicals, the methodology will be able to choose the best technology process alternative from a set of them to produce final petrochemicals.

e) Another part of the model will be developed in order to show the final petrochemicals production from crude oil, is at least equally competitive than the exportation of it. The value of the Mexican crude oil exportation will be the reference of comparison.

f) The feasibility to produce petrochemicals with more added value than exporting only crude oil will be showed.

2. Mathematical Tools to be Utilized in the Methodology

2.1. Coordination Models

A lot of work have been done in this field; see references as [1-3,5,14,15,17,18,22, 24-26,36,38].

2.2. Network Approach

Chavez has used PASCAL to build a graphical linked data structure, with the nodes representing the chemicals and processes [13], and arcs indicating the relations between them. Then, through recursive programming, the procedure could traverse the graph both up-and downstream to observe the affects of any perturbations. In this manner it is possible to examine the process individually, within the context of the industry, rather than observing all of the process as a single unit. This removes the tendency (found in LP formulations) to operate one section of the industry sub optimally in order to improve some industry-wide objective function. For the Mexican Petrochemical Industry, Escobar and Rodriguez have used the same approach, focusing it to increment the added value along the chain of production [16].

The "traversing the arcs" algorithm can be expressed mathematically as the Generalized Network Problem (GNP) [37]:

From GNP, we will only use the following constraints:

Let x_{ij} = the amount of flow over arc (i, j) during the planning horizon.

Then a generalized network model is:

$$\sum_{j=1}^{p} x_{kj} - \sum_{i=1}^{p} x_{ik} = T_k \quad \text{for each intermediary node "}k\text{"} \tag{1}$$

where: T_k is the flow value at each node k.

We will consider as S_i the production capacity of a petrochemical plants i, ($i = 1,2,\ldots m$) and there are n different final products whose annual demand is known as D_j for each product j ($j = 1,2,\ldots n$). For different petrochemical plants and a_{ij} indicates the corresponding relative production efficiencies (input/output), *i.e.* the real stoichiometric coefficients of chemical reactions described in the network.

Then we have the following additional constraints:

$$\sum_{j=1}^{n} x_{ij} \le S_i \qquad for\ i = 1, 2, ..., m \tag{2}$$

and,

$$\sum_{i=1}^{m} a_{ij} x_{ij} \ge D_j \qquad for\ \ j = 1, 2, ..., n \tag{3}$$

$$x_{ij} > 0 \qquad for\ all\ i\ and\ \ j \tag{4}$$

Constraint (3) is the driven force for this network, because it induces the production of any product in the network trough the exogenous demand.

2.3. MCDA Methods

We don't discuss here the importance of Multicriteria Methods; a lot of bibliography is available to the interested lector. See: [6,7,9-13,27, 29-32,36] among others.

One of the more important methods of this kind is the PROMETHEE family. [6,8]

The PROMETHEE II complete ranking is based on net flow $\phi(a)$ that is computed from the pair wise comparison.

PROMETHEE V will be used to determine the production of the refinery, and to choice the better configuration.

The followed steps will be used to apply PROMETHEE V:

Step 1: The multicriteria problem is considered first, without constraints. In our case, we have utilized PROMETHEE II results; the rankings are obtained and the net flows for the best technological routes for each final petrochemical have been computed as also the subset of the best final petrochemicals, using the same criteria to choose the technological routes.

Step 2: The following mixed integer linear program could be considered in order to take into account additional constraints.

$$\begin{aligned} &Max \sum_{i=1}^{k} \phi(a_i) x_i \\ &s.t.: \ \sum \lambda_{p,i}\, x_i \ \{=, \ge, \le\}\ \beta_p \qquad p = 1,2,..., P \\ &\quad x_i \in (0,1); \qquad\qquad i = 1,..., n \end{aligned} \tag{5}$$

where $\lambda_{p,i}$ and β_p are coefficients and right hand sides associated to the constraints.

The coefficients of the objective function are the net outranking flows.

3. A Technology Evaluation Model

The model is supported by Ackoff´s interactive planning theory [39,40] and by Rudd and Watson [33] with the multilevel attack on very large problems.

Nevertheless, the evaluation model is completed using MCDA, network and mixed integer linear (MILP) techniques, in order to choose the better alternatives of a large and complex problem. The case study is a complex problem considering different combinations in order to produce a final product.

This model serves as a focus for bringing together the results of the formulation of the mess and ends planning with technology choice as it relates to various activities along of the whole industry's added value chains. [19,23]

Figure 1 show a simple example of a complex problem, which is characterized by two levels (upper and lower) of coordination. In the lower level are the different subsystems linked with both, another subsystem and with the upper level, who is the coordinator. It is clear that should have a flow of data among some coordination variables in order to make the better decisions to solve the problem jointly. It looks like simple but it does not.

It is important define that each:

- local decision unit represent a set of processes to produce a final product from a set of raw materials,

- process is structured for a sequence of intermediate process or chains of production or process' routes,
- chain of production is a technology to be assessed.

Also,

- The raw material for each process unit is transformed to intermediate product; which is the new raw material for next process and;
- Each final product has been selected by a marketing study being its demand an exogenous variable of the problem.

In consequence, the complexity of the problem is increased. Nevertheless, using a mixed methodology, the problem can be solved. This methodology is divided in three large steps, taking them as iterations. See **Figure 2**.

The first and the second iteration represent the upper and lower level of coordination showed in **Figure 1**; in **Figure 2** are represented by steps 1 to 6. Once the results are obtained from the first and second iteration, step 7 is performed and step 8 (MILP model) is developed. The results are then sent to the central unit in order to make the better decision.

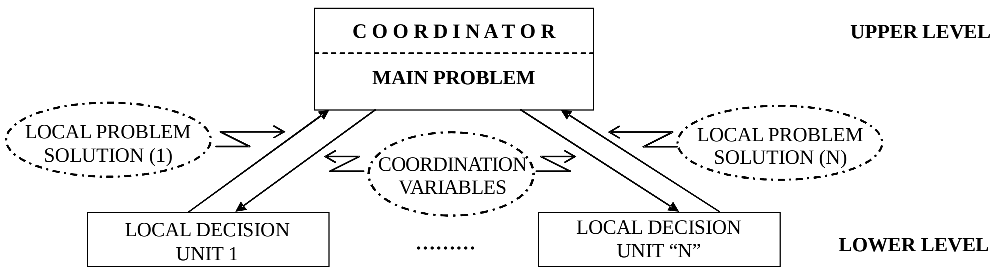

Figure 1. A two level attack structure.

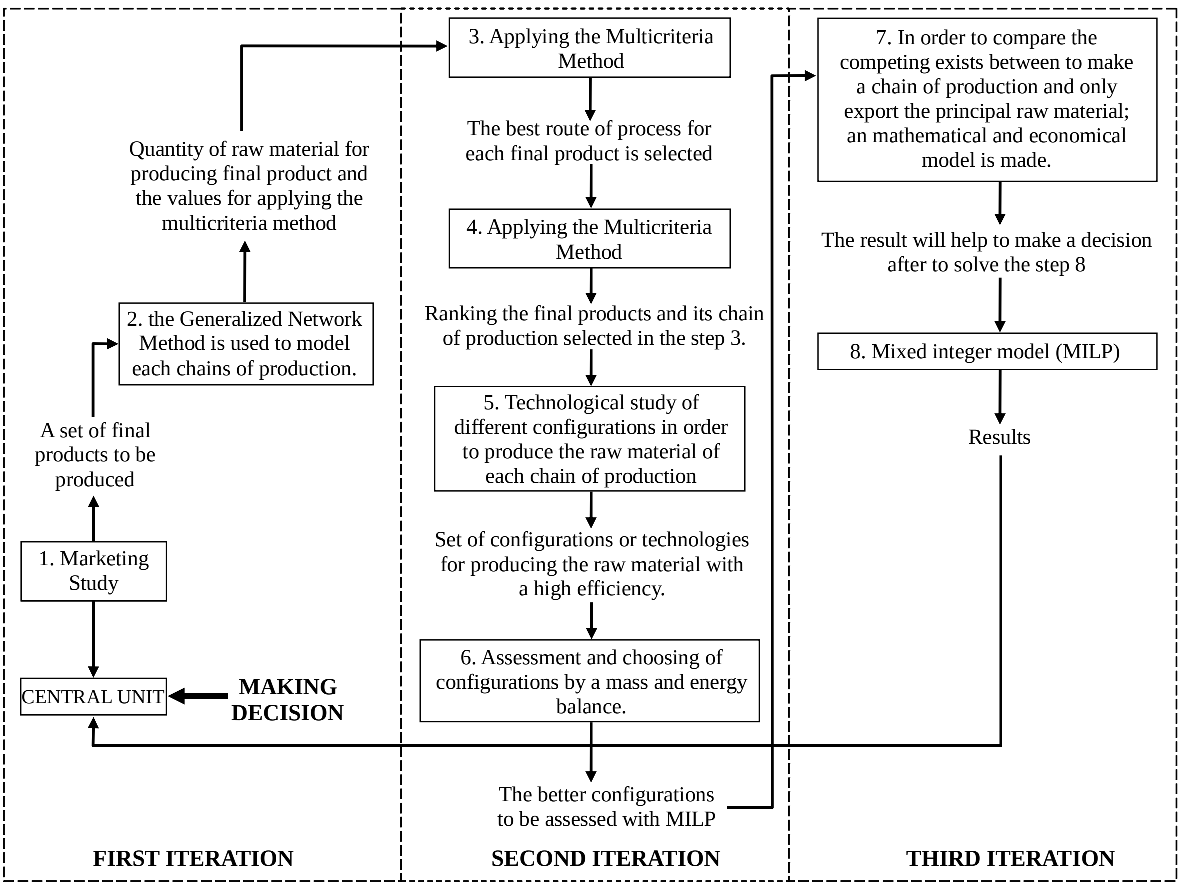

Figure 2. Generalized methodology proposed.

4. Case Study: Introduction to the Petrochemical Industry

The hierarchical multilevel model planning, to be developed in this paper, to be well understood, requires a brief presentation of the Petrochemical Industry. This important Industry is a huge of network of processes and products.

The petrochemical industry system is a large, complex, and constantly changing industry. There are more than 8000 different compounds in commercial production derived from petroleum and natural gas. It is capital and energy intensive. It has also structured in an oligopoly. The petrochemical products multiply their value along the chain of production until their final destination. For example: p-xylene increments 170 times in a shirt, PVC increments 40 times in a tennis ball and the acrylonytrile increments 150 times in a sweater.

The Petrochemical Industry is based upon the production of chemicals from petroleum and natural gas. This industry also deals with chemicals manufactured from the by-products of petroleum refining. Also included, are chemicals produced from natural gas liquids.

Those raw feed stocks, petroleum and natural gas, are found at the beginning of the production chain. From these feed stocks it can be produced a relatively small number of important building blocks. These building blocks include the lower olefins and aromatics: ethylene, propylene, butylenes, butadiene, benzene, toluene and xylenes.

These building blocks are then converted into a complex array of thousands of intermediate and final chemicals, considering of course, their technology processes. The final products of the petrochemical industry are generally not consumed directly, but are used by other industries to manufacture consumer goods. Such versatility, adaptability and dynamic nature are three of the important features of the modern petrochemical industry.

The structure of the petrochemical industry is extremely complex. It is severely cross-linked, with the products of one process being the feedstock of many others. For most chemicals, the production route from feed stocks to final products is not unique, it includes many possible alternatives. As complicated, as it may seen, this structure is however comprehensible, at least in a general form [4,34]. In fact, there is a multitude of production routes available for most chemicals which are produced by more than one technology. The classification and description of petrochemical end products is not an easy task, because petrochemicals find their way into such a broad diversity of products and frequently a particular product will fall into more than one category. However, it is generally agreed that the main end products are in the form of polymers and copolymers: as plastics, but also elastomers, fertilizers and fibbers. Other products are solvents, detergents, paints, coatings, pigments, dyes, cosmetics, pharmaceutical forms, and food uses.

When the oil crises and embargoes came, the environment in which the international petrochemical industry operates suddenly changed. No longer were feedstock supplies and costs steady and predictable, nor was energy consumption a minor consideration.

In 90's decade, the three critical factors in the changing international industry face were: severe cycles in profits, globalization and continuing and substantial industry learning curve effects.

4.1. Mexico's Petrochemical Industry

Petrochemical industry was one of the largest Mexico's industries. Up 35% of Mexican industries required petrochemicals in their operations at the moment of this industry was at its best level of production (1950-1990).

The Mexican politician decision makers, have took the decision to sell the entire infrastructure and go, briefly speaking, to sell more crude oil abroad the country, considering that it could be an interesting business. Mexico lost in that moment the opportunity to increase the added value along the production chain of crude oil exported. In all these decisions the country lost the possibility of real industrialization, producing more petrochemicals for the internal market and to then develop the manufacturing industry still more.

Then, the three critical factors described above and the industrial flexibility has not taken into account in Mexico's Petrochemical Industry planning and consequently, it lost both; the dynamic growth and the possibility to add value to their products.

5. Applying the Methodology to the Case Study

In this section we propose a model to assess technologies within a set of petrochemicals chains as case study, in order to promote the industrial development and then their added value.

The system can be viewed in its general form in the **Figure 3**.

From left to right, in the "*t*" period of planning horizon, the **Figure 3** shows the sequence of the problem; it starts with the crude oil availability as raw material of a refinery to produce basic petrochemicals using a ad-hoc technological configuration and then, use those basic petrochemicals to produce intermediate and finals depending of the exogenous demand of the later.

From right to left, in the same figure, the situation becomes more complex, *i.e.*, with the exogenous demand coming from the manufacturing industry, the production

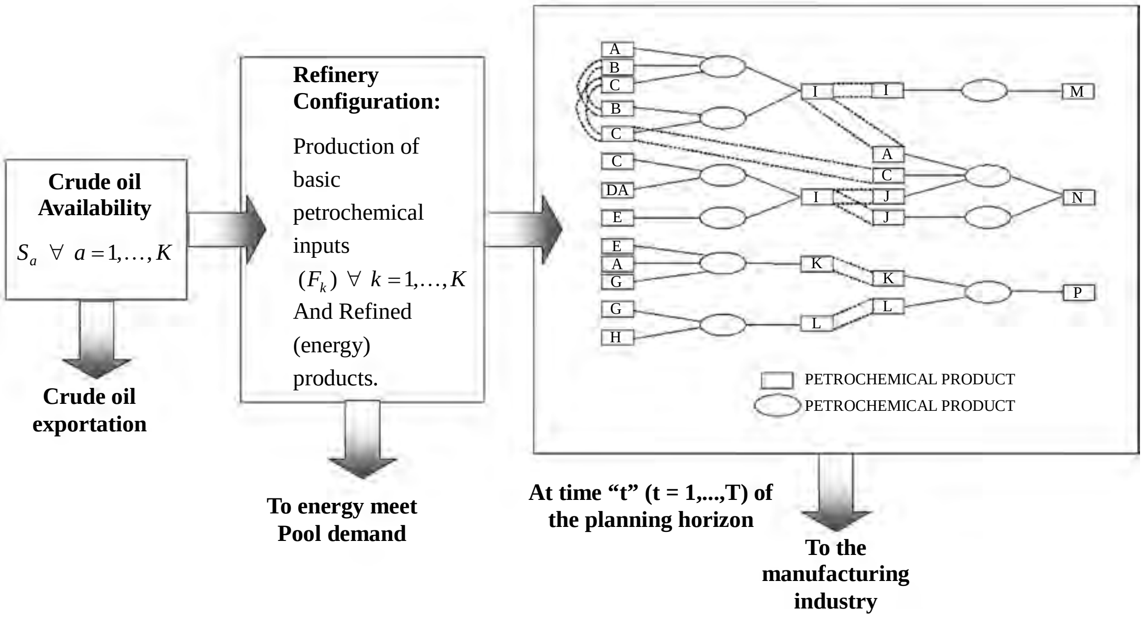

Figure 3. Intermediate and final petrochemical industry.

of final petrochemicals should be defined using network analysis; select the best routes of production considering different criteria (MCDA) and then choose the final demanded products using the same criteria. The productions of intermediate and basic petrochemicals are then induced depending on the route chosen. A mixed-integer linear programming model is built in order to choose the best refinery configuration and to define the production of the basic petrochemicals and the size of the chosen refinery configuration.

Then, the exogenous demand-coming by the manufacturing industry-defines which the final petrochemicals candidates for production are. The network analysis induce de intermediate and basic petrochemicals, generating alternatives, meanwhile MCDA is used to select the best routes of production for final petrochemicals, defining the intermediate's and basic's. Also, MCDA is used to select the final petrochemicals to be produced and the integer linear programming to schedule and size the better refinery configuration, among a subset of technological configurations available. In order to know if the best solution is obtained, it is utilized a multilevel planning decentralization procedure to be sure that the solution converges.

This methodology will be discussed in subsection 5.3.

Therefore, the following data are needed to develop the methodology:

1) Value of every petrochemical product (VP) (total costs-excluding the cost of intermediate and final products-plus i% Return on Investment); i = rate of return.

2) Value of every petrochemical product (VP) (total costs-excluding the cost of intermediate and final products-plus i% Return on Investment); i = rate of return.

3) Total costs of production and investments for all the petrochemical processes.

In the case of investments, a source of economic and technical data, were 3 different production capacities for each one of all products/technologies in the network, considering the Process Economic Program information published by Stanford Research Institute. Then, we have needed a function to find a correlation between those 3 capacities, considering economies of scale, in order to interpolate o extrapolate other capacity:

$$\begin{aligned} \log(Inv) &= \log(\alpha) + \beta \log(Cap) \\ Inv &= \alpha * Cap^{\beta}, \quad 0 \le \beta \le 1 \end{aligned} \tag{6}$$

Where: α and β are constants to be calculated by a regression; *Inv* = Investment and *Cap* = Production capacity.

4) To calculate the added value into the whole petrochemical system. This amount is: (VP) variable costs, for each petrochemical product.

5) To search a set of technological configurations for a Refinery with interesting basic petrochemicals yields. This search was one of the most important contributions in the chemical engineering field [20].

6) To search indexes of damage to the environment and to human health in every chemical produced along the petrochemical chains.

It is important to leave clear, that it was searched the best Refinery's configurations among a lot of possibilities. At that point, we have dressed a technology intelligence system in order to have sufficient alternatives about those configurations. We have got a reduced number of refinery configurations and then, we design them.

To have confidence of those configurations, a process simulation program was used to be sure that all of them will operate with the necessary yields, obtaining the basic petrochemicals needed. With those designs, the investment and operating costs were calculated.

5.1. Network Model Representation of the Petrochemical Industry

The network structure processes and products linked by "chains of production" in a production route are shown in **Figure 4**. As it can be seen, there are five important elements on this network. The first, on the left hand side are a few "basic" products (coming from a petroleum refinery production). On the contrary, there is a huge quantity of "intermediate products" in the network being these products one hundred times more than the basic products. The final of the network there also are a few "final products". Second, the intermediate products can be shared to produce the final products, beginning always with any one or more of basics. Third, in order to traverse the arcs, one should know (exogenously) which final products are needed to be produced. Fourth, it exits always at least one associated process of production for a product. Fifth, it is necessary to choose the technological route to take, in order to know the inputs of the final products, needed to be produce.

The algorithm constructed utilizes the Equations (1) to (4) and was constructed by Sevilla [35]. Then for "traversing the arcs" of the network composed by final products with an exogenous demand, intermediate and basic products, we "induced" the demand required meeting the final's products. Once the arcs are traversed and the demands of intermediate and basic products are calculated, we will utilize a multicriteria method in order to focus on the best route of production and reduce the dimension of the complexity due to the combinatorial problem.

5.2. Multicriteria Decision Analysis (MCDA)

To evaluate the best petrochemical chain for a given final petrochemical, we have utilized multicriteria decision analysis.

The criteria used are:

1) Maximization of the added value along the petrochemical chains (routes) in order to produce the final petrochemical "p_i";

2) Minimization of investments required trough the petrochemical chains to produce the final petrochemical product "p_i";

3) Minimization of the real quantity of energy needed by different process/products along the petrochemical chains to produce the final petrochemical "p_i";

4) Minimization of the risk of damage the environment by any of the products along the petrochemical chains for producing the final product "p_i".

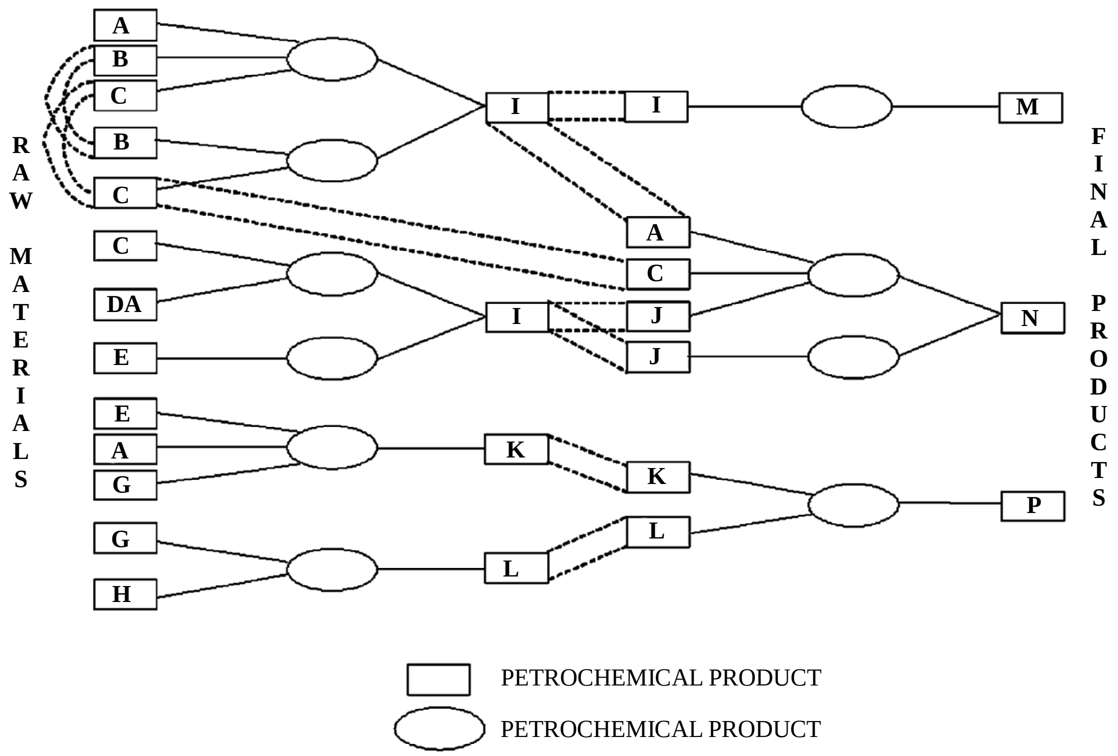

Figure 4. Graphical representation of petrochemical processes and products.

5.3. Multilevel Planning

The three steps to coordinate the decision making will be:

Consider a hierarchy of three levels, the first level, represents the Central Unit that receives information from "the market". The market demands of some final petrochemicals, a time "*t*" (*t* = *1*,...,*T*). This information came from econometric and prospective models, exogenously performed. The information (the calculated demand for one "*t*" of the horizon planning), is transmitted the "Central Unit", which is a strategic planning centre. This Central Unit also coordinates the levels below it. See **Figure 5**.

The Central Unit (CU) will then transmit the information to the next two lower levels, named "The Refinery" and the "Final and intermediate petrochemicals' Producers". At the same time the CU, is transmitting the information to decentralize the decisions. At the second level, the Refinery knows the conditions under which it can use crude oil to produce petrochemicals. This is considered as the first iteration.

Of course all the levels have the information about the "induced" demands of intermediate and basic petrochemicals.

The coordination variables under the control of the CU are the market demands of final petrochemicals and the four criteria to choose the best technological chains utilizing multicriteria decision making.

In the second iteration of the lower levels decentralization procedure, the final petrochemical producers will select the best chain of production taking into account a multicriteria analysis. This information is returned to the CU. On the other hand these petrochemicals producers will induce the demand of basic petrochemicals. The information is communicated to the Refinery with the product values. The Refinery will inform to the CU how are the values of those petrochemicals that will be equivalent to a certain price of the crude oil. The CU will inform to the market if it is possible to produce all the products (production = demand) or not: production is lower than demand.

If the final demand is not satisfied, the CU can take the decision of import the necessary quantity to meet the final demand. But the CU, ask the producers to take a multicriteria decision making with the same criteria, but now in order to know which final products can be really considered, ordered in a hierarchy, ranking process. With this information, it will be possible to know which products are outranked to others. This valuable information serves to solve a linear programming problem to know the refinery's assignment and scheduling solution. So, the Refinery will search their own best technological configurations with high yields of basic petrochemicals, and the petrochemical's producers will rank the final products for each one of the final products demanded.

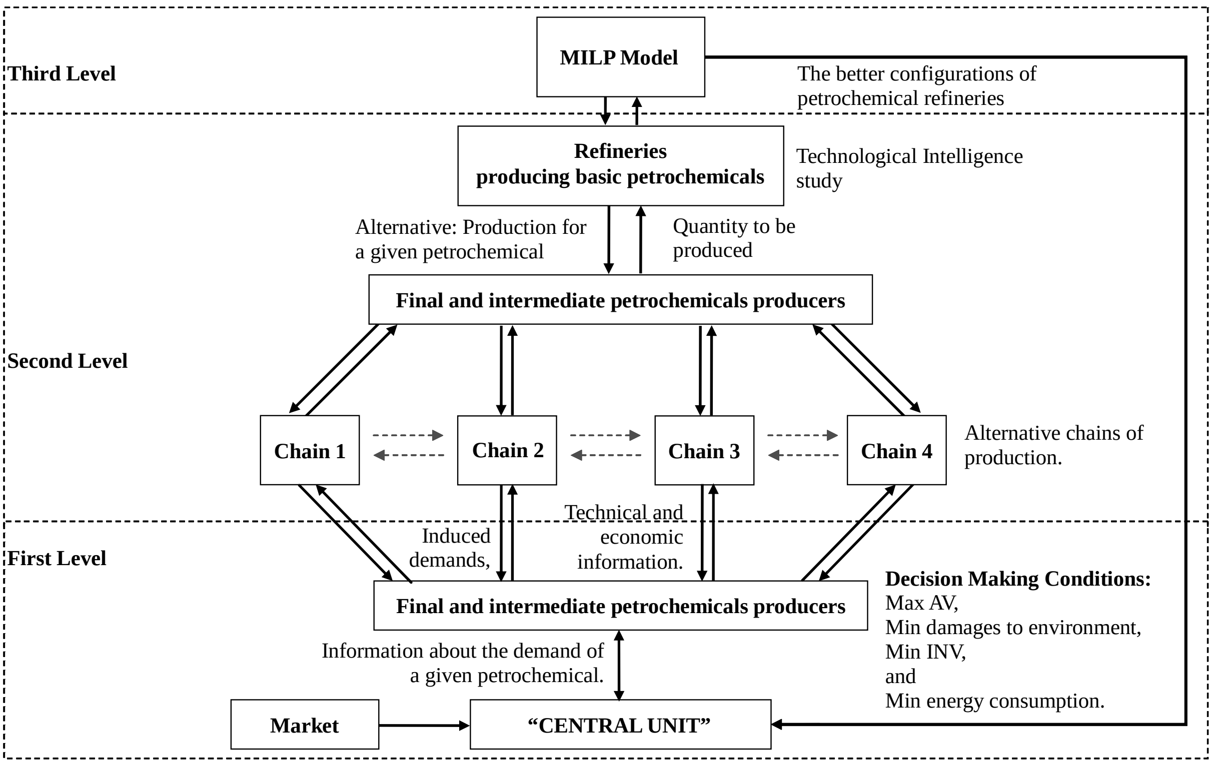

Figure 5. Graphical representation of the problem.

This information is taken for the Refinery decision makers to select finally the basic petrochemicals to be produced taking into consideration the quantity of crude oil allowed and the technical configurations. This is the third and last iteration if the solutions converge in a feasible technical solution.

The CU gives the order to the Refinery to solve jointly with the petrochemical's producers, a MILP model, using as general idea the procedure of PROMETHEE V. This model is explained in the next section.

Finally, this information is taken for the Refinery decision makers to select the basic petrochemicals to be produced taking into consideration the whole added value of the chains of production and also its own. The iterative process has finished.

5.4. The MILP Model and the Equivalence of Crude Oil

Considering the choice of the best technological routes for every final petrochemical product in the network, was solved utilizing PROMETHEE II (complete ranking), we are going to purpose a new approach considering as a framework the procedure of PROMETHEE V, in order to solve the refinery's problem. The refinery's problem consists in choosing a mix of the best technological configurations of refineries, and then obtaining the schedule of production of basic petrochemicals to meet the demand of finals, through the routes ranked, using multicriteria techniques as it was pointed out in previous sections. To do it, the objective function, will use the values of the net flows obtained by PROMETHEE II in the case of ranked final petrochemicals.

We will define the constraints needed in our case to treat the Refinery's problem: The total crude to be processed to obtain petrochemicals for all periods of the Horizon Period (HP) will be an allowed quantity of crude oil in "*t*" period.

For other periods of HP, it is possible to increment the capacity of processing crude oil until a maximum of a fixed quantity.

The Planning Horizon will be taken by periods of 3 years each one until we reach the last year of the HP (*t = 1…, T*).

We will call [$REUTCRU_{k,t}$] the set of constraints that:

$$PQCRU_{k,t} \le (\#_t) \qquad \forall\ k;\ \forall t \tag{7}$$

where # is the quantity of crude oil assigned by the Central Unit for each technology; and $PQCRU_{k,t}$ is the quantity of crude oil allowed to the basic petrochemical production and being "*k*", the possible refinery's configuration.

Because we should choose the better production program among six refinery configurations, we will use integer variables in order the model can decide which configurations are best than others and also to know how many refineries will be needed of each configuration, replacing Equation (7) as follows:

$$[REUTCRU_{k,\ t}]:\ XPQCRU_{k,\ t}\text{-}\#{*}K_k\ =\ 0; \tag{7a}$$

where: K_k is an integer.

The total balance [TOTAL] for all refineries can be chosen is, then:

$$\sum_{k=1}^{k} XPQCRU_{k,t} \le \text{Total crude oil available, in each period "t"} \tag{7b}$$

The refinery's LP problem is then transformed to a Mixed Integer Linear Programming (MILP).

The production of basic petrochemicals [$PRBPQ_{i,t}$] for configuration k is as follows:

$$For\ all\ "t";\ t = 1,\ldots,T$$

$$\begin{aligned}
&Ethylene: \sum_{k=1}^{K} ce_{k,t} PQCRU_{k,t} - PRETL_t = 0\\
&\Pr opylene: \sum_{k=1}^{K} cp_{k,t} PQCRU_{k,t} - PRPRL_t = 0\\
&Mixed\ Butadiene: \sum_{k=1}^{K} cm_{k,t} PQCRU_{k,t} - PRBUT_t = 0\\
&Benzene: \sum_{k=1}^{K} cb_{k,t} PQCRU_{k,t} - PRBEN_t = 0\\
&Toluene: \sum_{k=1}^{K} ct_{k,t} PQCRU_{k,t} - PRTOL_t = 0\\
&Xylenes: \sum_{k=1}^{K} cx_{k,t} PQCRU_{k,t} - PRXIL_t = 0\\
&Gasoline: \sum_{k=1}^{K} cg_{k,t} PQCRU_{k,t} - PRGASOL_t = 0\\
&Fuel: \sum_{k=1}^{K} cc_{k,t} PQCRU_{k,t} - PRCOMB_t = 0
\end{aligned} \tag{8}$$

Being $PRBPQ_{i,t}$ = {*PRETL, PRPRL, PRBUT, PRBEN, PRTOL, PRXIL, PRGASOL, PRCOMB*}.

The coefficients

$$cip_{q,k,t} = \left\{ce_{k,t},\ cp_{k,t},\ cb_{k,t},\ ct_{k,t},\ cox_{k,t},\ cpx_{k,t}, cg_{k,t},\ cg_{k,t},\ cc_{k,t}\right\}$$

are the yields in weight % of each product (ethylene, propylene, mixed butadiene, benzene, and toluene, xylenes, gasoline and fuel). These yields could be different for each "*k*" configuration in the period "*t*" of the PH.

$$\begin{aligned}
&\alpha_{i,l^*\in L,t} = \frac{Ton\ of\ basic\ petrochemical}{Ton\ of\ final\ petrochemical\ (l^* \in L)}\\
&and: \quad PRFPQ_{i,l^*\in L} = all\ final\ petrochemical.\\
&\therefore \quad \alpha_{i,l^*\in L,t}\ PRFPQ_{i,l^*\in L} - PRBPQ_{i,t} = 0
\end{aligned} \tag{9}$$

where $PRFPQ_{i,l^*\in L}$ denotes the final petrochemicals production resulting from MCDA selection and describes all better technological chain which has outranked all others, and $l^*\in L$ for all final products and for all "*t*" (*t = 1,…,T*).

On the other hand for each period "*t*", the demand constraints [$DEMANDFPQ$] for all final petrochemical, are:

$$PRFPQ_{i,l^*\in L,t} \le Demand_{i,l^*\in L,t} \qquad \forall\ i\in l^*\in L,t \qquad (10)$$

where $Demand_{i,l^*\in L,t}$ was calculated by an econometric model and a prospective approach.

Additionally, we have modelled another constraint to take into account that the offer of the Refineries is not necessarily equal to the final petrochemicals demand. This constraint is called [*PROFIT*]. We can write:

$$\begin{aligned}&\sum_k\sum_i pqb_{i,k} * cip_{i,k} * PQCRU_{k,t} - \\ &\sum_k\sum_i pqb_{i,k} * \alpha_{i,l^*\in L,k} * PRFPQ_{i,l^*\in L,k,t} - \\ &\sum_k \cos top_k * PQCRU_{k,t} - SPROFIT = 0 \qquad \forall\ "t"\end{aligned} \qquad (11)$$

where: $pqb_{i,k}$ is the market price of the basic petrochemicals "*i*" from "*k*" configuration, $\cos top_k$ is the operation cost of the "*k*" configuration and $SPROFIT$ is the refineries' margin profit.

Of course all variables are greater or equal to zero.

The objective function is then:

$$Max \sum_{i\in L}\phi_{i,l^*\in L,t}\left(PRFPQ_{i,l^*\in L,t}\right) \qquad \forall t \qquad (12)$$

Being $\phi_{i,l^*\in L,t}$ the net outranking flows came from PROMETHEE II, for each final petrochemical ($PRFPQ_{i,l^*\in L,t}$) at period "*t*".

5.5. Crude Oil Equivalence Value of One Ton of Versus the Final Petrochemical's Product Value

The problem here is to answer the following question: which is the marginal rate of substitution of petrochemicals for crude oil exportation. In others words it should be answer the following question: Which is the equilibrium price that equals the crude oil price with the product value of basic petrochemicals?

To answer to this question, we present a procedure below.

$$VP_i = \mathrm{d}_j + 0.25\,\mathrm{I}_{0,j} \qquad (13)$$

$$d_j = d_1 + d_c \qquad (14)$$

$$d_c = p_c q_c \qquad (15)$$

$$VP_i = d_1 + p_c q_c + 0.25 I_{0,j} \qquad (16)$$

All terms in Equation (16) are annualized (*F*), where *F* is $\sum_{t=1}^{n}\frac{1}{(1+i)^n} = \left[\frac{(1+i)^n-1}{i(1+i)^n}\right] = F$.

Being "i" the rate of return.

$$VP_i * F = d_1 * F + p_c\left(q_c * n\right) + 0.25\frac{I_{0,j}}{F} \qquad (17)$$

Then p_c is:

$$p_c = \frac{VP_i * F - d_1 * F - 0.25\frac{I_{0,j}}{F}}{q_c * n} \qquad (18)$$

where:

VP_i = Product value of petrochemical "*I*" through the chain of production (US$)

$I_{0,j}$ = Annualized investment of the "*j*" (*j=1,…,6*) Refinery configuration (US$)

d_1 = Total costs of production but not considering the crude oil (US$)

d_c = Cost of the crude oil (raw material) (US$)

p_c = Crude oil market price (US$/Ton)

q_c = Demanded quantity of crude oil being utilized by the Refinery (Ton)

$0.25_{0,j}$ = 25%, is the rate of return on investment (ROI)

n = Number of years in the horizon planning (HP).

6. Results Obtained

In order to have a reference framework to present the results obtained in this work, we will present in **Figure 6** a generalized flow sheet of the proposed methodology and then, following with that description, the results have been obtained.

6.1. Flow Sheet of the Proposed Methodology

Figure 6 shows the flow sheet of the proposed methodology for the case study. This figure has been taken from the Section 3 and adapted for the purpose of the case study.

6.2. The Case Study

We will use a case study a part of Mexico's Petrochemical Industry. For doing that, we need to define the final petrochemicals for planning their better way of production, taking into account the several technological routes.

The CU receives information about the market requirements in form of demands considering $t = 1$ as 2009, the first year of the HP $t = T$, the end of the HP as 2025. **Table 1**, gives an overview of the market needs.

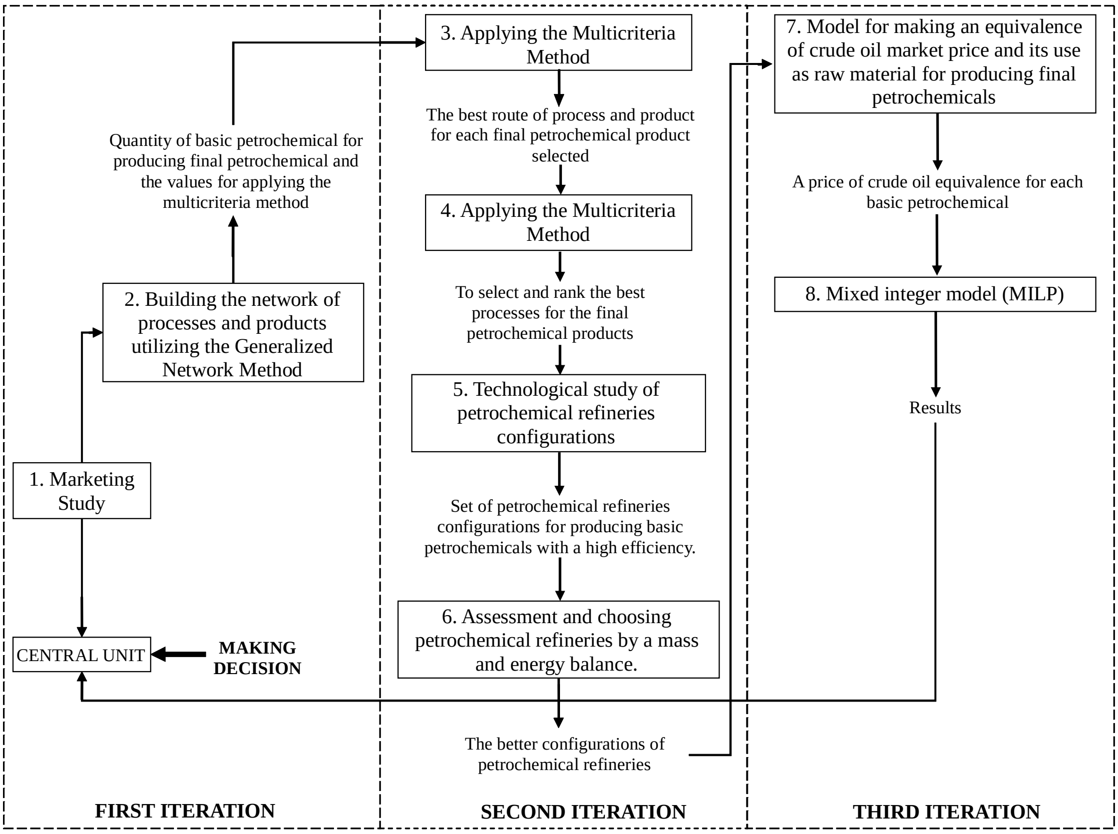

Figure 6. Applying the methodology to the case study.

Table 1. Demand overview for some final petrochemicals.

YEAR	**2009**	**2025**
PRODUCT (10^3 Ton/year)		
Polystyrene (normal and expanded)	545	2,800
Polyurethane	220	556
Polyester fibbers	366	2,283
Polyethylene Terephthalate resins and films (PET)	1,704	2,972
High density Polyethylene (HDPE)	1,040	3,900
Low density Polyethylene (LDPE)	1,061	2,600
Linear low density Polyethylene (LLDE)	305	728
Polypropylene	1,158	407
Styrene/Butadiene Rubber (SBR)	279	430
Styrene Latex	15	31
Acrylonytrile/Butadiene/styrene (ABS) and Styrene Acrylonytrile (SAN) resins	529	887
Phtalic Anhydride	86	105
Polybutilen Terephthalate (PBT)	220	349

With this information, the CU sends it to the petrochemical producers and also to Refinery decision makers. The petrochemical's producers (intermediate and final), will build their alternative chains of production.

They proceed to make the selection of the best technological routes (chains) using multicriteria decision analysis with PROMETHEE II, having as criteria:

1) Maximization of the added value along the petrochemical chains (routes) in order to produce the final petrochemical "p_i"(Weight: 4.8).

2) Minimization of investments required trough the petrochemical chains to produce the final petrochemical product "p_i"(Weight: 2.0).

3) Minimization of the real quantity of energy needed by different process/products along the petrochemical chains to produce the final petrochemical "p_i"(Weight: 1.7).

4) Minimization of the risk of damage the environment by any of the products along the petrochemical chains for producing the final product "p_i" (Weight: 1.5).

The results from PROMETHEE II are presented in the **Table 2**.

As an example of how PROMETHEE II is applied, in **Figure 7** is presented the case of polyester fibbers.

From this figure, whose results have been obtained from Decision-Lab software, it is possible to conclude that the best technological route for the polyester fibbers is the number 1, taking into account the four above mentioned criteria.

Considering this "best" technological routes to produce the final petrochemical, the second step is to make compete products considering the technological route chosen. We also utilized PROMETHEE II. With the same 4 criteria, same weights and same threshold function. **Table 3**, shows the data for this competition.

With these results the Petrochemical producers communicates to the CU which route is the best for each final product. The CU asks to the final producers to make a selection of the best final products, but considering the best technological route have been chosen previously. The results, coming from data in Tables 2 and 3, are presented in **Table 4**.

The CU makes an exploration taking into account the quantities of basic petrochemicals needed to be produced, consulting the Refinery's decision makers.

These last decision makers look for an appropriate configuration to produce those basic petrochemicals. The first outcome is considered that all the final and intermediate petrochemicals are derivatives from benzene, toluene, orthoxylene, and paraxylene and also from ethylene, propylene and butadiene. They will search the alternative refineries configurations. The results are as follows [21].

It was found 6 configurations having as characteristic that more petrochemicals yield they have more investment and operations costs are put into consideration. See **Table 5**.

For the whole solution of the problem, it is necessary now to solve the MILP model having as objective function the values of the net flows obtained for PROMETHEE II, when the final products have ranked.

The results obtained will tell the decision makers how much of the final petrochemicals could be produced and also whose refinery's configurations or a mixed of them could be possible to operate. On the other hand these results will compare the marginal value of use a ton of crude oil for producing petrochemicals instead of export it, when the marginal benefit is about 60 $/barrel.

At the end the Refinery communicates to the CU how much crude oil can be put in operation to produce the demanded petrochemicals and also communicates to the petrochemical producers how much basic petrochemicals could be produced.

Table 2. First step: competition among chains.

Final Petrochemical Product	Number of Alternative Chains
Phtalic Anhydride	2
Polyester Fibbers	9
Styrene/Butadiene Rubber	14
High Density Polyethylene(HDPE)	4
Low Density Polyethylene (LDPE)	2
Linear Low Density Polyethylene (LLDPE)	4
Polybutilen Terephthalate (PBT)	14
Polystyrene (normal and expanded)	14
Polypropylene (PP)	4
Polyurethane	8
Acrylonytrile/Butadiene/styrene (ABS) and Styrene Acrylonytrile (SAN) resins	14
Polyethylene Terephthalate Resins and Films (PET)	9

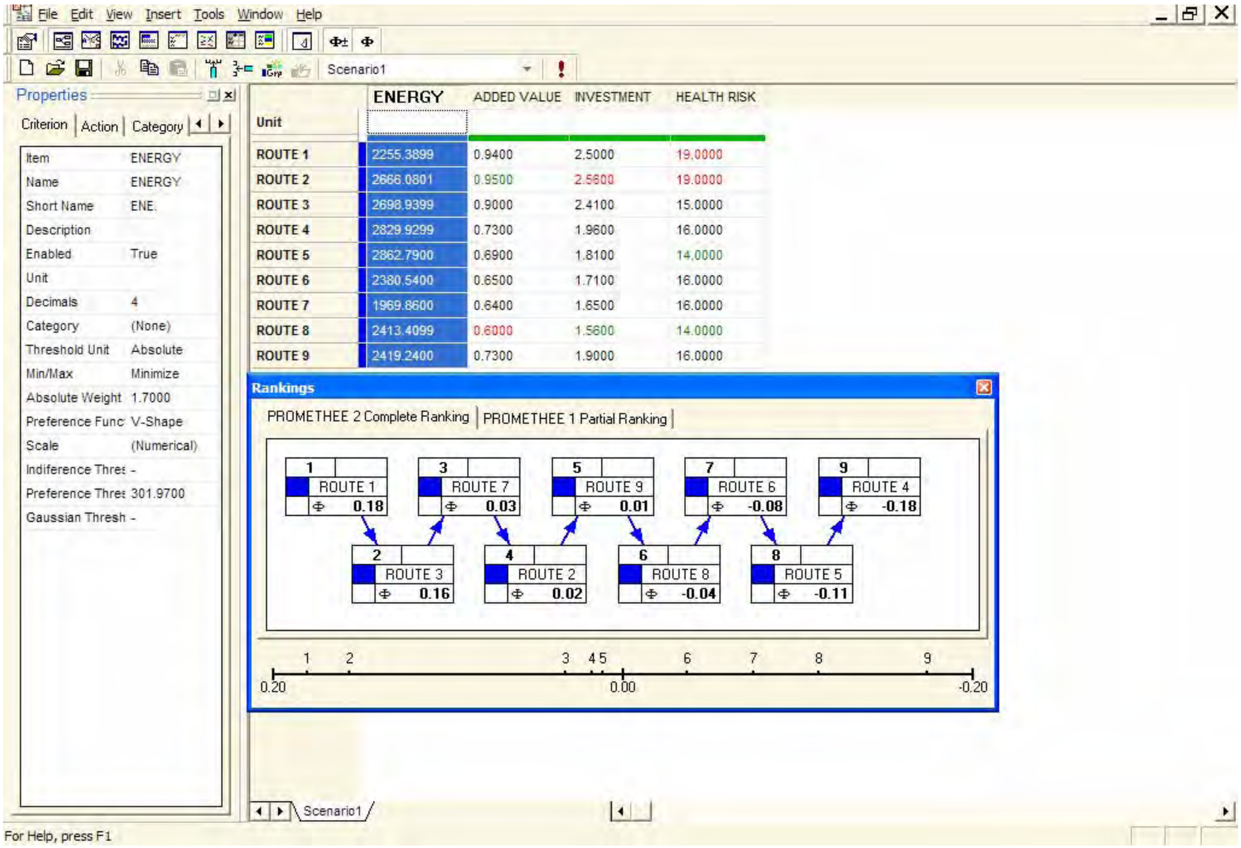

Figure 7. Choosing of process' route for polyester fibbers using PROMETHEE II.

Table 3. Data to select final petrochemical products.

Final selected petrochemical from technological chains	Min: Energy 10^6 kcal/kg	Max: Added Value 10^6 US$/kg	Min: Investment 10^6 US$/kg	Min: Environmental Damages Index
Phtalic Anhydride	167.214	0.243	0.700	10
ABS Resins	1081.006	0.385	0.908	22
High density Polyethylene	294.394	0.117	0.252	13
Low density Polyethylene	771.097	0.168	0.413	10
Linear low density Polyethylene.	213.598	0.156	0.311	13
PET resins	1932.450	0.579	1.740	18
PBT resins	2569.233	1.487	3.690	17
Polyester Fibbers	2255.389	0.938	2.501	19
Polyurethane	4774.572	1.802	3.862	50
Polypropylene	138.215	0.101	0.151	11
Styrene-Butadiene Rubber	2002.784	0.649	1.388	19
Polystyrene	2179.858	0.387	1.156	17

6.3. Refinery's LP Solution

The solution of LP model (set of Equations (7) to (11)), solved with the" LINGO" 10" SOFTWARE, is as follows:

1) The solution had a global optimal.

2) The solution considers the exploitation of 300,000 b/day of crude oil (15 millions ton/year), using the six technical refinery configurations at its upper limit of the availability.

3) The final and basic petrochemical products considered in the solution are as follows (see **Table 6**).

Table 4. Final petrochemicals in competition. Results.

Final Petrochemical	Values of ϕ for final petrochemicals in competition
Phtalic Anhydride	0.0974
Polyester Fibbers	0.0245
Styrene Butadiene Rubber	0.0075
High Density Polyethylene	0.0021
Low Density Polyethylene	0.0285
Linear Low Density Polyethylene	0.0285
Poly Butylen Terephthalate	0.1063
Polystyrene	–0.1568
Polypropylene	0.0463
Polyurethane	–0.037
Abs-San Resins	–0.0944
PET Resins	–0.0527

Table 5. Technical and economical data for Refinery's configurations.

Refinery Configuration Weight, %	1	2	3	4	5	6
Ethylene	8.7	16.1	18.3	18.9	22.5	26.0
Propylene	4.6	9.1	11.0	12.9	12.8	15.0
Butadiene	1.5	2.8	3.4	3.1	3.9	4.6
Aromatics	4.9	8.2	9.7	14.4	12.0	13.9
Total basic petrochemicals	19.7	36.2	42.4	49.3	51.2	59.5
Gasoline	2.3	3.9	4.7	8.4	5.6	6.4
Other products	69.8	47.6	38.3	22.6	25.5	12.6
Total Investment (10^6 US$)	346.5	450.4	517.4	570.6	595.9	686.1
Process Cost (US$/Ton of crude oil)	56.64	76.70	90.18	95.55	103.17	118.00
(US$/bbl of crude oil)	7.76	10.50	12.35	13.09	14.13	16.19

Table 6. Production of final petrochemicals.

Final Petrochemical	Production Ton/year	Demand Ton/year	Unsatisfied demand Ton/year
Polyester Fibbers	192,855	366,000	173,145
Styrene-Butadiene Rubber	294,000	294,000	
High Density Polyethylene	1,040,000	1,040,000	
Low Density Polyethylene	1,061,000	1,061,000	
Linear Low Density Polyethylene	305,000	305,000	
Polybutilen Terephthalate	220,000	220,000	
Phtalic Anhydride	86,000	86,000	
Polypropylene	1,158,000	1,158,000	

4) The following data has been taken from the optimal solution; it concerns the basic petrochemicals to be produced to obtain the quantity of final petrochemicals and the quantities put on the free market to be sold (See **Table 7**).

The dual of the problem has some significance: The reduced costs as well as the dual prices express that no final products will be produced if the *Φ*'s have a negative value; nevertheless an important set of dual variables, are then associated to the upper level of crude oil quantity allowed for each refinery configuration (see **Table 8**). For example the more important configuration are the forth. That configuration has a dual variable many times greater than the other five, as follows:

As an experiment to prove that configuration 4 is the better, we put 6 times a module of this configuration, *i.e.* $PQCRU_4 \leq 2.5 \times 10^6$ Ton/year, 6 times. We have obtained better results: the objective function has increased from 0.1334227 to 0.1376648, because it has produced the total demand of the Polyester fibbers, from 192,855 Ton to 366,000 Ton. The rest of the solution was the same reported in **Table 6**. Other interesting results from the dual problem were that if some final products had positive values in the objective function (*i.e.* their flows had been able to be positives), the production of ABS resins, were incremented the value of objective function (reduced cost).

5) Other results about the properties of the solution are as follows:

In the **Table 9**, all the values correspond to the petrochemicals chains from basic to finals and do not include nor the Refinery's expenses as operations costs does

Table 7. Production of basic petrochemicals.

Basic Petrochemicals (Ton/year)	Production (Ton/year)	Used to produce petrochemical finals (Ton/year)	Send to external market (Ton/year)
Ethylene	2,797,000	2,556,070	241,930
Propylene	1,665,500	1.204,323	461,177
Benzene	612,100	59,432	552,668
Toluene	516,000	0	516,000
Xylenes (o and p)	342,000	342,000	0

Table 8. Shadow price comparison.

Refinery Configuration	Number of times that the shadow price of Configuration 4 is greater than:
1	6.50
2	3.61
3	2.95
5	2.50
6	2.17

Table 9. Productvalues, added values, investment and energy consumed (Millions).

Final Petrochemicals	Product value US $/year	Added value US $/Year	Investment $US	Energy kcal/year
Polyester Fibbers	428.02	180.97	428.30	434.96
Styrene-Butadiene Rubber	426.46	190.91	408.02	588.82
High Density Polyethylene	192.6	122.18	261.87	306.17
Low Density Polyethylene	266.28	178.21	438.72	818.13
Linear Low Density Polyethylene	76.80	47.51	94.96	65.15
Polybutilen Terephthalate	528.26	327.23	811.82	565.52
Polypropylene	404.66	117.39	174.91	160.05
Phtalic Anhydride	29.75	20.87	60.24	14.38
Total of final petrochemicals	2,352.83	1,185.27	2678.84	2953.18
Refinery's Investment			3164.0	
Total (Investment)			5,896.84	

Table 10. Equivalence of final petrochemicals to one barrel of crude oil (US $/bbl).

Refinery Configuration	1	2	3	4	5	6	TOTAL BY FINAL PRODUCT
Polyester Fibbers	26	39	44	47	53	58	267
Styrene Butadiene Rubber	51	86	99	100	120	133	589
High Density Polyethylene	5	6	6	6	6	6	35
Low Density Polyethylene	5	6	6	6	6	7	36
Linear Low Density Polyethylene	5	6	6	6	6	7	36
Polybutilen Terephthalate	6	7	7	10	7	8	45
Polypropylene	5	6	6	6	6	6	35
Phtalic Anhydride	5	5	5	6	6	6	33

neither the energy use.

The total investment, considering the Refinery's is about 5, 897 millions US $. With this last figure, it is possible to express and 1US $, gives an added value of 0.20 US $, much better than nothing if the only exportation of crude is take into account.

On the other hand, if it is added the sales income for the basic petrochemicals sold to the external market, the product value of 2,353 millions US $ is risen to 4,014 millions US $. This figure can be considered as an income and then, a benefit/cost relationship is about 70%. These figures do not take into account the gasoline, fuel oil and other products produced by the refineries, to be sold in the free market.

6) Equivalence of crude oil price for the petrochemicals produced: The marginal rate of substitution.

Considering that one of the objectives of this work, was to compare the equivalence of the petrochemical's chains with one barrel of crude oil to be exported at least at $ US 65 per barrel, in the following table (**Table 10**), it is dressed the values in terms of their crude oil equivalence. It is important to consider that these values are calculated for the whole chains, using the Equations (12) to (17).

The difference between the refinery's configurations is due both, to the complexity of them and also to the fact of more complex are the refinery more basic petrochemicals products can be obtained. One can also see that with these total values for the petrochemical chains of US$/bbl 1,076 can paid more than16.5 times the exportation price of the same barrel of crude oil, *i.e.* US $ 65/bbl.

7. Conclusions

1) We have successfully finished with a new characterized model to coordinate decision makers at different levels of a decentralized hierarchy, considering a mix of operational research tools as the generalized net work technique jointly with multicriteria decision aid methods and mixed integer linear programming.

2) We have reduced the complexity of the combinatory decision making to select more efficiently the final petrochemicals chains.

3) In the case study, we have shown the petrochemical products give more added value comparing those values with the only crude oil exportation. A multiplier of the investment of about 0.20 US$, has a great significance. On the other hand a relationship of 70% of benefice/cost is very attractive one.

4) We have found the dual of the MILP problem. From it, we have been able to select the better of technological configurations of the Refineries.

5) We have also been able to experiment with a "natural ranking" of the Refineries trough the shadow prices of the dual problem, whose value help us to improve the first 'optimal' solution found.

6) We can also show that the equivalence of the petrochemicals compared with only exportation of crude oil is well paid. It is important to mention then, that use crude oil as petrochemical raw material instead of export it is a good business and will serve to develop the industrialization of the country.

7) All the values coming from the whole methodology does not have the concept of real "optimal solutions" as a mathematical programming model has, but these solutions are the 'best' can be obtained considering the decision maker's preferences.

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Discrete Time Markov Reward Processes a Motor Car Insurance Example*

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Abstract

In this paper, a full treatment of homogeneous discrete time Markov reward processes is presented. The higher order moments of the homogeneous reward process are determined. In the last part of the paper, an application to the bonus-malus car insurance is presented. The application was constructed using real data.

Keywords: Markov Rewards Processes, Higher Order Moments, Bonus-Malus Systems

1. Introduction

In the sixties and seventies, Markov reward processes were developed, mainly in the engineering fields in discrete and continuous time [1]. In [2] an application of Continuous Time Markov Reward Processes in life insurance was presented.

In this paper, we present the Discrete Time Markov Reward Processes (DTMRWP) as given in [3]. The evolution equation of the expected value of the DTMRWP is presented with different reward structures. Furthermore, the relations useful for the computation of the higher order moments of the Markov reward process are presented and they are given in matrix form too. To the authors' knowledge, it is the first time that higher moments of a discrete time Markov reward process and the matrix approach for the first n moments are given. The matrix approach facilitates the algorithm construction as for example it is explained in [4] for semi-Markov reward processes.

We believe that DTMRWP can describe any kind of premiums or benefits involved in a generic insurance contract then they represent tool to approach in a general way actuarial problems.

In the last section an example on the application of DTMRWP in the motor car insurance is given using real data applied to the bonus-malus Italian rules.

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2. Reward Structure, Classifications and Notation

The association of a sum of money to a state of the system and to a state transition assumes great relevance in the study of financial phenomena. This can be done by linking a reward structure to a stochastic process. This structure can be thought of as a function associated with the state occupancies and transitions [1].

In this paper the rewards are considered as amounts of money. These amounts can be positive, if they are benefits for the system and negative if they are costs.

A classification scheme of different kinds of DTM RWP is reported in [5] page 150.

2.1. Discounting Factors

The following notations will be used:
$r(1), r(2), \ldots, r(t), \ldots$, for the discrete time homogeneous interest rates and

$$\dot{v}(t) = \begin{cases} 1 & \text{if} \quad t = 0, \\ \prod_{h=1}^{t} \left(1 + r(h)\right)^{-1} & \text{if} \quad t > 0, \end{cases}$$

for the discrete time discount factors.

See [6] or [7] for further details on this topic.

2.2. Reward Notation

ψ_i, $\psi_i(t)$, denote the reward that is given for the permanence in the *i*-th state; it is also called rate reward, see [8]; the first is paid in the cases in which the period amount in state *i* is constant in time, the second when the payment is a function of the state and the time of payment. ψ represents the vector of these rewards.

γ_{ij}, $\gamma_{ij}(t)$, denote the reward that is given for the transition from the *i*th state to the *j*th one (impulse reward). $\mathbf{\Gamma}$ is the matrix of the transition rewards.

The different kinds of ψ rewards represent an annuity that is paid because of remaining in a state. This flow is to be discounted at starting time. In the *immediate case*, the reward will be paid at the end of the period before the transition; in the *due case* the reward will be paid at the beginning of the period. On the other hand, γ represents lump sums that are paid at the instant of transition. As far as the impulse reward γ is concerned, it is only necessary to compute the present value of the lump sum paid at the moment of the related transition.

Reward structure can be considered a very general structure linked to the problem being studied. The reward process evolves together with the evolution of the Markov process which it is linked. When the studied stochastic system is in a state then a reward of type ψ is paid; once there is a transition an impulse reward of γ type is paid.

This behaviour is particularly efficient at constructing models which are useful to follow, for example, the dynamic evolution of insurance problems e.g. [9] and [10].

2.3. Matrix Operations

We give some matrix operation notation useful to describe the equations of the moments of the Markov reward processes in matrix form.

Given the two matrices **A**, **B** with the notations

$$\mathbf{A} * \mathbf{B} \text{ and } \mathbf{A} \cdot \mathbf{B}$$

are denoted, respectively, the usual row column product and the element by element product.

Definition 2.1 Given two matrices $\mathbf{A}, \mathbf{B}$ that have row order equal to m and column order equal to n, the following operation is defined:

$$\mathbf{c} = \mathbf{A} \circ \mathbf{B}$$

where **c** is the m elements vector in which the i-th component is obtained in the following way:

$$c(i) = \sum_{j=1}^{n} a_{ij} b_{ij} = \mathbf{a}_{i*} * \mathbf{b}_{i*}$$

3. Homogeneous DTMRWP

Markov reward processes are a class of stochastic processes each of them with different evolution equations. The differences from the analytic point of view can be considered irrelevant but from the algorithmic point of view they are very significant and must be taken into account in the construction of the algorithms.

Let consider a discrete time homogeneous Markov chain with state space $I = \{1, 2, ..., m\}$ and transition probability matrix $\mathbf{P} = \left[p_{ij} \right]_{i,j \in I}$. As it is well known the n-step transition probability matrix is given by $\mathbf{P}(n) = (\mathbf{P})^n$.

Definition 1: Let denote by $\xi_i(n)$ the discounted rewards accumulated in *n* periods given that at time 0 the system was in the state *i* and the reward are paid in the immediate case. It is defined recursively as follows:

$$\xi_i(n) = \xi_i(n-1) + \nu(n) \sum_{i,j=1}^{m} 1_{\{X(n-1)=i, X(n)=j\}} \left(\psi_j(n) + \gamma_{ij}(n) \right) \tag{1}$$

where $\xi_i(0) = 0$

Similar relations can be easily written for discounted homogeneous due cases. We denote by:

$$V_i(n) = E\left(\xi_i(n)\right); \quad \mathbf{V}(n) = \left[V_1(n), V_2(n), ..., V_m(n) \right]$$

With $\ddot{V}_i(n) = E\left(\xi_i(n)\right)$; the mean present value of the rewards paid in the investigated horizon time in the due cases is represented. In this case, in the definition of the $\xi_i(n)$ process we put $\xi_i(0) = \psi_i$.

For the sake of understanding, first we present the simplest case in immediate and due hypotheses after only the general relations in the discrete time environment will be given.

The immediate homogeneous Markov formula in the case of fixed permanence and without transition rewards is the first relation presented. The DTMRWP present value after one payment is:

$$V_i(1) = (1+r)^{-1} \psi_i = (1+r)^{-1} \psi_i$$

after two payments,

$$V_i(2) = (1+r)^{-1} \psi_i + \nu^2 \sum_{k=1}^{m} p_{ik}^{(1)} \psi_k = V_i(n) + \nu^2 \sum_{k=1}^{m} p_{ik}^{(1)} \psi_k$$

and in general, taking into account the recursive nature of relations, at n-th period it is:

$$V_i(n) = V_i(n-1) + \nu^n \sum_{k=1}^{m} p_{ik}^{(n-1)} \psi_k$$

that in matrix form becomes:

$$\mathbf{V}(n) = \mathbf{V}(n-1) + \left(\nu^n \mathbf{P}^{(n-1)} \right) * \boldsymbol{\psi} = \nu \boldsymbol{\psi} + \cdots + \left(\nu^n \mathbf{P}^{(n-1)} \right) * \boldsymbol{\psi}$$

The general case with variable permanence, transition rewards and interest rates is presented. The present value after one period is:

$$V_i(1) = \nu(1)\left(\psi_i(1) + \sum_{j=1}^{m} p_{ij}\gamma_{ij}(1)\right),$$

after two payments,

$$\begin{aligned} V_i(2) &= \nu(1)\left(\psi_i(1) + \sum_{j=1}^{m} p_{ij}\gamma_{ij}(1)\right) + \\ &\quad \nu(2)\sum_{k=1}^{m} p_{ik}\left(\psi_k(2) + \sum_{j=1}^{m} p_{kj}\gamma_{kj}(2)\right) \\ &= V_i(1) + \nu(2)\sum_{k=1}^{m} p_{ik}\left(\psi_k(2) + \sum_{j=1}^{m} p_{kj}\gamma_{kj}(2)\right), \end{aligned}$$

and in general, taking into account the recursive nature of relation, at n-th period it is:

$$\begin{aligned} V_i(n) &= V_i(n-1) + \\ &\quad \nu(n)\sum_{k=1}^{m} p_{ik}^{(n-1)}\left(\psi_k(n) + \sum_{j=1}^{m} p_{kj}\gamma_{kj}(n)\right). \end{aligned} \tag{2}$$

This relation can be written in matrix notation in the following way:

$$\begin{aligned} \mathbf{V}(n) &= \nu(1)\boldsymbol{\psi}(1) + \cdots + \left(\nu(n)\mathbf{P}^{(n-1)}\right) * \boldsymbol{\psi}(n) + \\ &\quad \nu(1)\left(\mathbf{P} \circ \boldsymbol{\Gamma}(1)\right) + \cdots + \left(\nu(n)\mathbf{P}^{(n-1)}\right) * \left(\mathbf{P} \circ \boldsymbol{\Gamma}(n)\right). \end{aligned}$$

In the case of payment due the permanence reward is paid at beginning of the period and the transition reward at the end. It results:

$$\ddot{V}_i(1) = \psi_i(1) + \nu(1)\sum_{j=1}^{m} p_{ij}\gamma_{ij}(1),$$

$$\begin{aligned} \ddot{V}_i(2) &= \psi_i(1) + \nu(1)\sum_{k=1}^{m} p_{ik}\gamma_{ik}(1) + \nu(1)\sum_{j=1}^{m} p_{ij}\psi_j(2) + \\ &\quad \nu(2)\sum_{k=1}^{m} p_{ik}\sum_{j=1}^{m} p_{kj}\gamma_{kj}(2) \\ &= \ddot{V}_i(1) + \nu(1)\sum_{k=1}^{m} p_{ik}\psi_k(1) + \nu(2)\sum_{k=1}^{m} p_{ik}\sum_{j=1}^{m} p_{kj}\gamma_{kj}(2). \end{aligned}$$

$$\begin{aligned} \ddot{V}_i(n) &= \ddot{V}_i(n-1) + \nu(n)\sum_{k=1}^{m} p_{ik}^{(n-1)}\sum_{j=1}^{m} p_{kj}\gamma_{kj}(n) + \\ &\quad \nu(n-1)\sum_{k=1}^{m} p_{ik}^{(n-1)}\psi_k(n). \end{aligned} \tag{3}$$

That in matrix notation is:

$$\begin{aligned} \ddot{\mathbf{V}}(n) &= \mathbf{I} * \boldsymbol{\psi}(1) + \left(\nu(1)\mathbf{P}\right) * \boldsymbol{\psi}(2) + \cdots + \\ &\quad \left(\nu(n-1)\mathbf{P}^{(n-1)}\right) * \boldsymbol{\psi}(n) + \left(\nu(1)\mathbf{P}\right) \circ \boldsymbol{\Gamma}(1) + \cdots + \\ &\quad \left(\nu(n)\mathbf{P}^{(n-1)}\right) * \left(\mathbf{P} \circ \boldsymbol{\Gamma}(n)\right). \end{aligned}$$

Remark 3.1 In this section, general formulas were presented. In the construction of the algorithms the differences between the possible cases should be taken into account. For example in the non-discounting case the following can be stated $\nu(k) = 1,\ k = 1, \ldots, n$.

4. The higher Order Moments of Markov Reward Processes

In [11] relations for higher order moments of the integral of a generic function that evolves following a semi-Markov process were given. In more recent works (see [4] and [12]), the relations for higher moments of rewards associated to a semi-Markov backward system were presented.

In this section, following the methodology used in the last two quoted papers, the recursive relations useful for computing the higher moments in a Markov reward environment are provided.

It should be stated that the equations of this paper are different from that of [4] and [12] because we consider the conditioning on the starting state but also on the arriving state.

We will give only the discounted case.

According to Section 3 let us define the following stochastic process:

Definition 2: Let denote by $\xi_{ij}(n)$ the accumulated discounted rewards in n periods given that at time 0 the system was in the state i and at time n it will be in state j:

$$\begin{aligned} \xi_{ij}(n) &= 1_{\{X(n)=j\}} \cdot \xi_i(n-1) + \\ &\quad 1_{\{X(n)=j\}} \cdot \nu(n)\sum_{a,b=1}^{m} 1_{\{X(n-1)=a, X(n)=b\}}\left(\psi_b(n) + \gamma_{ab}(n)\right) \\ &= 1_{\{X(n)=j\}} \cdot \xi_i(n-1) + \\ &\quad \nu(n)\sum_{a=1}^{m} 1_{\{X(n-1)=a, X(n)=j\}}\left(\psi_a(n) + \gamma_{aj}(n)\right). \end{aligned} \tag{4}$$

Moreover we denote

$$V_i(n) = E\left[\xi_i(n) \mid X(0) = i\right] = E_{(i,0)}\left[\xi_i(n)\right];$$

$$\mathbf{V}(n) = \left[V_1(n), V_2(n), \ldots, V_m(n)\right]'$$

$$V_{ij}(n) = E[\xi_{ij}(n) \mid X(0) = i, X(n) = j] = E_{((i,0);(j,n))}[\xi_{ij}(n)];$$

$$\mathbf{W}(n) = \left[V_{ij}(n)\right]_{i,j \in \{1,2,\ldots,m\}}$$

and the higher order moments are defined as

$$V_i^{(r)}(n) = E_{(i,0)}\left[\left(\xi_i(n)\right)^r\right];$$

$$\mathbf{V}^{(r)}(n) = \left[V_1^{(r)}(n), V_2^{(r)}(n), \ldots, V_m^{(r)}(n)\right]'$$

$$V_{ij}^{(r)}(n) = E\left[\left(\xi_{ij}(n)\right)^r \mid X(0) = i, X(n) = j\right] = E_{((i,0);(j,n))}\left[\left(\xi_{ij}(n)\right)^r\right];$$

$$\mathbf{W}^{(r)}(n)=\left[V_{ij}^{(r)}(n)\right]_{i,j\in\{1,2,\ldots,m\}}$$

and it results for all r that $V_i^{(r)}(n)=\sum_{j=1}^{m}p_{ij}^{(n)}V_{ij}^{(r)}(n).$

Similar relations can be easily written for non discounted cases

Theorem 4.1 The moments of $\xi_{ij}(n)$ in the discounted immediate case, in matrix form, are given by:

$$\begin{aligned}\mathbf{W}^{(r)}(n)=&\left(\left(\mathbf{P}^{(n-1)}\cdot\mathbf{W}^{(r)}(n-1)\right)*\mathbf{P}(n)\right)\cdot\tilde{\mathbf{P}}^{(n)}+\\&\sum_{l=1}^{r-1}\frac{r!}{l!(r-l)!}\left[\dot{v}(n)\right]^{r-l}\cdot\\&\left(\left(\mathbf{P}^{(n-1)}\cdot\mathbf{W}^{(l)}(n-1)\right)*\left(\mathbf{P}\cdot\mathbf{C}^{(r-l)}(n)\right)\right)\cdot\tilde{\mathbf{P}}^{(n)}+\\&\left[\dot{v}(n)\right]^{r}\cdot\left(\mathbf{P}^{(n-1)}*\left(\mathbf{P}\cdot\mathbf{C}^{(r)}(n)\right)\right)\cdot\tilde{\mathbf{P}}^{(n)}\end{aligned}\tag{5}$$

where:

$$\tilde{\mathbf{P}}^{(n)}=\left(\frac{1}{p_{ij}^{(n)}}\right)_{i,j\in E},$$

$$\mathbf{C}^{(l)}(n)=\left(c_{ij}^{(l)}(n)\doteq\left(\psi_i(n)+\gamma_{ij}(n)\right)^l\right)$$

Proof From (4.1) it results:

$$\begin{aligned}V_{ij}^{(r)}(n)&=E_{((i,0);(j,n))}\left[\left(\xi_i(n)\right)^r\right]\\&=E_{((i,0);(j,n))}\left[\left(1_{\{X(n)=j\}}\xi_i(n-1)+\right.\right.\\&\qquad\left.\left.\dot{v}(n)\sum_{a=1}^{m}1_{\{X(n-1)=a,X(n)=j\}}\left(\psi_a(n)+\gamma_{aj}(n)\right)\right)^r\right].\end{aligned}$$

$$\begin{aligned}&=E_{((i,0);(j,n))}\left[\sum_{l=0}^{r}\frac{r!}{l!(r-l)!}\left(1_{\{X(n)=j\}}\xi_i(n-1)\right)^l\cdot\right.\\&\qquad\left.\left(\dot{v}(n)\sum_{a=1}^{m}1_{\{X(n-1)=a,X(n)=j\}}\left(\psi_a(n)+\gamma_{aj}(n)\right)\right)^{r-l}\right]\\&=\sum_{l=0}^{r}\frac{r!}{l!(r-l)!}E_{((i,0);(j,n))}[E_{((i,0);(j,n))}[\left(1_{\{X(n)=j\}}\xi_i(n-1)\right)^l\cdot\\&\qquad\left(\dot{v}(n)\sum_{a=1}^{m}1_{\{X(n-1)=a,X(n)=j\}}\left(\psi_a(n)+\gamma_{aj}(n)\right)\right)^{r-l}\\&\qquad|X(n-1)]]\end{aligned}$$

The random variables $\xi_i(n-1)$ and $\xi_{ij}(n-1)-\xi_i(n-1)$ are independent given $X(n-1)$ then we get in:

$$\begin{aligned}&=\sum_{l=0}^{r}\frac{r!}{l!(r-l)!}E_{((i,0);(j,n))}[E_{((i,0);(j,n))}\\&\quad[\left(1_{\{X(n)=j\}}\xi_i(n-1)\right)^l|X(n-1)]\cdot\\&\quad E_{((i,0);(j,n))}[\left(\dot{v}(n)\sum_{a=1}^{m}1_{\{X(n-1)=a,X(n)=j\}}\left(\psi_a(n)+\gamma_{aj}(n)\right)\right)^{r-l}\\&\quad X(n-1)]]\end{aligned}$$

by independence between $1_{\{X(n)\}}$ and $\xi_i(n-1)$ given $X(n-1)$ and by measurability of $1_{\{X(n)\}}$ with respect to the information set $\{X(0)=i,X(n-1)=k,X(n)=j\}$ it results:

$$\begin{aligned}&=\sum_{l=0}^{r}\frac{r!}{l!(r-l)!}E_{((i,0);(j,n))}\big[E_{((i,0);(j,n))}[1_{\{X(n)=j\}}|X(n-1)]\\&\quad\cdot E_{((i,0);(j,n))}[\xi_i(n-1)|X(n-1)]\\&\quad\cdot E_{((i,0);(j,n))}[\left(\dot{v}(n)\sum_{a=1}^{m}1_{\{X(n-1)=a,X(n)=j\}}\left(\psi_a(n)+\gamma_{aj}(n)\right)\right)^{r-l}\\&\quad\cdot X(n-1)]\big]\end{aligned}$$

$$\begin{aligned}&\sum_{l=0}^{r}\frac{r!}{l!(r-l)!}E_{((i,0);(j,n))}\big[V_{i,X(n-1)}^{(l)}(n-1)\\&\cdot\left(\dot{v}(n)\left(\psi_{X(n-1)}(n)+\gamma_{X(n-1)j}(n)\right)\right)^{r-l}\big]\\&=\sum_{l=0}^{r}\frac{r!}{l!(r-l)!}\sum_{k=1}^{m}P_i\left[X(n-1)=k\,|\,X(n)=j\right]\\&\quad\cdot V_{i,k}^{(l)}(n-1)\left(\dot{v}(n)\left(\psi_k(n)+\gamma_{kj}(n)\right)\right)^{r-l}\\&=\sum_{l=0}^{r}\frac{r!}{l!(r-l)!}\sum_{k=1}^{m}\frac{P\left[X(n)=j\,|\,X(n-1)=k\right]P_i\left[X(n-1)=k\right]}{P_i\left[X(n)=j\right]}\\&\quad\cdot V_{i,k}^{(l)}(n-1)\cdot\left(\dot{v}(n)\left(\psi_k(n)+\gamma_{kj}(n)\right)\right)^{r-l}\end{aligned}$$

$$\begin{aligned}&=\sum_{l=0}^{r}\frac{r!}{l!(r-l)!}\sum_{k=1}^{m}\frac{p_{ik}^{(n-1)}p_{kj}}{p_{ij}^{(n)}}V_{i,k}^{(l)}(n-1)\\&\quad\cdot\left(\dot{v}(n)\left(\psi_k(n)+\gamma_{kj}(n)\right)\right)^{r-l}\end{aligned}$$

Consequently we obtain:

$$\begin{aligned}V_{ij}^{(r)}(n)=&\sum_{k=1}^{m}\frac{p_{ik}^{(n-1)}p_{kj}}{p_{ij}^{(n)}}V_{ik}^{(r)}(n-1)+\\&\sum_{l=1}^{r-1}\frac{r!}{l!(r-l)!}\sum_{k=1}^{m}\frac{p_{ik}^{(n-1)}p_{kj}}{p_{ij}^{(n)}}V_{ik}^{(l)}(n-1)\\&\cdot\left\{\left(\psi_k(n)+\gamma_{kj}(n)\right)\dot{v}(n)\right\}^{r-l}+\\&\sum_{k=1}^{m}\frac{p_{ik}^{(n-1)}p_{kj}}{p_{ij}^{(n)}}\left\{\left(\psi_k(n)+\gamma_{kj}(n)\right)\dot{v}(n)\right\}^{r}\end{aligned}$$

that in matrix form gives (5)

Now since $V_i^{(r)}(n)=\sum_{j=1}^{m}p_{ij}^{(n)}V_{ij}^{(r)}(n)$, by direct computation we get $V_i^{(r)}(n)$.

Corollary 4.1 The evolution equation of the higher order moment of the $\xi_i(n)$ process in the discounted immediate case, in matrix form is:

$$\begin{aligned}\mathbf{V}^{(r)}(n) = \mathbf{V}^{(r)}(n-1) + \left[\dot{\nu}(n)\right]^r \cdot \\ \left(\mathbf{P}^{(n-1)} * \left(\mathbf{P} \circ \mathbf{C}^{(r)}(n)\right)\right) + \\ \sum_{l=1}^{r-1} \frac{r!}{l!(r-l)!}\left[\dot{\nu}(n)\right]^{r-l} \cdot \left(\mathbf{P}^{(n-1)} \cdot \mathbf{W}^{(l)}(n-1)\right) * \\ \left(\mathbf{P} \circ \mathbf{C}^{(r-l)}(n)\right).\end{aligned} \tag{6}$$

By means of similar procedures, the following corollaries can be obtained.

Corollary 4.2 The higher moments of $\xi_{ij}(n)$ in the discounted due case, in matrix form, are given by the following relation:

$$\begin{aligned}\ddot{\mathbf{W}}^{(r)}(n) = \left(\left(\mathbf{P}^{(n-1)} \cdot \ddot{\mathbf{W}}^{(r)}(n-1)\right) * \mathbf{P}\right) \cdot \\ \tilde{\mathbf{P}}^{(n)} + \sum_{l=1}^{r-1} \frac{r!}{l!(r-l)!}\left[\dot{\nu}(n-1)\right]^{r-l} \cdot \\ \left(\left(\mathbf{P}^{(n-1)} \cdot \ddot{\mathbf{W}}^{(l)}(n-1)\right) * \left(\mathbf{P} \cdot \ddot{\mathbf{C}}^{(r-l)}(n)\right)\right) \cdot \tilde{\mathbf{P}}^{(n)} + \\ \left[\dot{\nu}(n-1)\right]^r \cdot \left(\mathbf{P}^{(n-1)} * \left(\mathbf{P} \cdot \ddot{\mathbf{C}}^{(r)}(n)\right)\right) \cdot \tilde{\mathbf{P}}^{(n)}\end{aligned} \tag{7}$$

where: $\ddot{\mathbf{C}}^{(l)}(n) = \left(\ddot{c}_{ij}^{(l)}(n) \doteq \left(\psi_i(n-1) + \gamma_{ij}(n)\right)^l\right).$

Remark 4.2 The possibility of computing the second order moments permits the obtaining of the variance and the sigma square, having in this way the opportunity to have a risk measure.

5. Motorcar Insurance Application

As it is well known, the bonus-malus motor car insurance model can be studied by means of Markov chains, see [13] for a complete description of bonus-malus systems. As far as the authors know, the premiums received and the benefits paid by the insurance company have never been studied simultaneously inside the evolution equation of the model as we propose here. In this way it is possible to have information on the future evolution of cash flows of the insurer and the possibility of computing higher order moments permits the obtaining of risk measures.

In order to apply DTMRWP we will construct a bonus-malus Markov reward model.

It should be noted that, as explained in [14], motor car insurance premiums could be a function of many factors such as type of car, mileage, age of the driver, region, sex and so on.

In Italy the only official distinctions are the province in which the car is insured and the power of its engine.

This example will use a transition matrix related to the motor car bonus-malus insurance rules that apply in Italy. In this case, the Markov model fits quite well because:

1) the position of each insured person is given at the beginning of each year,

2) there are precise rules that give the change of states in function of the behaviour of the policyholder person during the year,

3) the future state depends only on the present one.

The Italian bonus-malus rules are expressed by the function $T: I \times \mathbb{N} \to I$ that to each rating class $i \in I$ and number of accidents $k \in \mathbb{N}$ associates a new rating class $j \in I$ by means of the following law:

$$\begin{aligned}T(i,k) = 1_{\{k=0\}} \max\left(1, i-1\right) + \\ 1_{\{0<k<4\}} \min\left(18, \left(i-1\right) + 3k\right) + \\ 1_{\{k \geq 4\}} \min\left(18, \left(i-1\right) + 4k\right)\end{aligned} \tag{8}$$

The range of values of T is $\{1, 2, ..., 18\}$ expressing the classes of risk in which all drivers are classified. The stochastic process $X(t)$ describing the rating risk class evolution of the policyholder is assumed to be a Markov chain with state space $I = \{1, 2, ..., 18\}$. This choice is determined by the fact that the next risk class is determined through rule (5.1) as a function of the current risk class i and the number of accidents k the policyholder carried out in the current year.

The authors are in possession of the history of 105627 insured persons over a period of three years. This means that it was possible consider 316881 real or virtual transitions. The data are related to the years 1998, 1999 and 2000. The estimated Markov transition matrix obtained from the available data taking into account the bonus-malus Italian rules is given in the **Table 1**. In this table we report only the transition probability that are possible to be observed, the remaining are impossible due to the Italian BMS rules. Then for example, in one step, from state 1 it is possible to migrate only towards state 1 (0 accident), to state 3 (1 accident), to state 6 (2 accident), to state 9 (3 accident) and to state 12 (4 or more accident). The other transitions are not allowable and then their probabilities are zero and then not reported in the table.

The payment of a claim by the insurance company can be seen as a lump sum (impulse or transition reward) paid by the insurer to the insured person.

In **Figure 1** the premiums (they can be seen as permanence rewards) that are paid in Naples for a car of 2300 c.c. and in Oristano (a small Sardinian province) for a small car (about 1000 c.c.) are reported.

Table 1. One step transition probability matrix.

Starting state	Next state and related probability				
1	**1** 0.941655	**3** 0.056264	**6** 0.001973	**9** 0.000081	**12** 0.000027
2	**1** 0.935097	**4** 0.062379	**7** 0.002427	**10** 0.000097	**13** 0
3	**2** 0.941646	**5** 0.056611	**8** 0.001574	**11** 0.000169	**14** 0
4	**3** 0.948892	**6** 0.049364	**9** 0.001744	**12** 0	**15** 0
5	**4** 0.945231	**7** 0.052354	**10** 0.002314	**13** 0.000067	**16** 0.000034
6	**5** 0.949204	**8** 0.04908	**11** 0.00157	**14** 0.000146	**17** 0
7	**6** 0.934685	**9** 0.061856	**12** 0.00339	**15** 0.000069	**18** 0
8	**7** 0.92227	**10** 0.073137	**13** 0.004246	**16** 0.00026	**18** 0.000087
9	**8** 0.914103	**11** 0.082621	**14** 0.003185	**17** 0	**18** 0.000091
10	**9** 0.923854	**12** 0.071989	**15** 0.003827	**18** 0.00033	
11	**10** 0.92933	**13** 0.066723	**16** 0.003696	**18** 0.000251	
12	**11** 0.930156	**14** 0.066697	**17** 0.002994	**18** 0.000153	
13	**12** 0.937854	**15** 0.059651	**18** 0.002495		
14	**13** 0.920681	**16** 0.074704	**18** 0.004615		
15	**14** 0.885204	**17** 0.107143	**18** 0.007653		
16	**15** 0.777568	**18** 0.222432			
17	**16** 0.876733	**18** 0.123267			
18	**17** 0.888614	**18** 0.111386			

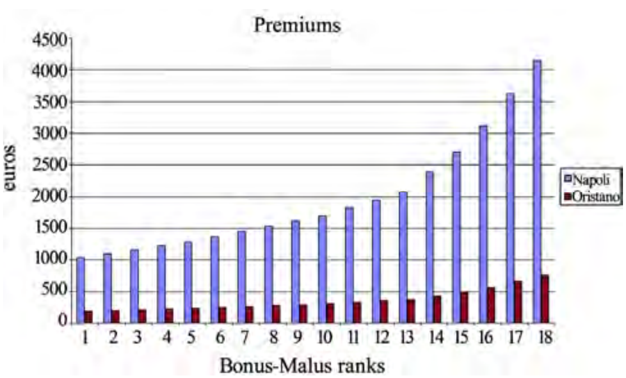

Figure 1. Naples and Oristano premiums.

The example is constructed from the point of view of the insurance company and premiums are an entrance for the company. It is to precise that these values correspond to the real premiums (that is loaded premiums covering costs and risk) paid by an insured in the year 2001 and officially given in the internet site of Assicurazioni Generali for that year.

In the example we suppose that the rewards are fixed in the time. Furthermore we suppose to have a yearly fixed discount factor of 1/1.03.

Table 2 gives the mean values of the expenses that the insurance company should pay for the claims made by the insured person.

More clearly stated, the element –7772.51 represents the expenses that, on average, the company has to pay for the two accidents that an insured person that was in the state 1 (lowest bonus-malus class) had and which then took him to state 6.

This table was constructed starting from the observed data in the authors' possession.

From the point of view of the model, the elements of this table are transition rewards. More precisely, as already mentioned, they can be seen as lump sums (impulse rewards) paid by the company at the time of the accident. In this case, being expenses for the company, they result negative.

Table 2. Mean insurance payments.

State	Expenses mean values in function of next state			
1	**3** –2185.57	**6** –7772.51	**9** –3240.77	**12** –7728.78
2	**4** –1956.4	**7** –3196.16	**10** –9004.43	**13** 0
3	**5** –2188.25	**8** –2846.52	**11** –4498.34	**14** 0
4	**6** –2853.19	**9** –2920.39	**12** 0	**15** 0
5	**7** –2245.02	**10** –3945.44	**13** –3240.77	**16** –6274.95
6	**8** –2676.12	**11** –3076.05	**14** –6703.61	**17** 0
7	**9** –2086.66	**12** –3391.18	**15** –1572.09	**18** 0
8	**10** –2198.02	**13** –4027.26	**16** –3286.39	**18** –3629.14
9	**11** –2017.77	**14** –6397.63	**17** 0	**18** –3687.5
10	**12** –2103.01	**15** –4931.93	**18** –5165.44	
11	**13** –3110.63	**16** –4710.94	**18** –5993.19	
12	**14** –3048.69	**17** –3893.94	**18** –11602.3	
13	**15** –2613.27	**18** –8271.51		
14	**16** –3564.01	**18** –4145.45		
15	**17** –2468.23	**18** –7356.78		
16	**18** –2883.68			
17	**18** –3764.32			
18	**18** –2578.55			

In **Figure 2** are resumed in the first part the reward mean present values and in the second the related sigma square.

The permanence reward (insurance premium) increases in function of the state and, therefore, the money earned by the company increases in function of the starting state too. It is to observe that the Insurance company always earns. Only in one case in Oristano (the first year of the 16th rank) it looses some small sum.

The illustrated case is very particular. In Naples the premiums are higher than in the other part of Italy, the car is big and also for this reason the premiums are very high. In Oristano the premiums are among the lowest in Italy and we consider a small car.

6. Conclusions

The description of homogeneous Markov reward processes was presented. For the first time, at author knowledge, the relations useful to compute the higher moments for homogeneous Markov reward processes conditioned on the starting and arriving states are given. By means of the higher order moments it is possible to obtain variability indices.

The model was applied to motor car insurance regulations in Italy. The mean present values of rewards were computed. The results related to Naples and Oristano provinces were shown.

The authors hope to get a wider data set to construct a more reliable example and to understand if these first results that were obtained by the available data could be confirmed.

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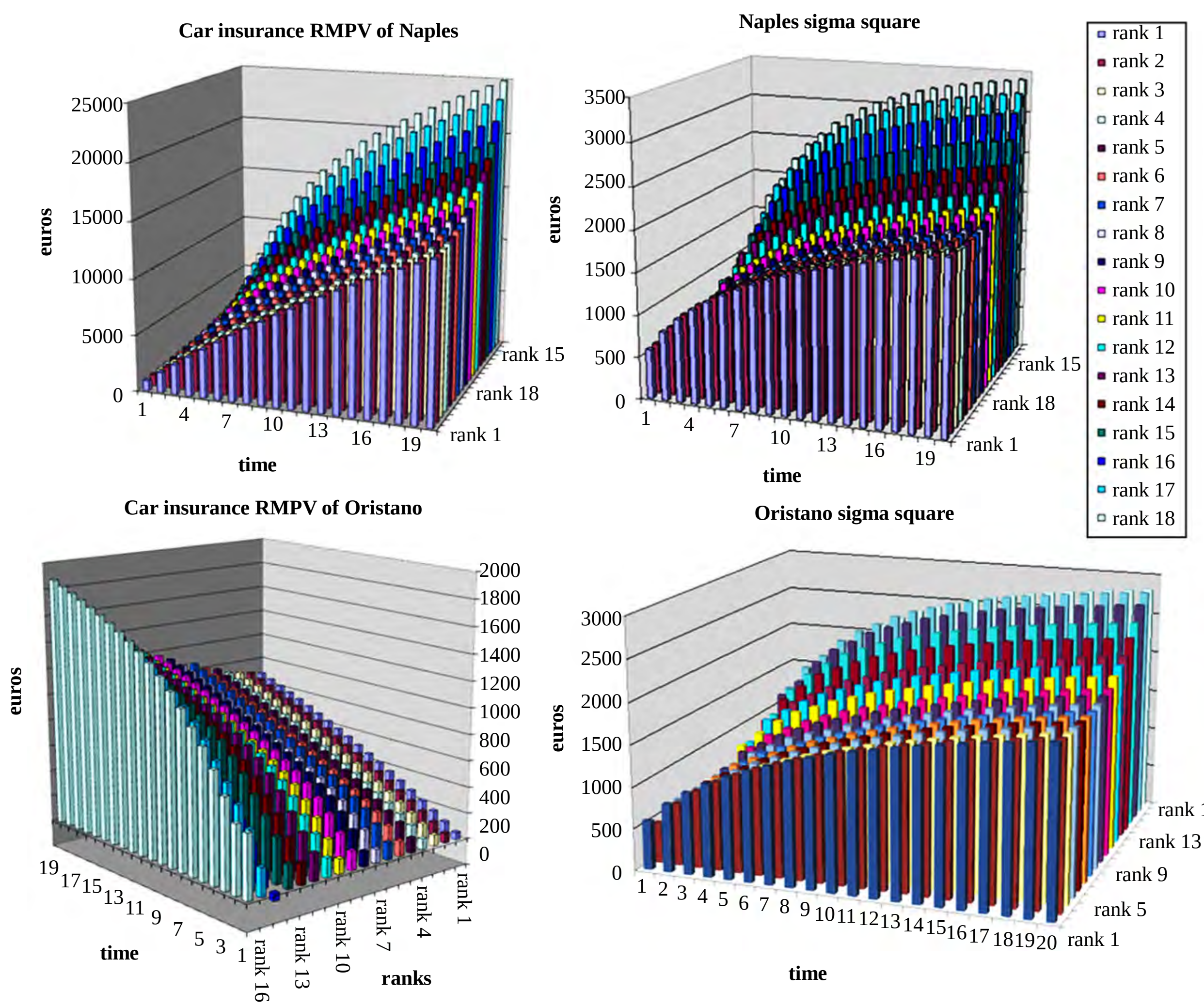

Figure 2. Mean present values and variances of Naples and Oristano rewards.

gave the data for the applications. The work was supported by a PRIN-MIUR and a Università di Roma "La Sapienza" grants.

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Labor Investment in a New International Mixed Market

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Abstract

This paper considers a continuous-time dynamic mixed market model of labor investment decisions of a domestic public firm and a foreign private firm. The paper studies the optimal levels of preemptive investment for the long-run structure of the international mixed market. It is then demonstrated that there are no perfect equilibria in which neither firm invests to its steady-state reaction curve.

Keywords: Lifetime Employment Contract, Continuous-Time Dynamic Model, Domestic Public Firm, Foreign Private Firm

1. Introduction

Following the pioneering work of Merrill and Schneider [1], the analysis of mixed market models that incorporate welfare-maximizing public firms has received significant attention in recent years and has been widely studied by many economists, such as [2-19].[1] However, these studies consider mixed markets with domestic private firms and do not include foreign private firms.

Some studies include foreign firms. For example, Fjell and Pal [20] extend the analysis to an international context by considering a model where a state-owned public firm competes with both domestic and foreign private firms and examine the effects of entry by an additional private firm. Pal and White [21] examine the effects of privatization on strategic trade policy by incorporating strategic trade policy instruments in an international mixed model where a state-owned public firm competes with both domestic and foreign private firms. Fjell and Heywood [22] consider a mixed oligopoly in which a public Stackelberg leader competes with both domestic and foreign private firms. Matsumura [23] examines a Stackelberg mixed duopoly where a public firm competes against a foreign private firm. Furthermore, Fernández-Ruiz [24] studies firm' decisions to hire managers when a public firm with social welfare objectives competes against a foreign private firm with profit objectives.

As is well known, international mixed oligopolies are common in developed and developing countries as well as in former communist countries. Public firms compete against foreign private firms in many industries, such as banking, life insurance, automobiles, airlines, steel, shipbuilding, and tobacco.[2]

Therefore, we examine a continuous-time dynamic model of the strategic investment decisions of a domestic welfare-maximizing public firm and a foreign profit-maximizing private firm. The possibility of firms using excess capacity to strategic investment was studied by [25-27], and was also extended in two-stage models by [28-34]. Furthermore, Spence [35] examines the strategic investment decisions of profit-maximizing private firms in a new industry or market by using a continuous-time asymmetric dynamic model. In Spence's model, there exist the leading and the following firms. He shows that the equilibrium is for the leading firm to invest as quickly as possible to some capital level and then stop. Fudenberg and Tirole [36] establish the existence of a set of perfect equilibria by using Spence's dynamic model and suggest that the steady state of the game is usually on neither firm's steady-state reaction curve; that is, there are early-stopping equilibria where neither firm invests to its steady-state reaction curve. Ohnishi [11] studies the perfect equilibria of a continuous-time mixed market model of the strategic investment decisions of welfare-maximizing public and profit-maximizing private firms and shows that the equilibrium outcomes of the mixed market model differ from those of Fudenberg and Tirole's private mar-

[1] Bös [15,16], Vickers and Yarrow [17], Cremer, Marchand, and Thisse [18], and Nett [19] provide excellent surveys.

[2] In the tobacco industries of France, Italy, Russia, Spain, Austria, Turkey, China, Japan, *etc*., we can find real-world examples in which state-owned public firms compete or competed against foreign private firms such as Philip Morris and R. J. Reynolds.

ket model; that is, there are no early-stopping equilibria where neither firm invests to its steady-state reaction curve.

All these studies focus on capital as strategic investment. On the other hand, we focus on labor; that is, we use lifetime employment contracts as strategic investment.[3]

The purpose of this study is to construct a set of perfect equilibria of a continuous-time dynamic model in which a domestic welfare-maximizing public firm and a foreign profit-maximizing private firm compete for labor investment.

The remainder of this paper is organized as follows. In Section 2, the elements of the continuous-time model are formulated. Section 3 characterizes the equilibrium outcomes of the continuous-time model. Section 5 concludes the paper.

2. The Model

Let us consider an international mixed market with one domestic welfare-maximizing public firm (firm D) and one foreign profit-maximizing firm (firm F). In the remainder of this paper, when i and j are used to refer to firms in an expression, they should be understand to refer to D and F with $i \neq j$. Time t is continuous, and the horizon is infinite. At each time, it is possible that each firm employs employees and legally enters into a lifetime employment contract with all of the employees.[4]

Firm i 's net profit at time t is given by

$$\pi_i(l_i, l_j, a_i) = p(L)l_i - c_i l_i - a_i \tag{1}$$

where l_i is firm i 's current labor stock, namely the current number of employees in firm i, $p(L)$ is price as a function of labor stock $(L = l_D + l_F)$, c_i is firm i 's cost per employee, and a_i is firm i 's labor investment at time t. We assume that $c_D > c_F$.[5] We also assume that $p' < 0$ and $p'' < 0$. That is, this function is strictly concave. An increase in employment reduces the price through an increase in output.

Labor stocks cannot decrease, and each firm has a constant upper bound on the amount of its labor investment at every time t; that is, $a_i \in [0, \bar{a}_i]$. At time zero, each firm enters the market with $l_i(0) \geq 0$ and can start investing. At each time, each firm employs employees, legally enters into lifetime employment contracts with them, and expands its scale. Therefore, there is an upper bound in the number of employees whom each firm can employ newly at each time.

Domestic social welfare at time t, which is the sum of domestic consumer surplus at time t and firm D's net profit at time t, is given by

$$W(l_D, l_F, a_D) = \int_0^L p(x)dx - c_D l_D - a_D - p l_F \tag{2}$$

Each firm's net present value of profits is

$$\Pi_i = \int_0^\infty \pi_i(l_i(t), l_j(t), a_i(t))e^{-rt}dt \tag{3}$$

where r is the common discount rate. This is firm F's objective function.

Firm D maximizes the net present value of domestic social welfare, given by

$$V = \int_0^\infty W(l_D(t), l_F(t), a_D(t))e^{-rt}dt \tag{4}$$

Π_F is not included in V because firm F is a foreign competitor. Therefore, it is thought that firm D behaves more aggressively toward firm F.

If r is high, then future values have a lower weight compared to the situation with a lower r. If r tends to zero, then firm D maximizes time-average social welfare, and firm F maximizes its time-average profit. Since the arguments in favor of the equilibrium outcomes of the discounting case are the same as in the no-discounting case, we shall devote our attention to the case in which firms do not discount their objectives.

We examine the perfect equilibrium outcomes of a state-space game. The state-space game is a game in which both the payoffs and the strategies depend on the history only through the current state. The perfect equilibrium is a strategy combination that induces a Nash equilibrium for the subgame starting from every possible initial state in the state space.

Firm i 's steady-state reaction function $R_i(l_j)$ is defined as the locus of points which give the final optimal level of l_i for each final value of l_j.

The equilibrium occurs where each firm maximizes its objective with respect to its own labor level, given the labor level of its rival. Firm D's steady-state reaction function is derived as follows. Firm D aims to maximize social welfare with respect to l_D, given l_F. The equilibrium must satisfy the following conditions. The first-order condition for firm D is

$$p - c_D - p' l_F = 0, \tag{5}$$

and the second-order condition for firm D is

[3]For details see Ohnishi [37, 38].

[4]Spence [35] and Fudenberg and Tirole [36] focus on capital as strategic investment, while we focus on labor investment.

[5]The assumption concerning the inefficiency of public sectors is often used in literature studying mixed markets. See, for instance, George and La Manna [4], Mujumdar and Pal [7], Pal [8], Ohnishi [11], Cremer, Marchand, and Thisse [18], Nett [19], Matsumura [23], and Fernández-Ruiz [24]. If firm D is more efficient than firm F, then firm D will try to maximize social welfare by supplying monopolistically in the market. In this paper, this behavior of firm D brings the same result as the pure market model. This assumption is made to avoid such a trivial solution.

$$p' - p'' l_F < 0 . \quad (6)$$

Furthermore, we have

$$R_D'(l_F) = \frac{p'' l_F}{p' - p'' l_F} . \quad (7)$$

Since $p'' < 0$, $R_D(l_F)$ is upward sloping. This means that firm D responds to more aggressive play with more aggressive play.

Next, we derive firm F's steady-state reaction function. Firm F aims to maximize its profit with respect to l_F, given l_D. The equilibrium must satisfy the following conditions. The first-order condition for firm F is

$$p' l_F + p - c_F = 0 \quad (8)$$

and the second-order condition for firm F is

$$2p' + p'' l_F < 0 . \quad (9)$$

Furthermore, we have

$$R_F'(l_D) = -\frac{p' + p'' l_F}{2p' + p'' l_F} . \quad (10)$$

Since $p' < 0$ and $p'' < 0$, $R_F(l_D)$ is downward sloping. This means that firm F's optimal response to more aggressive play by firm D is to be less aggressive. We assume that $R_D(l_F)$ and $R_F(l_D)$ have a unique intersection which will be the Nash equilibrium of the state-space game.

3. Equilibrium Outcomes

In this section, we analyze the perfect equilibrium outcomes of the continuous-time model. First, we consider the case shown in **Figure 1**, where R_i represents firm i's steady-state reaction curve. The figures in this paper are drawn with straight lines for simplicity. Spence [35] and Fudenberg and Tirole [36] define the industrial growth path (IGP) as a locus on which each firm invests as quickly as possible. Firms are willing to invest as quickly as possible if there are only profit-maximizing firms in a market and the reaction curves are downward sloping. However, in this paper, we examine the case of a mixed market. As understood from this figure, social welfare increases as firm F increases its investment. Firm D hopes that firm F will invest more. Hence, firm D does not have the incentive to invest as early as firm F does. Therefore, we will not introduce the IGP.

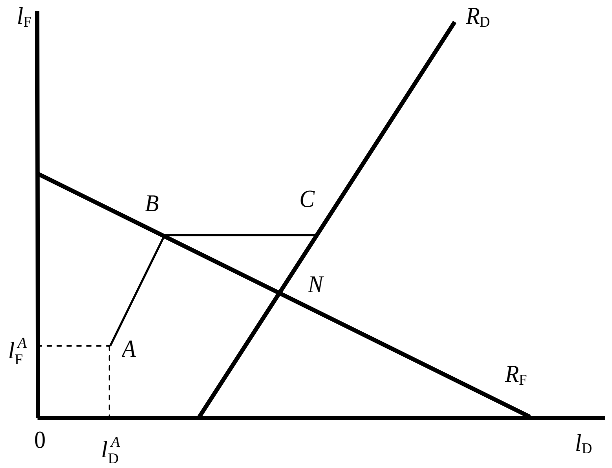

Figure 1. This investment path is *ABC*.

We discuss each firm's actual investment paths by using **Figure 1**. Let A be each firm's initial labor stock. That is, each firm has an exogenously given labor stock, $l_i(0) > 0$. Each firm can start investing at time zero. Each firm can employ new employees, given the constraints. Social welfare increases as firm F increases its investment, and therefore firm D hopes that firm F will invest more. Firm D will not have an incentive to invest as early as firm F does. Each firm continues to invest, given the constraints. If firm F continue to invest, then the industry continues to grow along AB, and each firm will stop investing at a point where it find optimal.

The industry continues to grow along AB, and reaches B on R_F. At B, if firm F continues to invest further, then its profit decreases. Hence, firm F invests up to B and then stops. However, social welfare increases if firm D invests whether firm F invests or not. Therefore, firm D continues to invest, given the constraints. If firm D continue to invest, then the industry continues to grow along BC, and firm D will stop investing at a point where it find optimal. The industry continues to grow along BC, and reaches C on R_D. If firm D continues to invest further, then social welfare decreases. Hence, firm D invests up to C and then stops. Neither firm will have an incentive to invest at C. This investment path becomes ABC in the figure.

Firm F's profit decreases as the industry grows along BC. Therefore, firm F may try to stop firm D's investment before the investment path reaches C. Even though firm F invests further, the best firm D can do is to invest to R_D. Since this profit of firm F is lower than its profit at C, this behavior of firm F is not a credible threat.

Second, we consider the case shown in **Figure 2**. Firm D has an exogenously given labor stock, $l_D(0) > 0$, while firm F has no labor, $l_F(0) = 0$. In this case, firm D's initial labor stock level is equal to or larger than firm D's labor stock level associated with the intersection N of both reaction curves. Since labor stocks cannot decrease, the equilibrium will never occur at any point to the left of N. Firm F can increase its own profit and social welfare by investing, and therefore it will invest. Firm D hopes that firm F will invest more. On the other hand, since firm D decreases social welfare by investing, the best it can do is not to invest. Therefore, firm F unilaterally continues to invest, given the constraints. The industry continues to grow along AE and reaches E on R_{F}. At E, if firm F continues to invest further, then its profit decreases. Hence, firm F invests up to E and then stops. Neither firm will have an incentive to invest at E. This investment path is AE.

Social welfare increases as firm F increases its investment, and thus an incentive by which firm F's investment is stopped before the investment path reaches E does not happen to firm D.

Third, we consider the case depicted in **Figure 3**. In this case, each firm has an exogenously given labor stock, $l_i(0) > 0$. Each firm can start investing at time zero. Since firm D can increases social welfare by investing, the best it can do is to invest. On the other hand, firm D decrease its own profit by investing, and therefore it will not invest. Firm D unilaterally continues to invest, given the constraints. The industry continues to grow along AG and reaches G on R_{D}. At G, if firm D continues to invest further, then social welfare decreases. Hence, firm D invests up to G and then stops. Since firm F decreases its own profit by investing, the best it can do is not to invest. Neither firm will have an incentive to invest at E. This investment path is AG.

From above discussions, we can see that there are no early-stopping equilibria in the international mixed market model. The main result of this study is described by the following proposition.

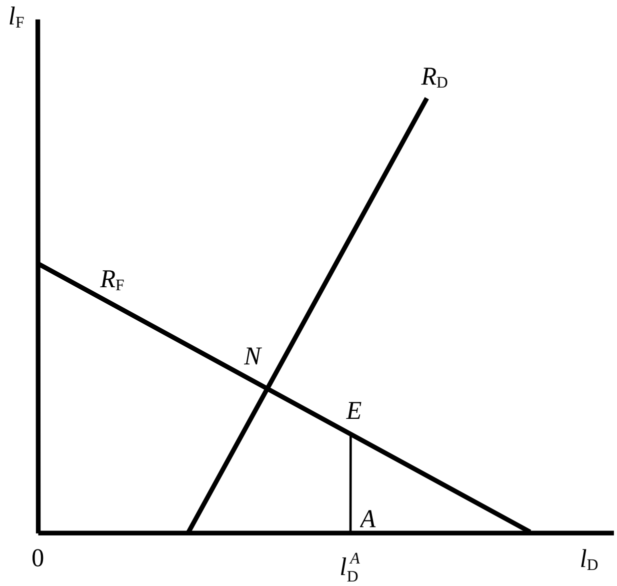

Figure 2. Firm D unilaterally continues investing from *A* to *E*.

Proposition 1. Call T –for terminal surface–the line formed by the intersection of the reaction curves, R_{D} to the northeast of the intersection of the reaction curves, and R_{F} to the southeast of the intersection of the reaction curves. T is depicted in **Figure 4**. One can construct perfect equilibrium strategies such that the equilibrium path stops on T.

Proof. We divide the state space into three regions as depicted in **Figure 4**: Region I is the set below R_{F}; Region II is the set not below R_{F} and above R_{D}; and Region III is the set not below R_{F} and not above R_{D}.

First, we show each firm's strategy in Region I. Since $\pi_{\mathrm{F}}(l_{\mathrm{D}}, l_{\mathrm{F}}, a_{\mathrm{F}})$ is assumed to be concave in l_{F}, firm F

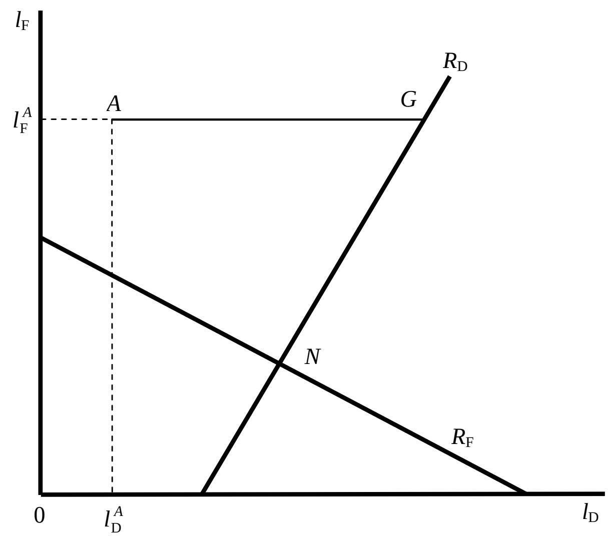

Figure 3. Firm F unilaterally continues investing from *A* to *G*.

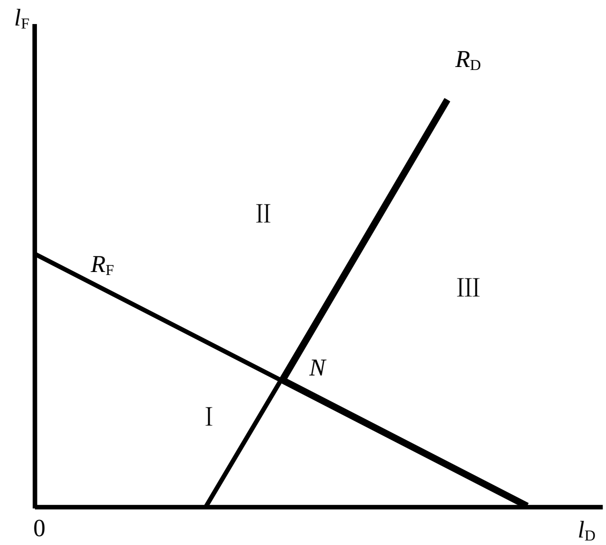

Figure 4. *T* is the bold line.

wishes to be as close to its reaction curve as possible. Therefore, the best firm F can do is to invest whether firm D invests or not. Both social welfare and firm F's profit increase as firm F increases its investment. Therefore, firm F continues to invest, and firm D does not have an incentive to stop firm F from investing. In Region I, since at least firm F continues to invest, the state will reach from Region I to either Region II or Region III.

Second, we show each firm's strategy in Region II. Since $\pi_F(l_D, l_F, a_F)$ is assumed to be concave in l_F, firm F wishes to be as close to its reaction curve as possible. Firm F's profit decreases if firm F invests whether firm D invests or not. Hence, firm F, which maximizes its own profit, never invests in this region. Firm D wishes to be as close to its reaction curve as possible. Therefore, the best firm D can do is to invest. Firm D will invest up to a point on its reaction curve. In Region II, since firm D unilaterally continues to invest, the state will reach from Region II to Region III.

Third, we show each firm's strategy in Region III. Each firm wishes to be as close to its own reaction curve as possible. If only firm F or both firms continue to invest, then firm F's profit will decrease. Hence, firm F does not invest. If only firm D continues to invest, then social welfare will decrease, and therefore firm D does not invest either. Each firm's best response to the other firm's strategy at any point of this region is not to invest. Consequently, each firm's optimization problem at any point in this region, given the other firm's strategy, induces a Nash strategy at any point of this region. Thus, the strategies are in perfect equilibrium, and the result follows. Q.E.D.

4. Conclusions

We have examined continuous-time dynamic competition of labor investment decisions of a domestic welfare-maximizing public firm and a foreign profit-maximizing private firm. Fudenberg and Tirole [36] examine continuous-time dynamic competition of capital investment decisions of private firms and show that there are early-stopping equilibria in which neither firm invests up to its steady-state reaction curve. On the other hand, we have demonstrated that there are no equilibria in which neither firm invests up to its steady-state reaction curve. There are many studies dealing with mixed markets that incorporate welfare-maximizing public firms. We will pursue further research on these studies in the future.

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An Exploration of the R & D Value beyond the Generally Accepted Accouting Principles

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Abstract

This paper utilized the real R & D option theory especial the Bellalah [1] information cost model as the discussion base for the exploration of R & D value. We extended Bellalah's model as to add the factors of Poisson event and exponential decay to approximate the reality; we calculated the derivative value of R & D investment and relaxed the Generally Accepted Accounting Principles (GAAP) as to deem the accumulated R & D investment the capital owned by a firm and to evaluate it as well. The empirical results enlightened us: our modified model meet with reality better than the original model; the derivative R & D value have explanatory power to the equity behavior especial the risk magnitude proxied by β and lastly, to entirely expense the R & D investment could be problematic since R & D investment own the property of capital.

Keywords: Real R & D Option, Poisson Event, Exponential Decay, GAAP

1. Introduction

Merton asserted the importance of information cost and documented that an investor shall demand higher stock return if higher information cost is expensed [2]. Following the context of Merton, Bellalah [1,3] incorporated the information cost factor in valuing both options and R & D. However, in Bellalah's setting only the factors influencing R & D's market value were considered. The truth is that R & D value will depreciate while time elapses; its value could also be vanished overnight because of any unexpected evolution. These facts imply some other exogenous factors which influence the R & D's payoff deserve to be comprehended. This study attempts to modify Bellalah's ROM as to incorporate factors like exponential decay (θ) and Poisson event (ξ) into consideration.

There are three types of information cost defined including the average cost prevailed in market (λ_M), the cost affiliated with R & D options (λ_F) and the cost affiliated with R&D yield's price (λ_P). The disposal in Bellalah [1,3] may have caused two issues: first, the individual effect of information costs was unknown and, secondly, the reason of why the λ_M, λ_F and λ_P were set to be 4% for example was unknown. For the level of information cost, Bellalah stressed the hardness in defining it and proposed an alternative as to find proxies from derivates markets; though this idea was not taken eventually. We are going to observe the individual effect of information costs; we are also going to actualize Bellalah's proposal to see what the real level of information cost could be.

2. Re-Modeling

The factors of exponential decay θ and Poisson event ξ are going to be considered. μ means the required rate of return which is the sum of expected capital gain α and dividend δ. While exponential decay and Poisson event are jointly considered, the project value can be:

$$\begin{aligned} V(P) &= \int_0^\infty \theta e^{-\theta T} P(1-e^{-(\delta+\xi\varphi)T})/(\delta+\xi\varphi)dT \\ &= \theta P/(\delta+\xi\varphi)\left[\int_0^\infty e^{-\theta T}dT - \int_0^\infty e^{-(\delta+\theta+\xi\varphi)T}dT\right] \\ &= P/(\delta+\theta+\xi\varphi) \end{aligned} \quad (1)$$

Through (1), a spiky event like θ and ξ can be smoothened as an additional discount factor in the denominator.

According to ROM, an R & D project value V can be seen as a combination of investment I and option value F

therefore $V(P) = I + F(P)$. We may utilize a portfolio $\Phi = F(P) - nP$ as to long one unit of option and to short n units output with price P and let its payoff be:

$$r\left[F - nP\right]dt = dF - ndP - n\delta Pdt \quad (2)$$

From (2) we can derive a corresponding Bellman equation:

$$(1/2)\sigma^2 P^2 F_{PP} + (r-\delta)PF_P - rF = 0 \quad (3)$$

In (3), we set $n = F^{'}(P)$ to eliminate the disturbance term dz. (3) is a Partial Differential Equation (PDE) and we can solve F by either analytical, if it has a close form solution, or numerical way. When the exponential decay, Poisson event and information cost are jointly considered, the Bellman equation becomes:

$$\begin{aligned}&(1/2)F_{PP}\sigma^2 P^2 + (r-\delta+\lambda_P)F_P P - \\ &(r+\xi+\lambda_F)F + \xi F((1-\varphi)P) = 0\end{aligned} \quad (4)$$

F solved from (4) is the value of a simple option and we denote it F_1 in latter expressions.

We further consider a complex situation as to let the option compound with succeeding replacement options. P^* means a threshold which is optimal to exercise the R & D project. When $P < P^*$, the value of the compound option over next interval is:

$$\begin{aligned}F = &Pdt + (1-\theta dt)e^{-(r+\lambda_F)dt}E\left[F(P+dP)\right] + \\ &\theta dte^{-(r+\lambda_{F'})dt}E\left[F'(P+dP)\right]\end{aligned} \quad (5)$$

This means an installed investment could either survive with probability $(1-\theta dt)$ or die with probability θdt in next short interval. when $P < P^*$, (5) can be expanded as:

$$\begin{aligned}F = &Pdt + (1-\theta dt)(1-(r+\lambda_F)dt) \\ &\left[F + F_P(\alpha+\lambda_P)Pdt + (1/2)F_{PP}\sigma^2P^2dt - \right. \\ &\left.\xi Fdt + \xi F((1-\varphi)P)dt\right] + \theta dt(1-(r+\lambda_{F'})dt) \\ &\left[F' + F'_P(\alpha+\lambda_P)dt + (1/2)F'_{PP}\sigma^2P^2dt - \right. \\ &\left.\xi F'dt + \xi F'((1-\varphi)P)dt\right]\end{aligned}$$

when $P > P^*$, (5) can be expanded as:

$$\begin{aligned}F &= Pdt + (1-\theta dt)e^{-(r+\lambda F)dt}E\left[F(P+dP)\right] + \\ &\quad \theta dte^{-(r+\lambda F)dt}E\left[F(P+dP) - I\right] \\ &= Pdt + (1-\theta dt)(1-(r+\lambda_F)dt) \\ &\quad \left[F + F_P(\alpha+\lambda_P)Pdt + (1/2)F_{PP}\sigma^2P^2dt - \right. \\ &\quad \left.\xi Fdt + \xi F((1-\varphi)P)dt\right] + \theta dt(1-(r+\lambda_F)dt) \\ &\quad \left[F + F_P(\alpha+\lambda_P)dt + (1/2)F_{PP}\sigma^2P^2dt - \right. \\ &\quad \left.\xi Fdt + \xi F((1-\varphi)P)dt - I\right]\end{aligned}$$

The respective Bellman equation becomes:

$$\begin{aligned}&(1/2)F_{PP}\sigma^2P^2 + (r-\delta+\lambda_P)F_P P - \\ &(\theta+r+\lambda_F+\xi)F + \theta F' + P = 0\end{aligned} \quad (6)$$

$$\begin{aligned}&(1/2)F_{PP}\sigma^2P^2 + (r-\delta+\lambda_P)F_P P - \\ &(r+\lambda_F+\xi)F - \theta I + P = 0\end{aligned} \quad (7)$$

Be noted that (6) and (7) will meet tangentially on P^*. F solved from (6) and (7) is the value of a compound option and we denote it F_2 in latter expressions.

3. Simulations

To illustrate the F_1 and F_2, we shall exploit an industrial case as the background to keep the simulations 'virtual'. The 'Local Area Network' (LAN) industry in Taiwan was selected due to its high R & D orientation. The LAN industry in Taiwan is eye-catching referring to its annual global share 76.5%, 53%, 90.9% and 84% on NIC, Hub / Switch, SOHO router and WLAN (wireless LAN). We focused on the listed LAN companies and collect their financial and stock parameters from both Taiwan Economic Journal (TEJ) and the website of Taiwan Stock Exchange Corporation (TSEC). Sample period is from January 1st, 1999 to March 31st, 2006.

We set the parameters σ, r, δ to equal the practical level and let ξ, λ_F and λ_P innovate in following simulations.

Figures 1 and **2** demonstrate the F_1 and F_2 value plane under influence of λ_F and ξ. **Figures 3** and **4** demonstrate an additional influence caused by λ_P. In **Figure 1**, the back (right) plane exhibits F_1 which moves with information cost λ_F while keeping ξ fixed; the front (left) plane exhibits F_1 which moves with information cost λ_F and Poisson event ξ simultaneously. As shown, the plane will mainly incline toward ξ axis if

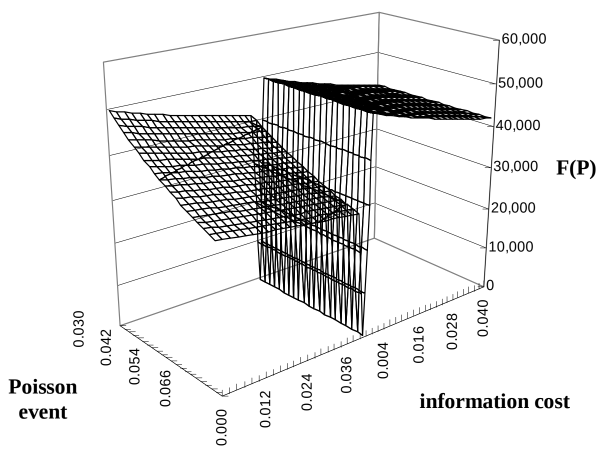

Figure 1. Value plane of F_1.

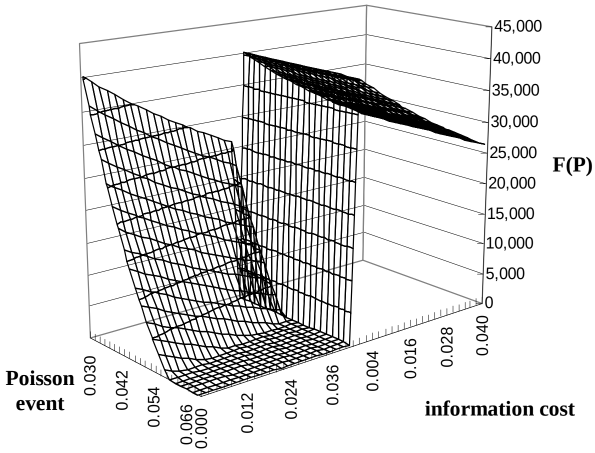

Figure 2. Value plane of F_2.

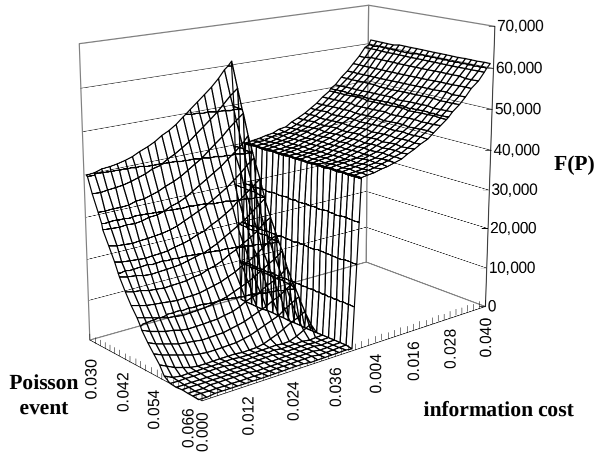

Figure 4. Value plane of F_2 (λ_P moves from 0 to 4%).

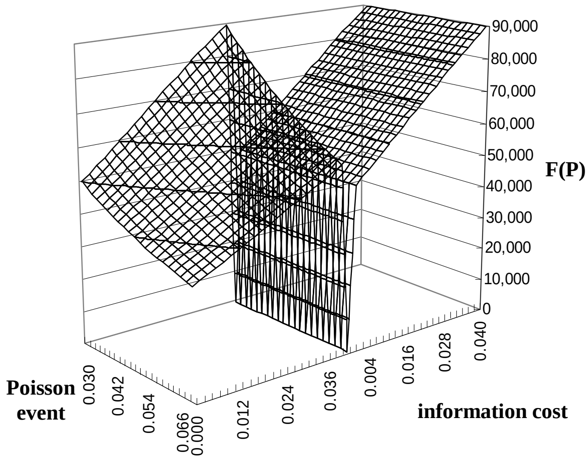

Figure 3. Value plane of F_1 (λ_P moves from 0 to 4%).

ξ is considered. This expounds that ξ is a more influential factor; the scenario of **Figure 2** is similar also. In **Figures 3** and **4**, we let the λ_P innovate with λ_F, which makes the plane toward information cost axis becoming a positive slope. The result implies that the appreciation of λ_P will raise the option value and partly cancel the influence of λ_F. The value depreciation caused by ξ can somehow be alleviated by the raise of λ_P but not much; ξ is still the major strength to domain the plane. Situations are similar if let the θ join except the influence of θ is minor than ξ. The simulations elucidate two things: first, the incorporation of exogenous factors which influence to R & D's payoff should be important since the new factors outweighs the information cost and, secondly, spending λ_P will improve the stochastic control on price thus a positive relationship with option value was observed.

4. An Exploration to the Level of Information Cost

Bellalah stressed that the magnitude of information cost is hard to define and proposed an alternative as to collect proxies from derivates markets [3]. We are going to actualize Bellalah's idea to find these proxies. The plausibility of proxies will be tested by the regression analysis:

$$\beta_{it} = \alpha_0 + \alpha_1 Finan_{it} + \alpha_2 DE_{it} + \alpha_3 LQ_{it} + \alpha_4 ROE_{it} + \sum_{k=1} \alpha_{5k} (V_j / S)_{i,t-k} + u_{it} \quad (8)$$

i denotes the sample companies, $j = 1, 2$, $V_j = I + F_j$, t denotes time. β means the beta coefficient belonging to CAPMi which represents the risk level. Since the higher R&D investment will incur a higher company's risk [4,5], we take β as a dependent variable to be regressed and a positive coefficient of V_j / S is expected. The financial leverage (Finan), debt-equity ratio (DE), liquidity (LQ) and profitability (ROE) are comprehended as control variables. We let V be divided by contemporaneous sales to eliminate the idiosyncratic scale effect. (8) implies that β is a function of multi-period R&D value. Be noted the multicollinearity could happen on V_j / S therefore a polynomial distributed lags (PDL) technique is exploited.[1]

---

[1]We set $\alpha_{5,k} = h_0 + h_1 k + h_2 k^2 + h_3 k^3$, $\sum_{k=0} \alpha_{5,k} (I)_{i,t-k} = \sum_{k=0} (h_0 + h_1 k + h_2 k^2 + h_3 k^3) \cdot (I)_{i,t-k} = h_0 W_{0t} + h_1 W_{1t} + h_2 W_{2t} + h_3 W_{3t}$, $W_{0t} = \sum_{k=0} (I)_{i,t-k}$, $W_{1t} = \sum_{k=0} k (I)_{i,t-k}$, $W_{2t} = \sum_{k=0} k^2 (I)_{i,t-k}$, and $W_{3t} = \sum_{k=0} k^3 (I)_{i,t-k}$. The degree is set to be three since the significance level of h remarkably descends from degree of four.

Before collecting the proxies of information costs, we need to clarify two issues including what the adequate proxy should be and how the proxy can be collected. For the first issue, we followed Amihud and Mendelson [6] who asserted that the bid-ask spread an adequate proxy of information cost; for the second issue, we followed the Chicago Board Options Exchange (CBOE) disciplines in estimating the volatility index (VIX).[2] λ_M, λ_F and λ_P can be estimated by Taiwan weighted stock index (TAIEX), stock options and common stocks. Anyway, we utilized the data from Taiwan stock index options (TXO) for λ_M and Taiwan electronics options (TEO) for λ_F since there's no TAIEX transactions and no individual stock options offered by sample companies. The proxies collected from markets are deemed the real level of information cost.

Table 1 shows the situation while $\lambda_M = \lambda_F = \lambda_P = 0$. On **Table 2** we start to consider the non-zero situation and let the cost be either Bellalah's [3] or real level. The AdjR^2 slightly changed between **Tables 1** and **2** while letting the cost be the Bellalah's level. The change becomes remarkable if let the cost be the "real". Be noticed that the averaged λ_M, λ_F and λ_P are 2.14%, 23.24% and 0.23%; which is much different with Bellalah's setting.

5. Conclusions

The Bellalah's [1,3] model can though depict the change of R & D's market value due to the spillover effect of information collecting, it cannot figure the change of R & D's payoff due to the competitor's activity. This makes Bellalah's model deviating to the reality. We made extension to Bellalah's models as to incorporate exogenous factors including exponential decay θ and Poisson event ξ for compensation on aforesaid deficiency.

The influence of information cost onto R & D value is roughly half to exponential decay θ and one third to Poisson event ξ, which tells the new added factors outweighs the information cost as well as support our modeling extension. Bellalah [1,3] did not observe the information cost individually but a lump-sum effect instead; we made an individual survey and found that the information cost affiliated with price λ_P moves conversely from the others. This finding implies that the cost in pursuing a more adequate price will boost the R & D value, *vice versa*.

Bellalah [3] commented that the information cost is hard to define and, therefore, suggested to find proxies from the derivates markets. However, such an idea was not taken eventually but only artificial numbers instead in Bellalah's simulations. We actualized Bellalah's idea and propose a working frame as to exploit the ways of

Table 1. The explanatory power of different R & D value approaches.

Dependent Var.: CAPMi's β							
	C	Finan	DE	LQ	ROE	$V_j/S(\sum_{k=1}^{52}\alpha_{5k})$	AdjR^2
V_1/S	–1.317 (–12.340)***	1.941 (21.332)***	–0.356 (-8.890)***	0.000 (2.620)***	1.323 (4.772)***	(13.179)***	0.612
V_2/S	–0.123 (–10.196)***	1.962 (19.368)***	–0.438 (–10.504)***	0.000 (2.038)***	1.277 (4.329)***	(9.253)***	0.551

$p < 0.1$*, $p < 0.05$**, $p < 0.01$***

Table 2. The explanatory power influenced by information cost.

	$\lambda_M = \lambda_F = \lambda_P = 5\%$		real λ_M, λ_F and λ_P	
	$\sum_{k=1}^{52}\alpha_{5k}$	AdjR^2	$\sum_{k=1}^{52}\alpha_{5k}$	AdjR^2
V_1/S	(13.547)***	0.618	(7.798)***	0.859
V_2/S	(8.782)***	0.545	(7.571)***	0.859

$p < 0.1$*, $p < 0.05$**, $p < 0.01$***

[2]CBOE demands the contract series of "near-the-money", "nearby" and "second-nearby" being applied for VIX estimation. For the contracts with days less than six to the expiration, CBOE demands the contract series of second-nearby and third-nearby being applied to avoid the possible fluctuation on price [7].

volatility indices estimation. The average level of the proxies of λ_M, λ_F and λ_P are 2.14%, 23.24% and 0.23%. The new level is much different than the conventional knowledge and seems more plausible since it brings better predictability on β, this helps investors being more prudent because he knows better the risk level what have borne by portfolio.

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