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Transportation model and value creation: A multicriteria decision analysis approach

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Glossary

ABC Activity Based Cost. 49

AHP Analytic Hierarchy Process. 25, 44, 45, 49

BEPS Base Erosion and Profit Shifting. 20

CER Corporate Environmental Responsibility. 49

CGP Chebyshev Goal Programming. 15

CLSC Closed Loop Supply Chain. 22, 49

CTR Corporate Tax Rate. 28, 29, 46

DM Decision Maker. 11, 15, 19, 21, 23, 27, 28, 33, 36, 39, 41, 43–45, 49

EBIT Earnings Before Interest and Taxes. 36

ERP Enterprise Resource Planning. 32

FCMU Full Cost Mark-up. 37, 42

FGP Fuzzy Goal Programming. 22

GNIC Gross National Income per Capita. 28, 29, 36

GP Goal Programming. 11, 12, 15, 16, 19–22, 24–26, 28, 35, 38, 48

GSCM Green Supply Chain Management. 12, 15, 49, 50

LGP Lexicographic Goal Programming. 15, 16, 22, 25

LP Linear Programming. 15

MCDA Multi Criteria Decision Analysis. 12, 13, 15, 24

MCP Multi Criteria Problem. 13

MNE Multinational Entity. 11, 19, 20

MOP Multiple Objective Programming. 13

OECD Organisation for Economic Co-operation Development. 27, 29

OLSC Open Loop Supply Chain. 49

PLI Profit Level Indicator. 33, 37–39, 42, 46, 48

ROA Return on Asset. 37

ROI Return on Investment. 37

ROS Return On Sales. 33, 37, 42

SCM Supply Chain Management. 12

TNMM Transactional Net Margin Method. 37

TP Transfer Pricing. 27, 37, 48

WFGP Weighted Fuzzy Goal Programming. 49

WGP Weighted Goal Programming. 15, 16, 22, 24

Introduction

"There are two ways of constructing a software design;
One way is to make it so simple that there are obviously no deficiencies.
And the other way is to make it so complicated that there are no obvious deficiencies.
The first method is far more difficult."
Sir Charles Antony Richard Hoare

Value and MNE were probably the pairs of elements that characterized the way business was done in the last centuries, and still, nowadays they are something that cannot be left aside when we talk about the business environment. However, the symbiosis behind the two is something that goes back to the begin of time, humanity and especially proto-capitalistic societies were always interested in creating the greatest value as possible but at the same time cutting any possible cost in order to gain extra profits out of this difference.
Because of this interest, different disciplines were created; ranging from management to accounting and from supply chain to logistics (which has its roots in the military planning field). In this dissertation, the scope will be to apply a multi-objective approach, namely the GP in order to prove the effectiveness of such method and its different flavors in the hand of the DM. The two models presented deal with the transportation of some particular element of the firm in order to create additional value for it. A firm and especially a MNE may be seen as a network of enterprises intertwined between each other in order to exploit the synergies provided by such union, if the framework of logistics it's used is possible to discern

the flow between two or more of such firms in three different aspects, namely:

- Goods: this flow is the most tangible one and may involve the movement of products from the rearline (production plan) to the frontline (retail stores);
- Information: this flow consists of all the information necessary for the network to work, a good example may be the information of the demand that has to move back to the production plan in order to be fulfilled;
- Finance: usually the finance flow is, among the information flow the one that permits the day to day operations of the network entities and supports the goods flow; this role is usually undertaken by the headquarter or in more complex groups to ad-hoc financial institutions inside the multinational company.

The following dissertation will be organized into four main blocks: where the first block, the introductory one, is devoted in giving an overview of the notions that will be used to model the two different problems proposed in the next chapters and specifically the focus will be about the MCDA and the general formulation of a GP model in its three main forms, namely the lexicographic form, the weighted form and the Minmax form. In Chapter 1 the model will be a transportation model used to allocate in an efficient way different economic components of the firm in order to achieve different types of goals such as overall tax liability minimization, taking into account the regulatory requirements imposed by the international tax principles (more specifically the regulation on transfer pricing). The problem in Chapter 2 will be more operation oriented and will be about SCM, and in particular GSCM. The aim of such model will be to fullfill the demand and at the same time comply with the different regulatory legislation in terms of recycling electronical waste. Ultimately a general conclusion will be given highlighting the pros and cons of using such approach in modeling different types of transportation problems.

Multiple Criteria Decision Analysis

Even if the practice of decision-making is old as man, academics tend to date the roots of modern MCDA in the early 60s, where the focus at the time was to find the most preferred solution, or generating an approximation to the entire efficient frontier[GEF16].
MCDA may be defined as a problem of MOP, that differs from a linear one, since more objective function are handled; its formulation is the following:

$$Min[f_1(x), f_2(x), ..., f_k(x)] \quad i = 1, ..., k \quad where \quad k \geq 2$$

This approach seems to fit better the real world since, in reality, more than one objective is pursued, and most of the time in contrast with one another. A solution to a MCP would be optimal if it'd respected the Pareto Efficient assumption, namely that no other feasible solution exists that is at least as good with respect to all objectives and strictly better with respect to at least one objective. Mathematically it means that $\{x_1, ...x_k\}$ is a solution if $\nexists \left\{x'_1, ...x'_k\right\}$ such that:

$$g(f_1(x), f_2(x), ..., f_k(x)) \leq g(f_1(x'), f_2(x'), ..., f_k(x')) \quad \forall n \quad \in \{1...k\}$$

However such increase in complexity given by multiple objectives is both the strength and the weakness of such methodology, this is due to the fact that we have to deal with N trade-offs deriving from the objectives we decided to include in our optimization problem. Because of this problem a lot of approaches and specific intelligent algorithms were proposed[Cui+17].

Focusing the attention on the approaches suggested, four main categories emerge, namely:

- A Priori methods: such methods are characterized by prior definition of the preference information, this category includes methods such as Weighted Sum Method, Constraints Method, Objective Programming Method, Dictionary Ordering Method and Analytic Ordering Method;
- Interactive methods: in this particular category the process is iterative, meaning that the Decision Maker interacts with the preference information he gave in search of the optimal solution, from this category belong two types of methods namely the Normal Boundary Intersection and the Normalized Normal Constraint;
- Pareto-dominated methods: these methods divides the optimal solution seeking in two parts, at first they try to compose the efficient frontier of a given multi-criteria problem, then they try to find the Pareto Dominant[1] solution;
- New Dominance methods: this methods may be considered as an extension of the Pareto-dominated methods, in that they try to build the efficient frontier, then they try to eliminate the Pareto-dominated solutions however they

[1]Given a vector of outcomes $\vec{S}$ that we identified as the Efficient Frontier $\vec{S}[s_{1 \dots n}]$ a solution $s^{\star}$ of such vector is Pareto Dominant if $\nexists$ a s_q that is Pareto superior to $s^{\star}$.

tend to use fuzzy methods and other solutions to avoid the computational drawback of the former one.

From the set of the A Priori methods belongs the GP (which develops from the concept of LP) and will be used to model the problems of entities allocation and GSCM proposed on the next chapters.

GP is a MCDA approach which allows the DM to consider simultaneously several conflicting objectives.

The idea behind such method is very simple, and is based on distance minimization; this means that at each objective function is associated a deviation variable that has to be minimized in batch with the other deviation variables coming from the other objective functions.

Such models may be represented algebraically as follows:

$$\begin{aligned} \underset{n,p}{\text{minimize}} \quad & a = h(n,p) \\ \text{subject to} \quad & f_q(x) + n_q - p_q = b_q \\ & x \in F \\ & n_q, p_q \geq 0 \end{aligned}$$

GP is vastly applied in many sciences[TJR98]. Its origins are dated back to the 50s, firstly introduced by Abraham Charnes and William Cooper[CCF55] with an article on the optimal estimation of executive compensation.

In such approach, three main different categories have been identified, namely the LGP, the WGP and the CGP.

The LGP, also named "preemptive" GP, distinguish itself from the other GP techniques as it has a number of priority levels chosen a priori. The mathematical formulation is the following one:

$$\begin{aligned}
\text{Lex}\ \underset{n,p}{\text{minimize}} \quad & [h_1(n,p),...,h_L(n,p)] \\
\text{subject to} \quad & f_q(x)+n_q-p_q=b_q,\ q=1,...Q \\
& x \in F \\
& n_q, p_q \geq 0,\ q=1,...,Q
\end{aligned}$$

As opposed to LGP, the WGP allows for direct trade-offs between all unwanted deviational variables by using weights. As a result,

is more flexible but as counter-effect it requires more computational power. The mathematical formulation is the following one:

$$\begin{aligned}
\underset{n,p}{\text{minimize}} \quad & \sum_{q=1}^{Q}\left(\frac{u_q n_q}{k_q}+\frac{v_q n_q}{k_q}\right) \\
\text{subject to} \quad & f_q(x)+n_q-p_q=b_q,\ q=1,...Q \\
& x \in F \\
& n_q, p_q \geq 0,\ q=1,...,Q
\end{aligned}$$

The last GP variant, presented by Flavell[Fla76]. It differs from the first two variants since it uses the underlying L_∞ means of measuring distance. Also, called Minmax GP it seeks to minimize the maximal deviation from any goal. Therefore, the primary goal of such approach is the balance. The mathematical formulation is the following one:

$$
\begin{aligned}
\underset{\lambda}{\text{minimize}} \quad & \lambda \\
\text{subject to} \quad & \frac{u_q n_q}{k_q} + \frac{v_q n_q}{k_q} \leq \lambda, \; q = 1, ...Q \\
& f_q(x) + n_q - p_q = b_q, \; q = 1, ...Q \\
& x \in F \\
& n_q, p_q \geq 0, \; q = 1, ..., Q
\end{aligned}
$$

Chapter 1

Tax planning and Base Erosion and Profit Shifting: a transportation model for optimal profit allocation

This chapter deals with the problem of MNE allocation based on three main factors, namely the costs, the tax pressure and the functional characterization of a certain entity. The solution suggested is a GP model that embeds these limitations imposed by the environment and tries to find an optimal solution that permits the DM to be competitive *vis-Ã -vis* multinational competitors. The results obtained from such model are many times different from the ones putted into places by multinationals, which tend to focus on minimizing only the tax base without taking into account other information that may result in significant value added from a tax planning perspective.

1.1 Scope of work

After the Great Recession, multinational companies found themselves in a very different environment; thriving to survive with competition on one side and higher restriction imposed by countries running financial crises. This led multinationals with a great challenge which consequently boost cost engineering, in an attempt to

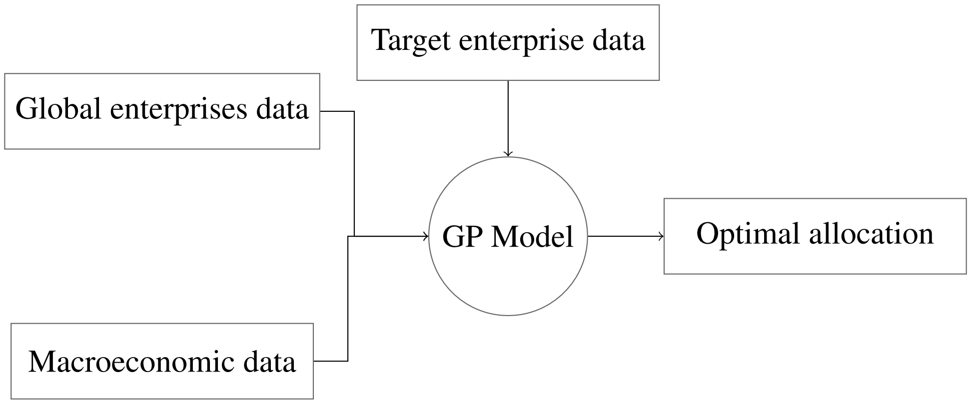

Figure 1.1: Model flowchart

survive in this new scenario. Another result was a new form of tax planning, most of the time barely legal in order to exploit the fiscal advantages of certain countries[OEC13]. Such problems forced the G20 to launch an inclusive framework called BEPS, bringing together about 100 countries in order to stop such unlawful tax planning. However, even if this action against such problem highlighted in a more specific way what should be considered as aggressive tax planning the border with legitimate cost engineering seems blurrier than ever[FS17].

In this chapter, is proposed GP model, Figure1.1, that given a set of criteria based on the accounting information of a specific MNE, it tries to perform the best allocation of its entities. The model will use both internal and external data and will follow three main objectives, namely minimize the costs, minimize the tax base and at the same time be compliant with the functional characterization of each and every entity constituting the multinational group. In other words the last objective impose that the multinational entity profitability has to be in line with independent actor in the market[OEC15] and should not be in any case a mere result of aggressive tax planning.

The following chapter is organized in four sections, apart from the first one which focuses on giving a brief introduction to the topic that is going to be addressed and modelled; the last chapters will be stand-alone sections developing specific parts of the process of model formulation and analysis. Specifically at section two a state-of-the-art review will be given, in order to give a pragmatic point of view of the new developments in the field. The state-of-the-art review will take into account three main area of application, and then the focus will be oriented to the cross field of accounting, which is the one where the model belongs.

Concluded this overview the formulation of the model will start from the data gathering process, the data will be categorized in three different typologies as highlighted by the flowchart in figure 1.1. After the process of data gathering, the full model will be formulated in a GP fashion defining, objectives, soft constraints and hard constraints.

Ultimately the model will be solved using the LINGO software package. The weights used will be subjected to a sensitivity analysis through different scenarios. Then, a set of weights will be chosen to take into account the DM preferences and the results will be discussed, in doing so some limitations of the model will be stated and further analyzed.

1.2 A state-of-the-art review: Goal Programming

The GP is probably one of the most used tool by academics and practitioners in solving multi criteria optimization problems, even though such preferences do not follow a linear path[Rom14][Sch95]. The main field of research and application of the GP are undoubtedly three, namely engineering, social sciences and management[CJM17], with the former one leading for the number of its applications. Especially in engineering the GP techniques used the most are the ones involving hybrid techniques (combining multiple different gp approaches) and FGP. The models proposed tackle macro-areas such as supply chain and logistics management, with problems involving CLSC, dealing with the treatment and recycling activities[ZSD11].
Quite the opposite occur in the applications of social sciences field, where, in the majority of the case to the field of economics. The last research in which is reported the use of GP was inherent the sub field of macroeconomics, analyzing the nature of the inter generational equity and sustainable development in order to understand how the players involved can achieve their aim of maximizing social welfare in the short run without compromising the future possibilities. In the case of social science the most used approaches are the plain vanilla ones of GP, ranging from LGP to WGP.
Lastly the management field which accounts for a great number of applications, especially in the field of strategic management, portfolio selection and marketing where there is a great diversity between techniques that ranges from fuzzy sets[Tre+14] to WGP and hybrid approaches.
All the three fields proposed when applied in modeling corporation have a com-

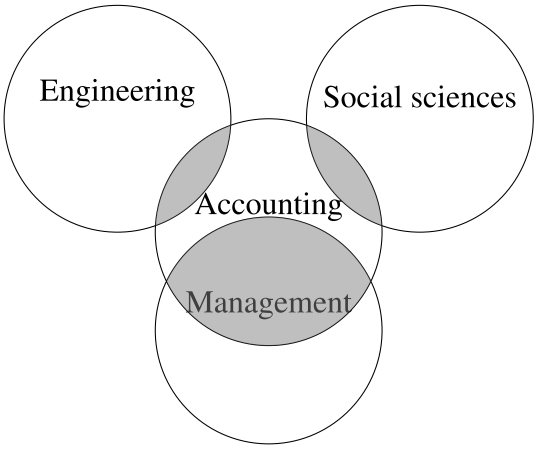

Figure 1.2: The meddling of accounting in the three main field of application of GP

mon backbone (as exposed by Figure 1.2) in which they gather information which is called accounting; embracing significant development particularly in areas dealing with, cost controlling, budgeting and operations planning; such cross literature will be treated in the following section.

1.2.1 Application in Accounting

The accounting field (where the model proposed belongs), as seen in the following year a brand-new interest among researchers. It's worth starting by defining what is meant for accounting, which may be defined as the process of recording and summarizing business and financial transactions, analyzing and reporting the results. Although this seems as passive process, sometimes accounting has reveled to be a very strong tool on the hands of the DM[DT61] to enact decision in the most informed way possible. In fact, because of the nature of accounting which may be seen as a cross organizational field, the DM has the possibility to test particular strategies having a series of objectives belonging from different departments, from the legal to the marketing and from the logistic to the production department.

In such situation the GP may turn out to be a very powerful tool, as highlighted by Aouni[AMA17]; generally accountants are facing complex decision-making situations where they aggregate simultaneously several conflicting and incommensurable factors. Given this situation a MCDA tool is, without any doubt the best fit approach possible and GP turns out to be used as framework because of its simplicity of formulation and at the same time the power of the flexibility that it provides. In the following table is proposed a review of the brand-new articles written in the field and their main contribution.

Author	Novelty
Ijiri and Kaplan[IK71]	The authors propose a WGP to set a perfect sampling policy in auditing according to four objectives, namely: representative, corrective, protective and preventive sampling.
Tayi and Gangolly[TG85]	The authors, building on what proposed in the filed of audit sampling, propose instead of a WGP, a sapling based on a new approach, namely a polynomial GP which guarantees a better contemplation of the trade-offs between objectives.
Killough and Souders[KS73]	The authors apply the GP in the field of audit staff planning for public accounting firms distinguishing between role and chargeable hours.

Welling[Wel77]	The author proposes a GP approach to solve the problem of human resource evaluation using non monetary based parameters.
Kruger and Hatingh[KH06]	The authors propose a combination of AHP and GP in order to address the risk of allocating the hours on several projects.
Gardner et al.[GHL90]	The authors use a multi period approach to audit the staff planning through a series of objectives, namely, profit, late completion of work, work declined, staff augmentation, staff reduction, under utilization of the work force, and shortfall in meeting professional development targets.
Kwak et al.[Kwa03]	The authors propose one of the first multiple-objective auditing model, combining strategic objectives and human resources allocation using fuzzy set.
Zamfirescu and Zamfirescu[ZZ13]	The authors apply a LGP to enact a performance based budgeting(PBM) on funds allocation in a real public company.
Tan et al.[Tan+08]	The authors propose a GP model in order to help contractors to decide the optimal level of resources to be consumed within a set of limitations.

Iranmanesh and Thomson[IT08]	The authors develop a model for product design based on Quality Function Deployment (QFD) whose aim is to optimize cost and design characteristics during product development.

Table 1.1: Application of Goal Programming in accounting: authors and novelties

From such table is possible to see how many GP models have been created to solve a broad range of accounting topics such as in audit sampling or other fields dealing with management accounting such as pricing, costing, capital budgeting and performance evaluation. This popularity is due to the fact that GP is easy to understand and to apply, plus it facilitates consideration of trade-off in the decision-making process which is perceived by the authors proposed as a deal-breaker when facing the decision on whether to use a GP approach.
However it's worth mentioning the fact that not every field of accounting gained the same attention by both researchers and practitioner and, aside from its popularity, the interest in international tax planning never arose. This may be due to the typical background that such researchers have on the field. In fact most of the research moved in this field pertain to the legal area, which probably lack from a point of view of mathematical modelling skills. From the other side the field of international taxation involves a great set of laws, both soft and hard, that may result in a great effort by practitioner to model. From an extensive review

of the field of study under scope, it's worth mentioning the work of Merville and Petty[MP78] who tried to model an optimal pricing policy which is indeed useful to set a global tax strategy since the TP core is base on that. However, one major problem of such model is given by the fact that it doesn't take into account the novelties introduced by the recent work of the OECD and the increasing importance of new tools at the disposal of multinational companies such as: extensive databases, and newer resource management tools.

Therefore, keeping what proposed by the literature, seems necessary to propose a new type of model which takes into account these new developments and result giving a powerful tool in the hand of the DM.

1.3 Model formulation

1.3.1 Data used to formulate the model

The data used in this particular GP model comes from different sources, and they can be summarized in the following categories:

- Macroeconomic data, is the set of data used by DM that came from the national economies;
- Target enterprise data, are the types of data that refer particularly to the firm under scope;
- Global enterprises data, these data comes from other enterprises that are in some way similar to the enterprise under scope, both in terms of business or because of the functions they perform.

Macroeconomic data

The group of Macroeconomic data includes the CTR defined as "the percentage on corporate income generated deemed to the State". The Figure 2 below shows how this rate is different from State to State. This means that different allocation of corporate entities may result in an advantage from a competitive perspective. For example, a new allocation from Germany to Estonia may result in a gain in terms of income of +30% on net income that may be reinvested in the company.

The second Macroeconomic data is the GNIC. This kind of index is a good proxy for the average cost of an employee per year which instead is computed by dividing the national-accounts-based total wage bill by the average number of employees in the total economy, which is then multiplied by the ratio of the

Figure 1.3: Corporate Tax around the world

average usual weekly hours per full-time employee to the usually average weekly hours for all employees. The latter indicator was not chosen since it computed in very few countries (the OECD countries) and doesn't permit to obtain a full range of choice by the model. Figure 3 reported below shows the geographical distribution of such index from state to state.

Figure 4 shows a scatter plot of the normalized CTR (x-axis) and GNIC (y-axis), to such data a K-mean cluster algorithm with K=5 was applied; this kind of algorithm randomly assigns each observation to a cluster, and finds the centroid of each cluster then, through iteration reassign data points to the cluster whose centroid is closest and calculate the new centroid of each cluster. The K was chosen with the "elbow method" with R^2 meaning that 5 was the number of cluster that return the best trade-off in terms of R^2 increase and cluster numerosity. The result were five clusters with the one highlighted by the circle indicating countries

Figure 1.4: Gross National Income per Capita

with both a low average cost of worker and a low taxation. However, even if these may seem the best locations to allocate the entities this is not always true, since the formula for taxation is the one proposed at section 4.2 and such entities have to be in the range proposed in section 4.3.

Target enterprise data

This data includes the information from our enterprise (the one in which we're going to reallocate the entities). Even though, the data that can be extracted from the enterprise are enormous, the decision was to depict the most valuable information on the enterprise keeping under control the numerosity of such parameters. The parameter identified are:

- Revenues: they represent the upper limit that, whether crossed, our strategy will result not profitable, this element can be either forecasted or in case of

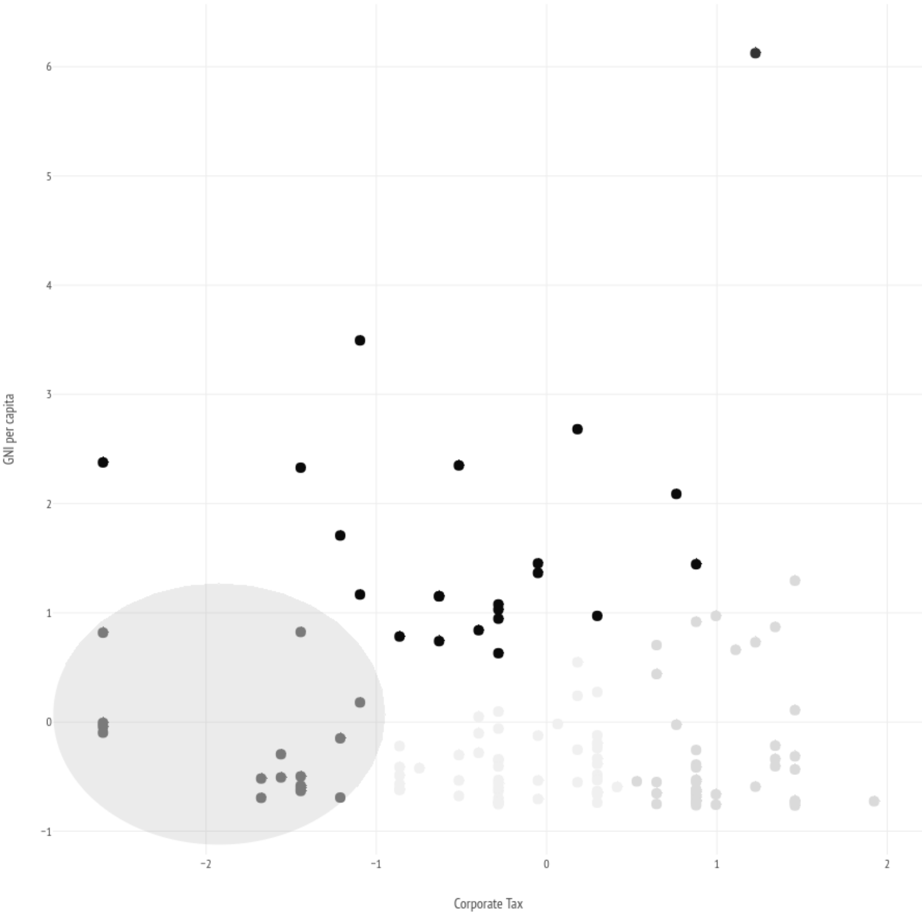

Figure 1.5: K-mean cluster on standardized Corporate Tax and GNI per capita

a constant flow of revenues over the years, obtained through historical data;

- Employees: this element is somehow tied to the revenues expected, plus some limitations dictated by the labor unions depending by the countries (which were not modeled);

- Cost of running the asset: this is a very crucial factor in case of business that rely heavily on machinery and industrial plant activities, in fact such parameter may be neglected or, take a secondary position in the decision process, in case of a business relying heavily on employees, as for example a software company or a consulting firm.

While obtaining the first two parameters is something not particularly intensive in terms of data gathering and may require some additional effort the forecasting part because of the uncertainty that some industries carry. In case of the cost of running the assets two choices are proposed; it's possible to either use the internal data coming from a unified ERP system or use the single entity financial data and try to forecast each single entity cost of running the asset and then scale it to a common base in order to do an "apple to apple" comparison. In order to extract such parameter with the latter method the operating expenses of the entity[Wil08] is used, subtracting from the operating expenses the wages the information inherent the cost of running the assets is obtained, the value is intended to be at a certain time t_0 for a certain volume of good V_0, dividing the cost of running the asset for V_0 will give a proxy of the marginal cost of asset given an increase of the production by one unit. This procedure has to be intended as measure of last resort in case of a non unified ERP system which still is the most reliable source of data in case of global entities located in very different countries.

It's worth noting that are part of the enterprise data other information which are not part of the above mentioned parameters, such data deals with the DM preferences and some of them may involve limits in the numerosity of the number of entities. In some cases many enterprises can result in a trade-off between potential synergies and the cost of keeping a constant flow of goods and information to them. This preference can narrow down till the functional characterization of an entity and may involve the localization in a particular country because of the public image of the Group.

Global enterprises data

This category contains all the data inherent the PLI of the specific functional enterprises operating in a certain State. A piece of this data is summarized by the following representation. Another important data that can be obtained is the cost of debt [BKC13] even though such measure has to take into account the proportion of two types of funding (namely equity and debt) the data provided by the comparable enterprises serve as a good proxy for such measure if used in conjunction with financial databases as Bloomberg. In our case, to obtain this data a private worldwide database was used called Orbis by Bureau Van Dijk.

In the figure 1.6, is represented how the PLI interquartile range changes from country to country in such case the PLI chosen was a ROS applied on independent companies whose activities are based on distribution (from wholesale to retail). Such difference can play a major role in deciding the optimal profitability level of the allocated entities. The PLI, which is a financial indicator (most of the time a ratio) that tracks the profitability of a certain function performed by the entity

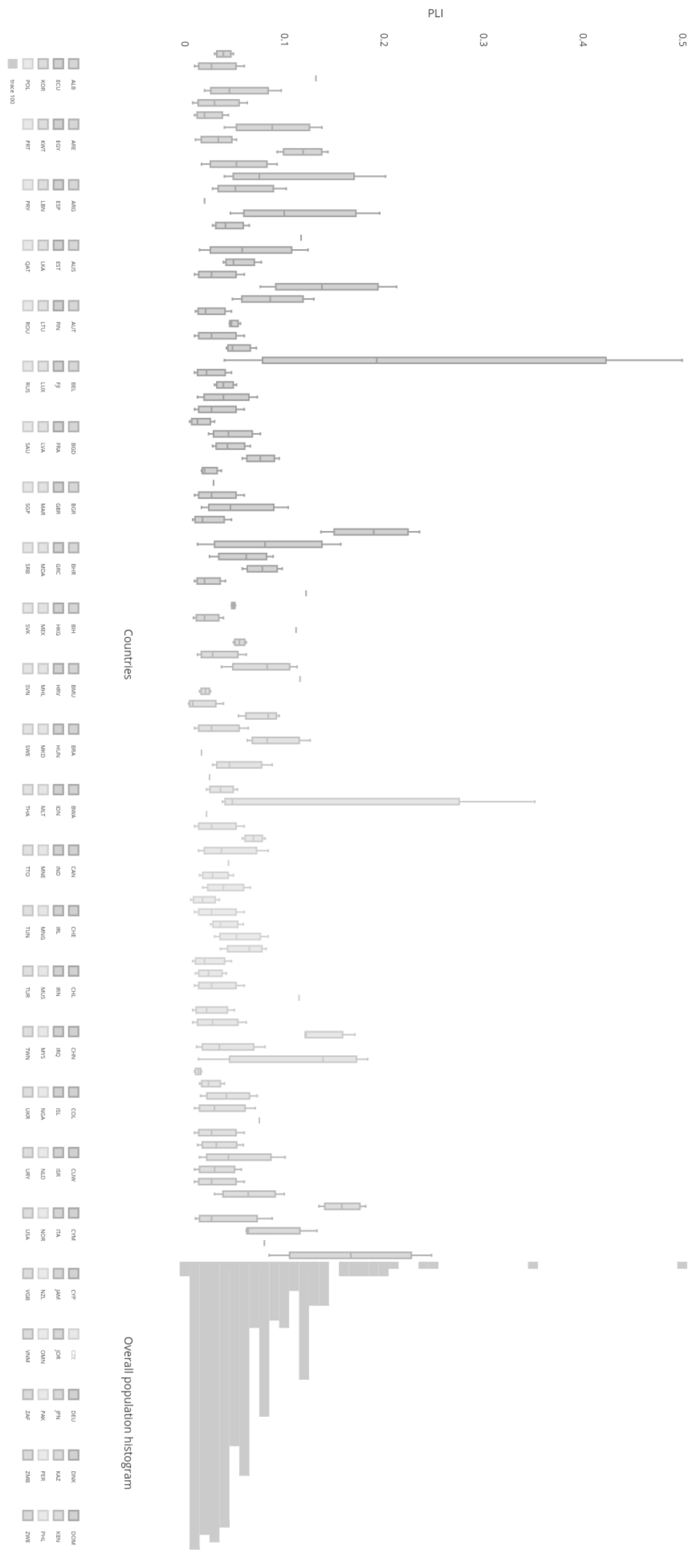

Figure 1.6: Interquartile range of distribution PLI sorted by country

under scope of analysis.

1.3.2 Objectives

The data reported above will be used to set up the GP model and constitutes part of the objectives and constraints that will be presented below. In order to model the overall allocation the following objectives should be pursued:

- The overall cost of production should be minimized;
- The tax liability should be minimized;
- The profit should be divided among the entities based on the contribution that such entity give to the overall process of value creation;
- The functional characterization of each entity must fall within a range achieved by comparable non controlled entities.

Cost minimization

This is a very basic objective in which the focus is to minimize the cost embodied in each national entity. The cost function for each entity is primarily given by three variables, namely employees (which constitute the major variable cost of an enterprise) then the specific cost of running the assets (machinery, offices etc...) and ultimately the cost of capital (meaning the remuneration expected share holders and financiers). All these variables contribute to the determination of costs. The approximation function derived will look as follows:

$$C(E,A,K) = ce_k \cdot E + ca_k \cdot A + ck_k \cdot K \quad \forall k \in \{1...N\} \tag{1.1}$$

Where $1.ce_n$ corresponds to the GNIC, this index was chosen because of its availability through the nations at scope and because it's a good proxy for the cost of labor in each State; $2.ca_n$ corresponds to the cost of running the assets and is derived as illustrate before by subtracting the wage cost to the operational expenses and then adjusting for the purchasing power; $3.ck_n$ corresponds to the cost of capital (in our case debt) calculated using data from comparable companies. Even if this three variables do not represent the full cost structure of each enterprise (cost of good sold was not mentioned) is helpful for the DM to take into account this three driver of cost since this information constitutes the main driver to address value adding activities in the overall value chain.

Tax base minimization

This objective is the crucial point of this work since an optimal tax strategy can be considered good for profit maximization. However, should be mentioned that this doesn't constitute any avoidance of taxes but a strategy to be competitive in the market. Such allocation result in the consolidated minimization of all the national tax base, which is given by subtracting from the revenues allocated to a particular State ($y_k \cdot R$) the cost allocated to the same State (here expressed as $x_k \cdot C(E,A,K)$. This residual forms the EBIT, the fraction of EBIT due to the tax authority is called the tax liability. The tax liability function will look as follows:

$$T(R,E,A,K) = [R - (ce_k \cdot E + ca_k \cdot A + ck_k \cdot K)] \cdot tx_k \quad \forall k \in \{1...N\} \tag{1.2}$$

Functional allocation

This objective derives from the TNMM technique used in accessing TP goodness. The method is based on the examination of the net profit relative to an appropriate base (e.g. costs, sales, assets) that a local entity realizes from a controlled transaction (or in our case to the entity itself). Basically, such objective works as a quality control that the overall process of maximization of profits as some confirmation also in the real market, made by independent actors. This is in certain sense a bond that helps the model in giving a solution viable also in an anti avoidance perspective.

In order to achieve this is necessary to identify which PLI to choose; this is an important choice that has to be made taking into account the functional characterization of such entity, that is, if an entity focuses on distribution the best PLI to test such entity is given by the ROS of its functional characteristics, that's because the sales are supposed to be the main element of a distributor (and not cost or assets). The main PLI used by practitioners are: ROS, FCMU, ROA, ROI.

After each functional characteristic is matched with its relative PLI it's necessary to find the data of comparable independent entities, in order to asses the profitability range that our entity has to obtain to be in an arm's length position.

The objective function returning such objective would be as follows:

$$f(x)\begin{cases} \frac{R-C(E,A,K)}{R} & \text{if } q=1 \\ \frac{R-C(E,A,K)}{C(E,A,K)} & \text{if } q=2 \\ \frac{R-C(E,A,K)}{A} & \text{if } q=3 \\ \frac{R-C(E,A,K)}{E} & \text{if } q=4 \end{cases} \tag{1.3}$$

The basic idea behind this objective is that for a moment we're forgetting about the group objective (the first and the second) that try to minimize the consolidated cost and tax base. In this case we're focusing on the profitability of each entity.

1.3.3 Profit split

This objective is represented by the goals (1.4e)(1.4f)(1.4g) and the methodology used to determine this type of split derives from the profit split method used in transfer pricing analysis. In particular the transfer pricing profit split method aims at: determining the division of profits that independent enterprises would have expected to realize from engaging in the transaction [OEC17]. In our case we'll use this method and particularly the contribution analysis to define the effort of each functional category in the value chain. Secondly we'll use this value driver to partition the profits in order to have, at the end, a structure that takes into account the internal value chain of the products and not just the information gained by independent comparable companies.

1.3.4 Constraints

Constraints represent the boundaries where the system will result unfeasible. Such constraints are expressed by the equation from (1.4h) to (1.4p); where the first two represent the boundaries on the PLI distribution namely the lower quartile and the upper quartile, outside this range the profitability may not be considered to be arm's length. The constraints (1.4j)(1.4k)(1.4l)(1.4m) represent the frontier of the possible allocable resources given by the company under the scope. The constraints (1.4n), (1.4o) and (1.4p) sets the positiveness of the deviation variables in order to avoid incorrectness of the overall GP model.

1.3.5 Goal Programming Model

This model aims to find the best allocation of costs and budgeted revenue in order to maximize profits minimizing costs and tax base, at the same time the model provides the best multinational functional allocation strategy to achieve such goal using both internal and external data from independent companies. The objectives are divided into two categories; the first one is given by three objectives namely cost minimization, tax base minimization, PLI coherence; the second focuses more on the control and limitations that the DM wants to implement in the model due to the specific characteristics of its business.

The overall model algebraically looks as follows:

$$\underset{p,n}{\text{minimize}} \quad \sum_{i=1}^{Q}({}_qp_i \cdot w_i) + w_3 \cdot \sum_{i=1}^{O}({}_on_i) + w_4 \cdot \sum_{i=1}^{N}({}_nn_i + {}_np_i) \tag{1.4a}$$

$$\text{subject to} \quad \sum_{q=1}^{N} C_q(E,A,K) - {}_qp_1 = 0, \tag{1.4b}$$

$$\sum_{q=1}^{N} T_q(R,E,A,K) - {}_qp_2 = 0, \tag{1.4c}$$

$$P_k(R,E,A,K) + {}_nn_k - {}_np_k = V_k, \forall k \in \{1...N\}, \tag{1.4d}$$

$$\sum_{q=1}^{D}(R_q - C_q(E,A,K)) + {}_on_1 = c_1 \cdot \sum_{q=1}^{N}(R_q - C_q(E,A,K)), \tag{1.4e}$$

$$\sum_{q=1}^{P}(R_q - C_q(E,A,K)) + {}_on_2 = c_2 \cdot \sum_{q=1}^{N}(R_q - C_q(E,A,K)), \tag{1.4f}$$

$$\sum_{q=1}^{M}(R_q - C_q(E,A,K)) + {}_on_3 = c_3 \cdot \sum_{i=q}^{N}(R_q - C_q(E,A,K)), \tag{1.4g}$$

$$P_k(R,E,A,K) \geq L_k, \forall k \in \{1...N\}, \tag{1.4h}$$

$$P_k(R,E,A,K) \leq U_k, \forall k \in \{1...N\}, \tag{1.4i}$$

$$\sum_{q=1}^{N} R_q = R^*, \tag{1.4j}$$

$$\sum_{q=1}^{N} E_q = E^*, \tag{1.4k}$$

$$\sum_{q=1}^{N} A_q = A^*, \tag{1.4l}$$

$$\sum_{q=1}^{N} K_q = K^*, \tag{1.4m}$$

$${}_qp_i, {}_qn_i \geq 0, \quad i = 1, ..., Q, \tag{1.4n}$$

$${}_np_i, {}_nn_i \geq 0, \quad i = 1, ..., N, \tag{1.4o}$$

$${}_op_i, {}_on_i \geq 0, \quad i = 1, ..., O \tag{1.4p}$$

Where the equations(1.4b)(1.4c)(1.4d) belong to the first category, where instead (1.4e)(1.4f)(1.4g) belong to the second, the latter in fact depend on the strategy of the DM and it's not given by any environmental variable.

1.4 Mathematical simulation: a case study

The simulation of the above-mentioned model was made using LINGO17 and specifically its linear solver. Even if the mathematical package was able to handle the total amount of data given by the model the simulation was done using a portion of this data, avoiding countries in which the company doesn't operate at all. Other limitations were implemented in order to avoid any possible non-linearity, resulting in an increase of the computational time to obtain a solution, this was possible by avoiding inserting the equation (1.4d), when instead the correlated constraints, namely (1.4h) and (1.4i) were linearized. Other limitations of the model are exposed below:

- The PLI chosen to set the functional range were only 2, ROS and FCMU;
- The cost of asset and equity was set to 0, meaning that the only cost driver was employees;
- The functional characterization was reduced to 3, namely distributor, producer and principal (which acts as an active holding);
- The number of employees was assumed to be continuous, meaning that part-time work and non full year worker can be used by the firm.

Concerning the data, the financials were taken from a company operating mostly in Europe and western countries in general, plus this company tend to produce and store most of its products in Asian countries and tend to have less inventory in its western distribution sites. The company under scope was underperforming at the time of this simulation its P/L statement registered a loss of roughly 6.000.000 USD. The revenues registered for the year under the scope were about 88.900.344 USD and the employees hired were 2.722.

1.4.1 Sensitivity analysis

In the sensitivity analysis, the value of the weights was preemptively determined; since the model for the case study has only three goals, namely the minimization of the operation cost, the minimization of the tax liability and conservation of the functional allocation. The aim of the sensitivity analysis was to measure all the possible frontiers between DM preference toward these choices. Therefore the objectives were subjected to different weights combination, however, the combinations didn't include any zero weight, this was done in order to avoid any Pareto solution that would result infeasible in reality. For the three objectives was given a set of possible weight alternatives following the equation reported below:

$$1 = x + y + z, \quad \forall x \in X, X = (0,1), \quad \forall y \in Y, Y = (0,1, \quad \forall z \in Z, Z = (0,1),$$

Where x is the preference for the minimization of the operational costs($w1$), whereas y stands for the preference of the DM toward the minimization of the tax liability($w2$) and z represents the preference for maintaining the functional characterization of the company($w3$). In order to give a better perspective of these different set of preferences, a ternary plot was created representing some of the possible choice given admitted by the equation defined previously.

As presented by the figure, pursuing largely the minimization of the operational cost could not be considered a great objective and the same as to be said by the sole objective of tax minimization, a much solid set of weights should be

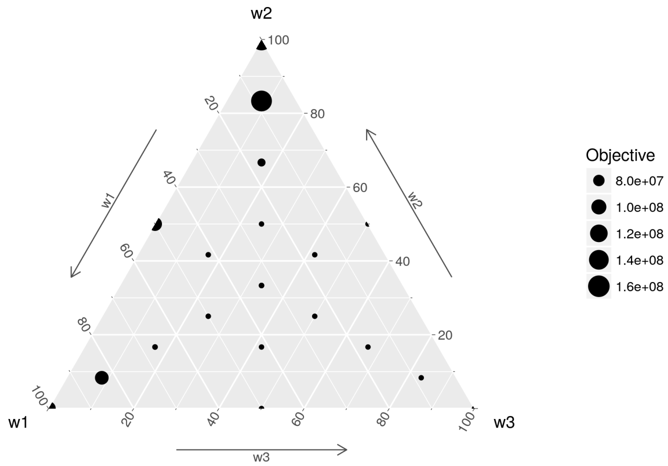

Figure 1.7: Weight sensitivity analysis

found taking into account these different outcomes.

1.4.2 Analytical Hierarchical Process for weight determination

Given the knowledge about the trade-offs that DM faces, the option was to choose a robust framework to select the sensitivity of the weights that were consistent with the expectation that the DM has about the process of profit allocation. The chosen framework was the AHP[Saa80]. The process was three tired:

- Step 1: given the set of criteria defined in the previous sections the pair-wise comparison matrix was computed indicating the importance of each criterion with respect to the other;

- Step 2: the pairwise matrix elements were normalized and consequently the priority vector was obtained;
- Step 3: the last step consists in the test of the consistency of the value reported and then the validation with respect to a randomly generated matrix consistency index.

The resulting table reports the pairwise comparison matrix pre normalization:

Criteria	Operation Costs	Tax Burden	Functional Allocation
Operation Costs	1.00	0.50	0.33
Tax Burden	2.00	1.00	0.50
Functional Allocation	3.00	2.00	1.00
Total	*6.00*	*3.50*	*1.83*

Table 1.2: Pairwise comparison matrix

In the pairwise matrix is visible the preference of the DM toward maintaining the functional allocation above all other objectives. Subsequently the step 2 of the AHP method was followed, and then the normalized priority vector was obtained, which is represented in the table below.

The order of importance was therefore functional allocation, followed by tax minimization and operational cost minimization. However, the resulting vector

Criteria	Weight
Operation Costs	0.16
Tax Burden	0.30
Functional Allocation	0.54
Total	*1.00*

Table 1.3: Priority vector

Objective	Value
Operation Costs	26137120
Tax Burden	14798710
Functional Allocation	26134390
Total	*67070220*

Table 1.4: Objective value according to the model

may be inconsistent because of different choices according to the tuples. Therefore the step 3 was necessary and a consistency check was made in order to assess the goodness of the priority vector. The consistency ratio scored by the following preferences was 0.79% and therefore accepted since the threshold suggested by Saaty[Saa80] is 10%. Then the priority vector obtained was used to calibrate the weights of the model. After the calibration, the model was solved through the LINGO[CS04] linear solver algorithm. The objectives achievement are reported in the table below.

The solution is summarized in the figure 1.8. The optimal solution was to create two different distribution entities namely one in India and one in Malta and keep the manufacturing in a country with a greater PLI (such as Denmark) because of the great margin between revenues and costs. The greater amount of this margin is possible to see in the principal function (located in Portugal) where this margin is increased because of the importance that such functions perform in the value chain. The solution proposed resulted in an average CTR below the 20%.

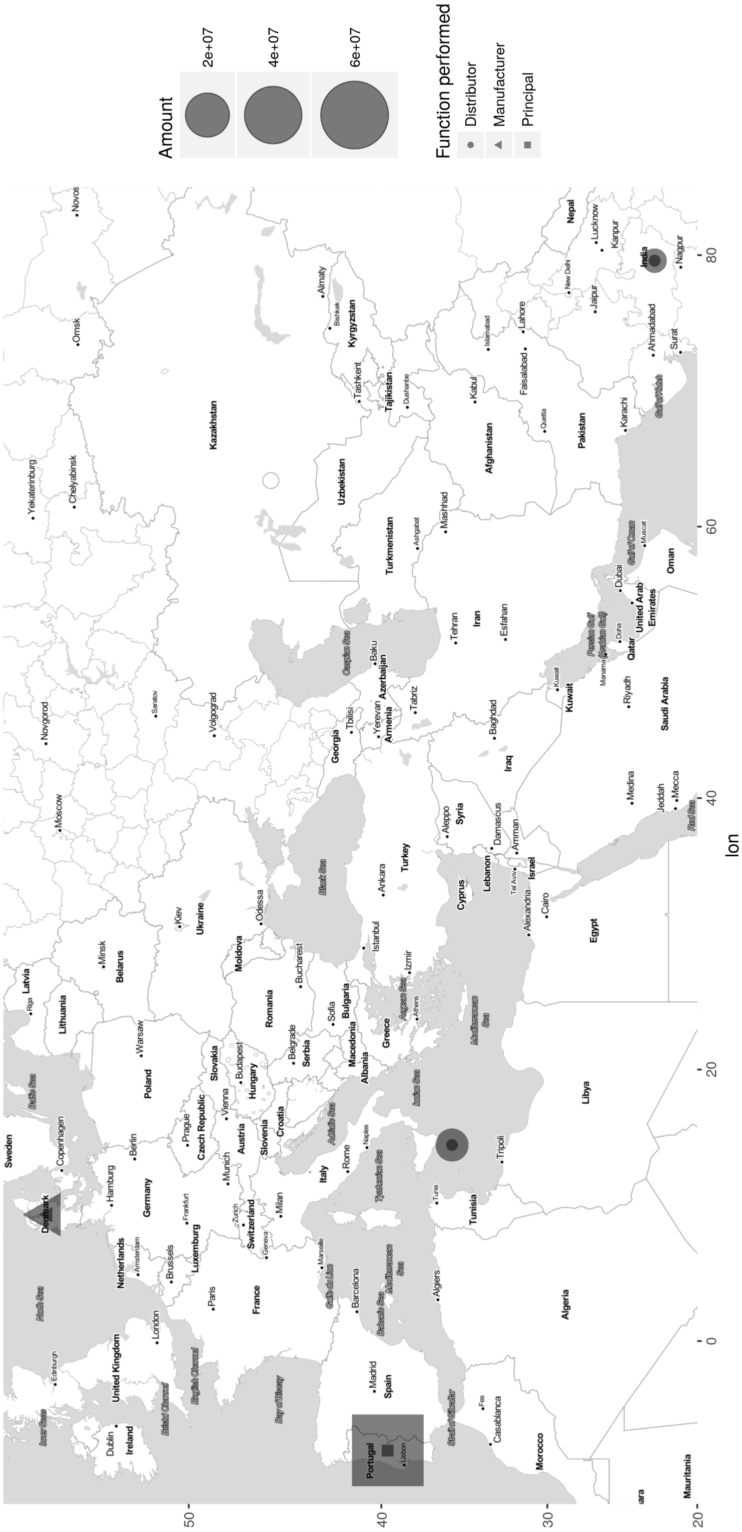

Figure 1.8: Cost and revenues allocation according to the model

1.4.3 Final remarks

The model proposed aims at seeking the optimal allocation of profits between the multiple multinational companies in order to be compliant with the TP regulation and with respect to the business carried by independent companies carrying similar functions. The lack of literature in the tax planning filed may be seen as a promising niche that researchers should pursue in the future. The model proposed apart from the simplistic assumption given in the case study could have been enhanced with other features belonging to the GP approach such as fuzzy sets to model the PLI range or other features.

Chapter 2

A Green Supply Chain transportation model: integrating closed loop logistics features

In the following chapter is proposed a multi-objective model for goods allocation in a GSCM framework. The model builds on the concept of the OLSC as suggested by Santoso with the integration of the Porter model for value chain, accounting for the costs of production using the ABC accounting method. Finally, the model is enhanced to embrace the flow of recycled goods and therefore be a CLSC. Above every block of the recycling process, a series of environmental constraints have been included, that the firm has to comply, with respect to specific country regulation, or in case of a particular CER policy. The resulting WFGP model is then solved and calibrated to the DM needs through AHP.

2.1 Scope of work

Global Supply Chain Management is probably one of the most used terms when the discussion of how the firms are running their business is brought to the table nowadays. Global Supply Chain Management may be defined as the allocation of goods and services along a series of transnational companies' global network to maximize profits and minimize waste. As the Supply Chain Professionals puts it, the goal of Global Supply Chain Management is threefold and focuses on delivering: (a) the right product; (b) to the right place; (c) at the right time. Inside this very wide paradigm, the concept of logistics serves as the backbone; recalling that logistics is developed to be in charge of the movement of goods, service, and last but not least information from the sourcing of raw material, till it reaches the end customer. Along with these two concepts a third one sticks with them, the GSCM. This idea brought to light by a more advanced concern about environmental matters of the developed countries, forced the firms to be accountable for their negative externalities related to the environment in which they operate[Sri07].

However such legislation lacks from a point of view of legal constraints, setting only a few qualitative restrictions, poorly measurable by the enterprises or in some cases letting the customers pay for their environmental behavior toward waste disposition. These facts are inevitably leaving some degrees of freedom to the firms, on the other hand, is also important to notice that these are only seeds of legislation that show us how the long-term trend will be about the tolerance given to the behavior of firms with environmental concerns, a trend that in the future may require firms to set particular frameworks to be accountable for their environmental impact. Nowadays such effort is not achieved by the legal frameworks provided by the domestic legislators but by the Corporate Environmental Responsibility (CER), meaning that are the stakeholders to impose the companies to be more responsible on their day to day operations.

Speaking about the literature, is observable an emerging branch which deals with the Green Supply Chain Management, a new paradigm of Supply Chain Management whose aim is to keep under control the behavior of the firm during its operations, by applying policies such as Green Manufacturing and Remanufacturing, Green Design etc... Because of that a Weighted Fuzzy Goal Programming model is proposed. In order to address such problems, following what proposed by literature, an enhanced model is proposed. such model, fixing quantitative and qualitative constraints to the recycled products handled by the company and tries to implement Decision Maker preferences with respect to the recycling programs enacted by the firm apropos the WEEE directive. In the case under proposed, the choice was to opt for a networking electronic appliance business (i.e. hub, switch or router). In order to measure such impact, the framework provided by the Activity Based Costing is used; such approach has the peculiarity to assess the marginal impact of any additional unit processed by the transnational firms, leaving outside the assessment any sunk cost.

The chapter is organized into four parts, where two of them are devoted to a review of the existing literature and the last two, which are respectively model and result oriented. In the first of the literature sections a full overview of the Green Supply Chain framework will be given; at the same time the focus will be directed to the legal implications that are affecting both producer and distributors operating in the European Union. After this overview a deep analysis will be given on the state-of-the-art techniques used to model both Supply Chain Management and Logistics topics, focusing the attention on peculiar applications such as Stochastic Programming and Fuzzy Goal Programming. Ultimately the two sections devoted to the model will be used to state the model proposed with its objectives and constraints; then the model's weights will be subjected to sensitivity analysis with different scenarios and ultimately calibrated to the DM needs via AHP.

2.2 Green Supply Chain

Green Supply Chain saw a steady growth of interest in many enterprises[DG11] as well as by academics; a growth that, looking to the data[Vol18], reached its hype between the 2012 and 2014 (Figure 2.2) and that may be strengthen in the next years because of the increasing environmental concern. The main research fields interested by this phenomena are the ones involving environmental sciences, management, operational research and more generally green sustainable sciences[SW18]

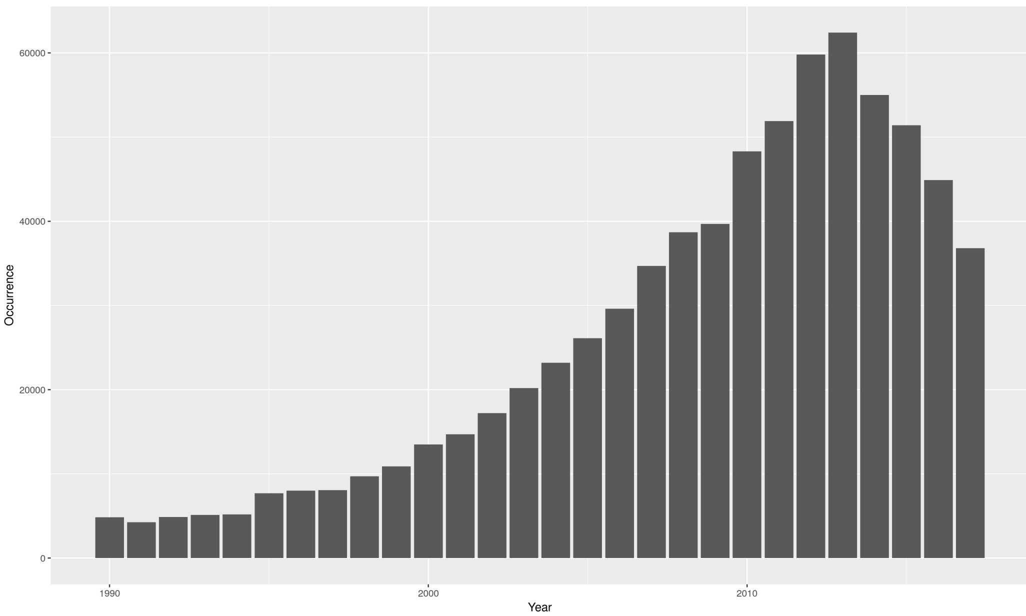

Figure 2.1: Occurrence of Green Supply Chain in papers indexed by Google Scholar

Although Green Supply Chain management is perceived as a game changer in order to unleash long-term sustainability of a business, it's worth noting the lack of a univocal definition. In fact, some of the academics see GSCM as a pro-

cess[Gil01], more specifically a "greening process" from this school of thought belongs the line of thought that the management has the duty of incorporating the environmental criteria along with all the organizational value creation process. Another definition sees the Green Supply Chain as a set of policies whose focus is to raise environmental concern along the production, distribution process[ZS01]. In this chapter is used a two-level definition the first definition is a formal one that builds from the concept of Supply Chain Management as defined by the Council of Supply Chain Management Professionals; the second is a substantial one and deals with the operations affecting the "green" practices inside the firm.
In formal terms, Green Supply Chain may be defined as the series of interconnected activities across the border of different enterprises that adds value to the goods and services from the sourcing to the market. Its aim is to improve performance in measures of sustainability, cost reduction, emission reduction. Whereas Supply Chain Management sets its objectives to maximize profits and minimize waste, in economic terms, Green Supply Chain sets its objectives even further, posing as its ultimate mission to lower the ecological impact that a firm or a series of them has in their day to day operations. Such green operations[Sri07][ZSL08] constitutes the substantial definition of Green Supply Chain Management, these operations are:

- Green Manufacturing and Re-manufacturing: is the process of controlling and reutilizing material in the manufacturing, in order to limit waste creation[USS13];

- Green Design: is an approach put in place to promote the environmental quality of a certain product or service, by reducing negative impacts on the natural environment; an example could be the automatic switch of the television after a period of idleness[CG16]; and

- Green Operations in general: by green operation is intended any type of activity which does not fall into the two categories mentioned above but is characterized by a "green" attitude as for example the optimization of the offices' consumption through a remote-working policy;

Apart from the definition and its importance in the business field is important to focus the attention of the main drivers affecting this change, in fact such drivers are many and involves the overall ecosystem of the firm (external drivers), and even the firm (internal drivers) in its reactions to this drivers plays a key role in setting its environmental behavior that may be reactive, focused, opportunistic, and proactive[YR07]. Speaking about the external drivers, they fall into four main categories:

- Legal frameworks: embraces all the set of laws either soft or hard laws, that implies certain standards and regulation over the operations provided along the supply chain;

- Customer relations and concerns: in this category pertain every possible action overtaken by the end-users who can force their pressure on the firm enacting nonbuying campaign and manifestation in general;

- Supplier/distributors relations: the actions pertaining to this category are similar to the ones of the customers, the only difference is that since are enacted by entities that are constituting the supply chain they can provoke major issue in providing good and services on the market;

- External stakeholders, this category embraces all the stakeholders that do not follow in the categories of either customers and suppliers, which may include stockholder, agents involved by the environmental behavior of the firm, is an example the households living near the production plan, etc...

Since the model proposed it's aimed at setting a Green Supply Chain network of products from the procurement sites to the end user market which is stated to be the Euro Zone; it's necessary to highlight the set of norms that characterize such market and in particular a specific attention will be given to the norms concerning electrical products.

2.2.1 The legal framework: an European perspective

In the market under scope which is the European one, there are several legislations concerning the environmental impact of certain e-Products[1]. The most important are:

- Waste Electrical & Electronic Equipment (WEEE);
- Restriction on Hazardous Substances (RoHS); and
- Ecodesign Requirement for Energy-using Product (EuP).

Such legal frameworks act at different levels from the sourcing to the customer involving community member States. The following flowchart illustrates this differences.

In the following subsection, an additional overview is given to such legislations.

[1]for e-Products, is intended an electrical or electronic equipment such as computers, TV-sets, fridges, cell phones and other electronic appliances

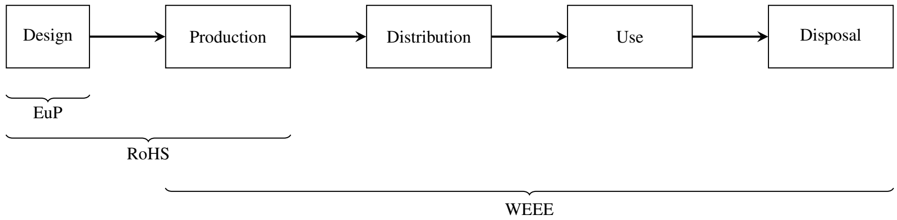

Figure 2.2: Legislation affection

Waste Electrical & Electronic Equipment

The Waste Electrical & Electronic Equipment also called WEEE is ruled in the European Community by Directive 2002/96/EC now repealed by the Directive 2012/19/EU. The objectives of the policy are, to preserve, protect and improve the quality of the environment, to protect human health and to utilize natural resources prudently and rationally. That policy is based on the precautionary principle meaning that the polluter should pay for its damage. Is important to notice that in the European market such directive is impacting all the community members is not perfectly homogeneous ways because of the implementation which is remitted to the local authorities. This problem may incur in potential elusive behavior as highlighted by the German firms who exploited gaps in the law which have allowed them to move large amounts of WEEE declared for recycling to developing economies including India, China, Nigeria and Eastern Europe [OWC11]. Despite such cases, the overall impact of this directive is mostly positive as highlighted by the Eurostat data here exposed.

The WEEE Directive currently sets a minimum collection target of 4 kg per year per inhabitant for WEEE from households. From 2016, the minimum collection rate shall be 45% calculated on the basis of the total weight of WEEE collected. Where the WEEE is calculated with the following formula:

$$W(n) = \sum t = t_{0n} POM \cdot L^p(t,n)$$

Where $W(n)$ refers to the specific quantity of electrical and electronic waste for a specific year, $POM(n)$ is the quantity of new electrical component injected in the market and L is the discard-based lifespan profile for the electrical component injected in the market. From the graph proposed below is possible to see how the target of minimum collection of 4 kg per year per inhabitant for WEEE from households was achieved by all the countries in the Eurozone however not all the countries has the same collection rate, meaning that some of them may have introduced legislation that complies only with the minimum target of the directive, leaving the households with the freedom to dispose of their WEEE in an unconventional manner. Clearly, this means for the enterprises fewer obligations on the collection of e-Products, but at the same time fewer products to be recycled and less opportunity of remanufacturing.

Restriction on Hazardous Substances

The Restriction on Hazardous Substances also called RoHS is represented by the Directive 2017/2102 (RoHS 2 recast). The scope is the restriction on the use of certain hazardous substances in electrical and electronic equipment (EEE) such as lead, mercury, cadmium, hexavalent chromium etc... In such case, as opposed to the WEEE the RoHS directive acts as a barrier to the products containing such minerals and not when they become waste. In considering such regulation is worth noting that there are no differences between the dimension of the distributing en-

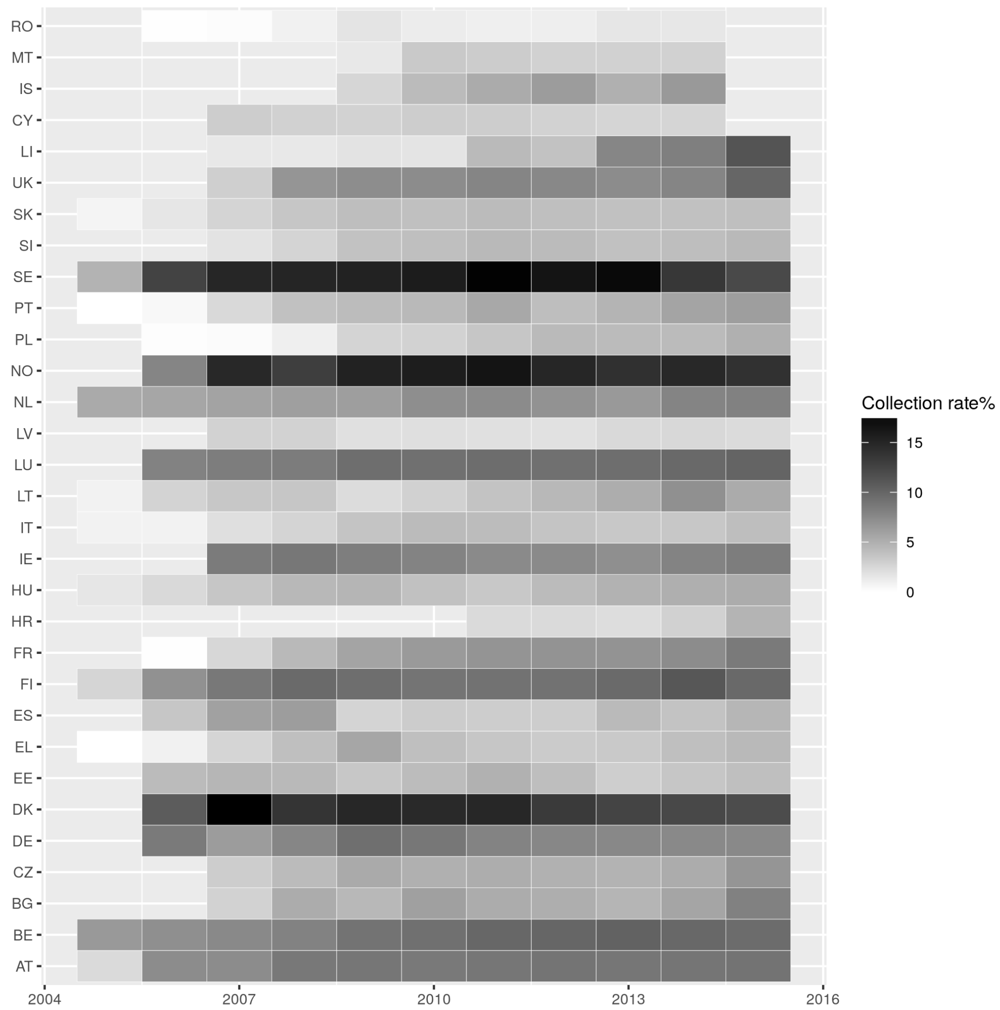

Figure 2.3: Kilograms of WEEE collected per capita

tity, meaning that small businesses, as well as large businesses, are equally affected by these restrictions. The only amendment is given to the batteries that may exceed such restriction.

Ecodesign Requirements for Energy-using Product

The Directive 2009/125/EC is meant to deal with Ecodesign regulations. Ecodesign regulations require manufacturers to decrease the energy consumption of their products by establishing minimum energy efficiency standards. In particular, The Ecodesign Directive provides a consistent legal framework for improving the environmental performance of products setting out a minimum mandatory requirement for the energy efficiency of these products. In case of the design of IT networking products such as routers and switches the firms are obliged by such directive to implement some ecodesign features such as the maximum wattage of 1W in case of off mode or a standby maximum consumption of 2W. Such measure per se does not impact in any case the supply chain since they are just additional features that have to be implemented in the products sold in Europe.

2.3 A state-of-the-art review: mathematical modeling in SCM

As proposed by the Council of Supply Chain Management Professionals, the Supply Chain Management (SCM) is the planning and the management of all activities involved in sourcing and procurement, conversion, and logistics as well as coordination and collaboration with the entities. The problem arising from such activities seems to be well addressed by mathematical modeling, other advantages of such approach are the economic sustainability and the possibility to scale the model in order to address different situations. From the comprehensive review built by Muna et al. [Mul+10] the methods used by the academic world and the specific situations they tried to model, are:

- Linear Programming: order quantity definition by means of decentralization[JJL08], production and distribution planning taking into account country specific regulations[OK06], multiple points of sales planning[KA05];
- Mixed Integer Linear Programming: network optimization and routing configuration[Rom+09], distribution planning in an environment with just a production plant and many distribution centers[RMD08];
- Non Linear Programming: optimization of production, transport and inventories[Ben89];
- Multi Objective Programming: replenishment production and distribution planning with conflicting objectives simultaneously[TH08], master planning[CH07];
- Fuzzy Mathematical Programming: distribution allocation considering different products and production/distribution centers[LC09];

- Stochastic Programming: addressing demand uncertainty accounting for the probability distribution[GM03];
- Heuristics Algorithms and Meta-Heuristics; and
- Hybrid Models.

Is worth noting how the majority of the models pertain to the category of Mixed Integer Linear Programming, this may be due to the fact that is probably one of the simplest and most reliable methods that can be used to solve such problems, however, this simplicity comes with some costs such as the focus on a single linear objective function with linear constraints whereas in reality different objectives have to be taken into account as for example the manager preferences toward greener choices. Another interesting topic brought into light by Aouni [AA17] is that such models are generally deterministic, where in reality such assumption does not hold most of the time, for example, the demand forecast can't be deterministic at all and derives from a stochastic process. This lack of deterministic variable lies also in case of the procurement where the price of a commodity is said to follow a sort of stochastic process, and an order may be placed several days after the decision to make it, however this does not apply to business depending on specific materials which are not sold as commodity, as for example processors or motherboards. Both of these situations, namely the fuzziness of the DM and the stochastic process of the demand will be modeled using two variances from the plain vanilla GP, that is Stochastic Goal Programming and Fuzzy Goal Programming.

2.3.1 Stochastic Optimization: a Goal Programming perspective

As previously stated, deterministic models seem to be the preferred choice by practitioners and academics whereas in reality there's a certain level of uncertainty that comes into play when deciding over the planning of the supply chain. When a Decision Maker is facing a multitude of random objectives is stated to face a multi-objective stochastic program (MSP). Because of its flexibility Goal Programming turned to be a very powerful tool in modeling multi-objective deterministic problem. The formulation originally proposed by Charnes and Cooper[CCF55] was built for deterministic scenarios, and with further development, starting from Contini[Con68], a newer branch was developed which accounted for nondeterministic situations, namely stochastic Goal Programming. The resulting model is generalized as follow:

$$\underset{\tilde{\delta^{+}},\tilde{\delta^{-}}}{\text{minimize}} \quad \sum_{i=i}^{N} \tilde{\delta_i^{+}} + \tilde{\delta_i^{-}} \tag{2.1a}$$

$$\text{subject to} \quad f_i(x) - \tilde{\delta_i^{+}} + \tilde{\delta_i^{+}} = \tilde{g}_i, \forall i \in N, \tag{2.1b}$$

$$x \in h_s(x) \leq 0 \quad \forall s \in M, \tag{2.1c}$$

$$\tilde{\delta^{+}}, \tilde{\delta^{-}} \geq 0 \tag{2.1d}$$

Where the goal variable $\tilde{g}$ is said to follow a certain probability distribution. A very common solution to deal with such stochastic problem is transform the undetermined problem into a deterministic one (also called deterministic equivalent formulation). Looking at the general formulation made before, if $\tilde{g}$(or the $\tilde{g}_i$ vector in our case) is said to follow a normal distribution $N(\mu;\sigma^2)$, therefore we can reformulate the program in its equivalent formulation[AA17]

$$
\begin{aligned}
\underset{\tilde{\delta^{+}},\tilde{\delta^{-}}}{\text{minimize}} \quad & \sum_{i=i}^{N} \tilde{\delta_i^{+}} + \tilde{\delta_i^{-}} && \text{(2.2a)}\\
\text{subject to} \quad & f_i(x) - \tilde{\delta_i^{+}} + \tilde{\delta_i^{+}} = \mu_i, \forall i \in N, && \text{(2.2b)}\\
& x \in h_s(x) \leq 0 \quad \forall s \in M, && \text{(2.2c)}\\
& \tilde{\delta^{+}}, \tilde{\delta^{-}} \geq 0 && \text{(2.2d)}
\end{aligned}
$$

2.3.2 Fuzzy Goal Programming

Fuzzy GP is a subset of Goal Programming models that uses fuzzy sets, which were firstly developed by Zadeh[Zad65]. The main advantage of fuzzy sets is that they can better model the level of imprecision of a particular feature of the model, usually, such imprecision deals with the target goal, but this does not mean that fuzzy target goals are the only factors that can be enhanced via fuzzy sets. The fundamental part of a fuzzy GP is the membership function (or in case of multiple fuzzy sets, functions)characterizing the shape of the fuzzy sets, and also how it penalizes values above and below some predetermined thresholds. In fuzzy GP the most common membership functions used are: (1) right-sided, used to penalize positive deviations; (2)left sided, used to penalize negative deviations; (3) triangular shaped, in this case the membership function penalizes both positive and negative deviations;(4) trapezoidal shaped, similar to the triangular shaped, since both positive and negative deviations are penalized, however in this case we allow for an interval of complete satisfaction. Recent works of fuzzy GP were made in the field of engineering where fuzzy sets where used to model the perfect selection of wind turbine in order to fully unleash the potential of each particular sites[RK17];

in the field of management, where a case study of wastewater treatment was proposed, combining both fuzzy GP and Stochastic GP[Día+18]; and in the field of social sciences where fuzzy GP was applied in analyzing environmental and sustainability goals of a country spotting improvement opportunities, requirement of efforts and implementing the sustainable development plans[Nom+16].

2.4 Model formulation

The hybrid model developed is based on the supply chain concept developed by Santoso[San+05]plus the integration of supporting activities as enunciated by Porter[Por98]in his concept of the value chain. Apart from these features, as the model is built with the concept of Green Supply Chain management seemed necessary to enhance the basic capabilities of an open loop supply chain network with the characteristics of a typical reverse supply chain network (which is intended to be in closed loop fashion). Because of the reverse supply chain network, a series of new entities have been introduced, namely the recollection points, which in our case are the same retail stores, and the recycling point that has to comply both with regulation and with management expectation in terms of recycled products. Therefore, a fuzzy goal is created using the fuzzy Goal Programming formulation developed by the [YJT08], such formulation, as reported previously, tries to capture the DM preferences about units recycled and the bottom line imposed by regulations.

2.4.1 Open Loop Supply Chain

In a very general open loop supply chain model the materials after been purchased pass through a series of entities where they are transformed into goods (operation activities), then follows the process of outbound logistics where the goods produced has to reach their specific market for satisfying consumer demand, however, such last operation is subject to certain costs, such as the sales force and marketing campaigns which are, generally, managed and supervised by the national retail stores in each specific country. A general formulation of such model is given by

Santoso and is formulated as follows:

$$
\begin{aligned}
\underset{y,\,x}{\text{minimize}} \quad & \sum_{i=1}^{P} c_i y_i + \sum_{k=1}^{K} \sum_{(i,j)=1,1}^{A} q_{ij}^k x_{ij}^k && && \text{(2.3a)}\\
\text{subject to} \quad & \sum_{i=1}^{N} x_{ij}^k - \sum_{l=1}^{N} x_{jl}^k = 0, && \forall j \in P, \forall k \in K, && \text{(2.3b)}\\
& \sum_{i=1}^{N} x_{ij}^k \geq d_j^k, && \forall j \in C, \forall k \in K, && \text{(2.3c)}\\
& \sum_{j=1}^{N} x_{ij}^k \leq s_i^k, && \forall i \in L, \forall k \in K, && \text{(2.3d)}\\
& \sum_{k=i}^{K} r_j^k \cdot \sum_{i=1}^{N} x_{ij}^k \leq m_j y_i, && \forall j \in P, && \text{(2.3e)}\\
& x \in \mathbb{R}^+ y \in Y[0,1] && && \text{(2.3f)}
\end{aligned}
$$

Where the objective function (2.3a) is to minimize both the variable and fixed costs (here represented by the cost of building a plant) of a particular supply chain network. The constraint posed in (2.3b) serves to maintain the flow constant in each passage(so-called flow conservation) it serves to balance the net inflow with the net outflow; the second and third constraint here represented by (2.3c) and (2.3d) are respectively controlling the volume of the demand (receiver side) and the supply (supplier side) of the supply chain network; whereas the fourth constraint (2.3e) is used to control the capacity of each node. Lastly, the x variable, indicating the flow of goods has to be positive and the variable y indicating the effective construction of the plant to assume a value that is either 1 or 0, in other terms y is said to be binary.

However the model is complete from a point of view of supply chain modeling it's worth noting that such model does not implement any support activities, whereas the Porter model mentions them. Therefore the hybrid model will contain a set of constraint indicating such activities and a new objective function embracing this change.

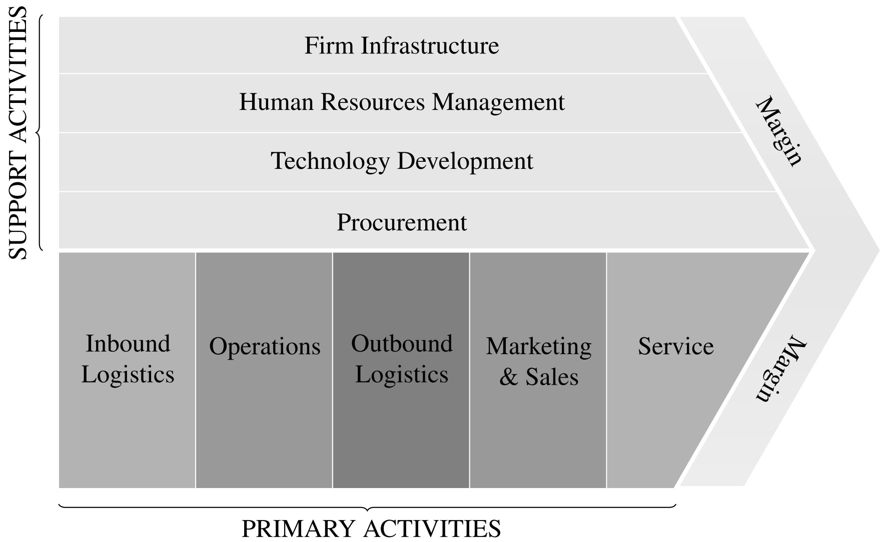

Figure 2.4: Porter’s Value Chain

Such activities are a fundamental part of the supply chain that serves as glue with the supply chain steps to the deliver the value to the end-customer. Therefore the hybrid model should take them into account, a revised version then is proposed.

$$\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{k=1}^{K} \sum_{(i,j)=1,1}^{A} q_{ij}^{k} x_{ij}^{k} + \sum_{i=1}^{N} c_i \sum_{k=1}^{K} \sum_{(i,j)=1,1}^{A} x_{ij}^{k} && \text{(2.4a)} \\
\text{subject to} \quad & \sum_{i=1}^{N} x_{ij}^{k} - \sum_{l=1}^{N} x_{jl}^{k} = 0, \ \forall j \in P, \forall \in K, && \text{(2.4b)} \\
& \sum_{i=1}^{N} x_{ij}^{k} \geq d_j^k, \forall j \in C, \forall k \in K, && \text{(2.4c)} \\
& \sum_{j=1}^{N} x_{ij}^{k} \leq s_i^k, \forall i \in L, \forall k \in K, && \text{(2.4d)} \\
& \sum_{k=i}^{K} r_j^k \cdot \sum_{i=1}^{N} x_{ij}^{k} \leq m_j, \forall j \in P, && \text{(2.4e)} \\
& \sum_{i=1}^{N} q_i^j = n_j, \forall j \in P, && \text{(2.4f)} \\
& x \in \mathbb{R}^+, && \text{(2.4g)}
\end{aligned}$$

In formulating our hybrid model is not taken into account the fixed cost of building a plant, this happened for two reasons. The first reason is the consideration of the cost of building a plant as a sunk cost and therefore it should not influence the economic decision on whether to allocate a particular quantity of goods on a specific plant. Secondly, since we use the Activity Based Cost method, the focus will be on the activities that contribute to creating the marginal cost of the good in the supply chain.

2.4.2 Closed Loop Supply Chain

In the previous sections a model of an open loop supply chain was presented, however in green supply chain something as an open loop supply chain network does not exist, this is because of the after-life treatment of the products sold by the company. Such procedure is also enforced by hard laws (as analyzed in the specific section). Therefore the revised model will have to capture these features. The closed loop supply chain network will be enunciated as follow:

$$\underset{x}{\text{minimize}} \quad \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c^f_{ijk} x^f_{ijk} + \sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{i=1}^{I0} c^r_{kli} x^r_{kli} \tag{2.5a}$$

$$\text{subject to} \quad \sum_{i=1}^{I}\sum_{j=1}^{J} x^f_{ijk} = d_k, \quad \forall k \in K, \tag{2.5b}$$

$$\sum_{l=1}^{L}\Big(\sum_{i=0}^{I} x^r_{kli} - x^r_{kli}\Big) = w_k, \quad \forall k \in K, \tag{2.5c}$$

$$\lambda \sum_{i=1}^{I0} x^r_{kli} \le x^r_{il}, \quad \forall k \in K, \forall l \in L, \tag{2.5d}$$

$$\sum_{k=1}^{K}\sum_{i=1}^{L} r_k x^r_{kli} \le \sum_{k=1}^{K} d_k, \forall i \in I, \tag{2.5e}$$

$$x \in \mathbb{R}^+, \tag{2.5f}$$

The model enunciated minimizes two different flow costs, namely the one implying the forward flow, the one from the production plant to the consumer and the reverse flow that follows the opposite direction, namely from the consumer to the production plant passing through ad-hoc dismantling plants. The constraints applied to such models are therefore a combination of both forward flow constraints, mitigated from the classical open loop supply chain, and the reverse flow constraints. The constraint at 2.5b is stating that the forward flow must equal the demand of the customer at a particular retailing site; where instead the constraint at 2.5c is enunciating the amount of waste that will not be part of the recycling process. The constraint at 2.5d focuses on imposing a threshold in which the units recycled will not be of any advantage for the production plan and therefore will constitute an additional waste. Lastly, constraint 2.5e that states the inequality about the products collected that should not exceed the products delivered at a k general retail store.

The model presented, however, does not implement any Decision Maker preferences toward recycling level goals (λ is only a crisp value that affects the plant necessity) nor any legal boundaries on which the recycling center has to be submitted. Because the electronic waste turns out to be a resource for the firm is necessary to model the fuzziness of such desire expressed by the DM, and therefore the implementation of a Fuzzy set[Zad65], turns out to be the best choice; such set has a membership function defined as:

$$\mu[f_k(x)] = \begin{cases} 1 & f_k(x) \geq b_k \\ 1 - \frac{b_k - f_k(x)}{n_{max}} & b_k - nmax \leq f_k(x) \leq b_k \\ 0 & f_k(x) \leq b_k - n_{max} \end{cases}$$

The defined set penalizes the negative occurrences from the target demanded by the Decision Maker, and at the same time guarantees a bottom line coherent with the local legislation. The following figure represents the graphical interpretation of the fuzzy set for a generic dismantling plant, whereas the n_{max} represent the legal boundaries in which any lower achievement will not be tolerated, conversely b_k is the goal sought by the Decision Maker as optimal, this may be due to some particular public image concerns enacted by the DM.

2.4.3 The Goal Programming model

Since we are facing a multitude of goals; some of them aims at the minimization of the transportation costs of both the forward flow and the recycling flow; some are set in order to control the supporting activities, and ultimately some are trying to capture the preference and necessities of the DM. Because of this multitude of goals a multi-criteria decision analysis tool was used, namely the Goal Programming approach. In this approach, the goal is to minimize a set of deviational variable applied to our desired goals. The model proposed builds from the concept of open loop supply chain (it's possible to see it in the first soft constraints) taking into account even the support activity costs of each individual step in the value chain. Then the supply chain loop is closed implementing the controls on the recycling flow. Additionally, the last soft constraints are an adaptation of the fuzzy set in order to be solved trough linear programming solvers.

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In the following sections a deep overview of the objectives, constraints and the model itself will be given.

Objective function

The objective function is a function containing all the deviational variables to be minimized as well as their relative weight, in the case under scope the interest is to minimize a series of costs, namely the cost of transportation of the goods from the production plan to the consumer K, and back from the consumer k to the plant I in the latter passage the waste, in other words, the nation collected products will be free of costs since won't be subject to any transportation. Another goal to be minimized is the cost of the supporting activities, this activities lies within each step of the value chain and are not part of any transportation cost, instead they are the cost that sustains the value of the product, a typical support activity cost may be the cost of a marketing campaign in a specific retail store K; such costs have to be minimized as well and for a matter of order the deviational variable and their relative weights will follow each particular step of the value chain. Apart from costs, additional goals may be more subtle; this is the case of demand fulfillment. Another goal not implying any cost is the reduction of the product wasted (meaning not recycled).

Soft Constraints

The soft constraints are the ones that do not constitute any particular boundary but carries the deviational variables and the goals that are tried to be achieved by the Decision Maker. The first soft constraints are the ones that deal with the transportation cost of the goods produced; the first flow of transportation is the forward flow and its soft constraint is represented as follows:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c_{ijk}^{f} x_{ijk}^{f} - \delta_{ijk}^{+} = 0$$

In this case, the goal is to minimize the cost of transportation of the good produced till it reaches the customer, the step that the product has to do in order to reach the customer are two, from the production plant to the distribution center and then to the retail center (indicated with k). The same goal has to be achieved by the recycling flow of products returned by the consumer, the soft constraint is similar to the first one and is represented as follows:

$$\sum_{k=1}^{K}\sum_{q=1}^{Q0}\sum_{i=1}^{I} c_{kqi}^{r} x_{kqi}^{r}, -\delta_{kqi}^{+} = 0$$

The peculiarity of this passage is given by the set $Q0$ which is not only the set of possible dismantling plant (the flow now is from consumer K to dismantling plant $Q0$ till the production plan$I$), but it also includes the set non-collection entity that contains all the units not collected because not necessary to the recycling process. The other set of soft constraint is given by the support activities and its formulated in the following general form:

$$(o_s^t \cdot x_s^t) - \delta_s^{+} = 0, \forall s \in S$$

Where the t stands for the type of flow that can be forward f or recycling r whreas the index s represent each specific step on the value chain that can be i for a production plant, j for the distribution center, k for the retailing center and q for dismantling plant. COnstitutes a soft constraint also the achievement of the demand by the supplied product, the deriving constraint is reported as follows:

$$x_k + \tilde{\delta_k^-} = EV[d_k], \forall k \in K$$

In this case, the demand is not a fully determined value but is determined through a stochastic process that; in this case, the deterministic equivalent formulation is used by calculating the expected value of the demand of each retailing center. Changing the perspective from the forward flow to the recycling flow some additional soft constraints are necessary; these constraints are respectively the fuzzy preferences of the DM and the minimization of the waste produced. The first soft constraint is given by the following equations:

$$x_q + \delta_q^- = b_k, \forall q \in Q0$$

$$\mu_q + \frac{\delta_q^-}{n_{max}} = b_k, \forall q \in Q0$$

Where the n_max represent the legal boundary of each dismantling facility, in case the legal boundary is not respected the flow will not be allocated to the facility but to any other disposable facility. Above the lower limit imposed by the legal constraints, we have the goal of the DM that may require a specific target to be achieved by the dismantling plant. The value μ_q serves to indicate the achievement of this goal, where 0 stands for not achieved at all and 1 indicates full achievement. Lastly, we have the goal of cutting waste, which is defined as the amount capable to be collected but not initiated to the recycling process, the specific deviational variable is part of the balance equation of the last node of the supply chain network and is expressed as follows:

$$\sum_{k=1}^{K}(x_k^r - x_i^r) - \delta_i^+ = w_i, \forall i \in I$$

Hard Constraints

The hard constraints represent the boundaries in which the solution will not be feasible such constraints may be implied by the approach itself, such as the positivity of the deviational variables, or implied by the model, is an example the limit recycled goods that should not be greater then the goods demanded. In the case under scope the hard constraints are:

- The conservation of the flow: such constraint is needed in the nodes where is not necessary the use of any deviational variable, is an example the flow of goods from the production plant to the distribution warehouse, in that case, there's a need to maintain the balance of the inflow and the outflow to be 0;

- The upper limit on the recycled product, which cannot be greater than the delivered product;

- The limit on the product to be recycled to an amount sustainable for the production plant, since the return rate is different from each and every retail, is not worth to collect and recycle all the possible product available but just the quantity necessary for the production plant.

- The limit on the capacity of each shipment: not every quantity can be shipped from a node to another, this may due to some limitation imposed by the carrier service.

From this constraint which is given by the modeled scenario it's necessary to apply other constraints such as the aforementioned positivity of the deviational variables and the value range of the fuzziness membership function value that as to be a number between 0 and 1, this constraint is imposed by the fuzzy set definition.

Model formulation

Given the objective function, the soft constraints and the hard ones, the model is proposed in its mathematical form at the end of the following section. In the next section the model will be subject to a weight sensitivity analysis and then the weights will be assigned using an Analytical Hierarchy Process, subsequently the model will be solved via a linear programming solver and the results, with the weights derived from the AHP will be further analyzed.

$$
\begin{aligned}
\underset{\delta^-,\delta^+}{\text{minimize}} \quad & w_1^\star\Big(\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{q=1}^{Q0}\sum_{i=1}^{I}\delta^+_{ijkqi}\Big)+ \\
& w_2^\star\Big(\sum_{i=1}^{I}\delta_i^+ + \sum_{j=1}^{J}\delta_j^+ + \sum_{k=1}^{K}\delta_k^+ + \sum_{q=1}^{Q0}\delta_q^+ + \sum_{i=1}^{I}\delta_i^+\Big)+ \\
& w_3^\star\Big(\sum_{k=1}^{K}\tilde{\delta_k^-}\Big) + w_4^\star\Big(\sum_{q=1}^{Q0}\delta_q^-\Big) + w_5^\star\Big(\sum_{i=1}^{I}\delta_i^+\Big) \\
\text{subject to} \quad & \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c^f_{ijk}x^f_{ijk} - \delta^+_{ijk} = 0, \\
& \sum_{k=1}^{K}\sum_{q=1}^{Q0}\sum_{i=1}^{I} c^r_{kqi}x^r_{kqi}, -\delta^+_{kqi} = 0, \\
& (o_i^f \cdot x_i^f) - \delta_i^+ = 0, (o_j \cdot x_j^f) - \delta_j^+ = 0, && \forall i \in I, \forall j \in J, \\
& (o_k \cdot x_k^f) - \delta_k^+ = 0, (o_q \cdot x_q^r) - \delta_q^+ = 0, && \forall k \in K, \forall q \in Q0, \\
& (o_i^r \cdot x_i^r) - \delta_i^+ = 0, && \forall i \in I, \\
& x_k + \tilde{\delta_k^-} = EV[d_k], && \forall k \in K, \\
& x_q + \delta_q^- = b_k, && \forall q \in Q0, \\
& \mu_q + \frac{\delta_q^-}{n_{max}} = 1, && \forall q \in Q0, \\
& \sum_{k=1}^{K}(x_k^r - x_i^r) - \delta_i^+ = w_i, && \forall i \in I, \\
& \sum_{i=1}^{I} x_i^f - \sum_{j=1}^{J} x_j^f = 0, \sum_{k=1}^{K} x_k^r - \sum_{q=1}^{Q0} x_q^r = 0, \sum_{q=1}^{Q0} x_q^r - \sum_{i=1}^{I} x_i^r, \\
& \lambda\sum_{i=1}^{I} x^r_{kqi} \le x^r_{iq}, && \forall k \in K, \forall q \in Q0, \\
& \sum_{k=1}^{K}\sum_{j=1}^{J} r_k x^f_{kji} \le \sum_{k=1}^{K} d_k, && \forall i \in I, \\
& r_k x_k^f = x_k^r && \forall k \in K, \\
& x \in \mathbb{R}^+, \mu \in [1,0],
\end{aligned}
$$

2.5 Results and Conclusion

The model was tested with a set of data with the following features:

- N. 1 production plant;
- N. 4 links from the production plant to the distribution centers (1toN);
- N. 4 distribution center;
- N. 36 links from distribution center to retail center, in this case, the relations were not made NtoN since each distribution center was allowed to fill only some specific retail center and not the entire number of them;
- N. 27 retailing centers;
- N. 108 links from the retailing center to the dismantling plants and to the "noncollection" plant (NtoN);
- N. 4 dismantling plants, including the "noncollection" plant;
- N. 4 links from the dismantling plant to the production plant (Nto1).

The model was solved using the NEOS servers[FMM97][Dol01] by their API with the data sent through a script built in R, using the R[R C17] package rneos; since the problem was linear the solver chosen was the CPLEX. Further analysis were developed using the tools delivered by R and it's packages.

2.5.1 Sensitivity analysis

In the sensitivity analysis, the value of the weights was preemptively determined, since the model represents two different flows of products: delivered to the costumer and recycled the aim of the sensitivity analysis was to measure all the possible frontiers between DM preferece toward greener goal in comparion with the forward flow driven preferences. Therefore the objectives were grouped in two different clusters, the first was the cluster of "push" objective in the sense of the supply push of products to the customer, conversely the second cluster was characterized by the pull by the firm for recycling units instead of simply disposing the after consumer returned them. In the figure represented below is possible to observe the trade-off concearning the weight calibration by the Decision Maker preference. For the two clusters was given a set of possible weight alternatives folowing the equation reported below:

$$y = 1 - x, \quad \forall x \in X, X = (0, 1)$$

Where x is the preference for a consumer-driven preference as we defined as "push", and y stands for the preference of the DM toward greener choice. The aftermath was that a greener choice will always result in an increase of the optimal solution resulting in higher costs whereas a "push" driven preferences will accomplish a better result in economic terms but with the other side of the coin, namely a process which barely comply with the legislation, as set by the fuzzy goal applied on the recycling plants.

Given the knowledge about the trade-off that DM faces between greener choices with comparison with choices that may satisfy customers in the first place, the option was to choose a robust framework to select a set of weights that are consistent with the expectation that the Decision Maker has about the process of Green Supply Chain. The chosen framework was the Analytical Hierarchy Process [Saa80].

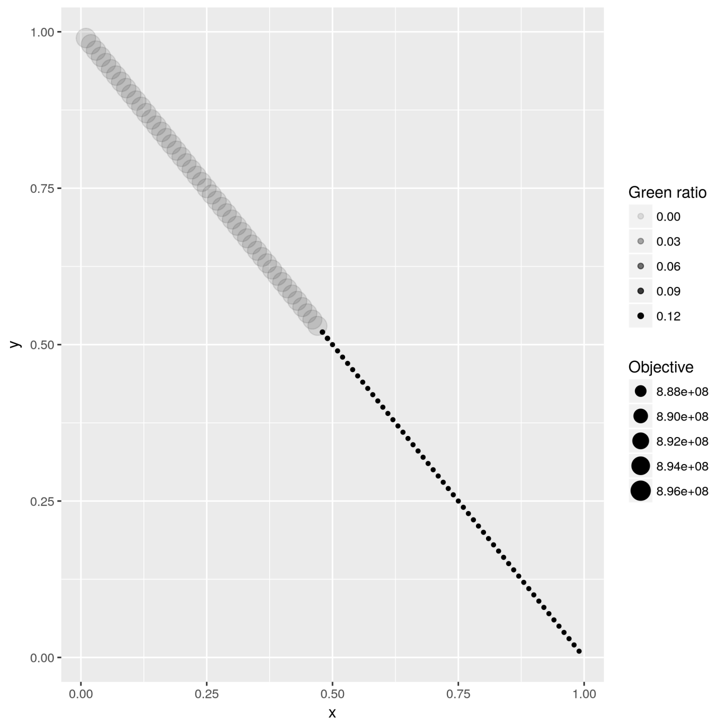

Figure 2.5: Tradeoff between different combination of DM preferences

The process was three tired:

- Step 1: given the set of criteria defined in the previous sections the pairwise comparison matrix was computed indicating the importance of each criterion with respect to the other;
- Step 2: the pairwise matrix elements were normalized and consequently the priority vector was obtained;
- Step 3: the last step consists in the test of the consistency of the value reported and then the validation with respect to a randomly generated matrix consistency index.

The resulting table reports the pairwise comparison matrix pre-normalization, from such matrix, is possible to observe how the attention of the DM is particularly interested in fulfilling the demand in the first place and then cutting potential waste.

Criteria	Transportation	Supporting Activities	Recycling Goal	Fulfill Demand	Cut Waste
Transportation	1.00	2.00	3.00	0.14	0.33
Supporting Activities	0.50	1.00	2.00	0.14	0.50
Recycling Goal	0.33	0.50	1.00	0.11	0.20
Fulfill Demand	7.00	7.00	9.00	1.00	4.00
Cut Waste	3.00	2.00	5.00	0.25	1.00
Total	*11.83*	*12.50*	*20.00*	*1.65*	*6.03*

Table 2.1: Pairwise comparison matrix

Then from the normalization of the priority vector was obtained, as reported from the pairwise matrix the attention of the DM was primarily toward demand fulfillment and waste minimization, however, the priority expressed may contain some inconsistency. Therefore, in order to avoid this situation, a consistency test was performed with respect to a random pairwise matrix.

The consistency ratio scored by the following preferences was 3.70% below the rejection value of 10%, therefore the priority vector was accepted. The resulting priority vector was used to calibrate the weights of the model. After the

Criteria	Weight
Transportation	0.11
Supporting Activities	0.08
Recycling Goal	0.04
Fulfill Demand	0.57
Cut Waste	0.20
Total	*1.00*

Table 2.2: Priority vector

Objective	Value
Transportation	146689000
Supporting Activities	749030000
Recycling Goal	170000
Fulfill Demand	0
Cut Waste	0
Total	*895889000*

Table 2.3: Objective value according to the model

calibration, the model was solved through the CPLEX algorithm. The objectives achievement are reported in the table below.

From the table is noticeable the achievement of the last two objectives which corresponds to the preferable objectives by the Decision Maker. Such achievement is better represented by the figure 2.6 which sees the symbolic NOCO entity scoring zero inflows, meaning that none of the retail stores opted for not recycling the WEEE disposed of by the consumers. the other first two goals implied non zero value in case of demand fulfillment and finally, the recycling goal was achieved only partially because of the lower importance set by the Decision Maker.

2.5.2 Final remarks

Green Supply Chain is a huge and popular topic nowadays and the past researchers on the field show how this topic is a mixture of different objectives, from forward to backward flow, and last but not least the regulations imposed by the countries that try to minimize waste risk imposing qualitative and quantitative restrictions. Because of this complex environment, Multi-Criteria Decision tools play and will play a fundamental role in this field and probably a new set of researches with the corroboration of the two will take place in the short term.

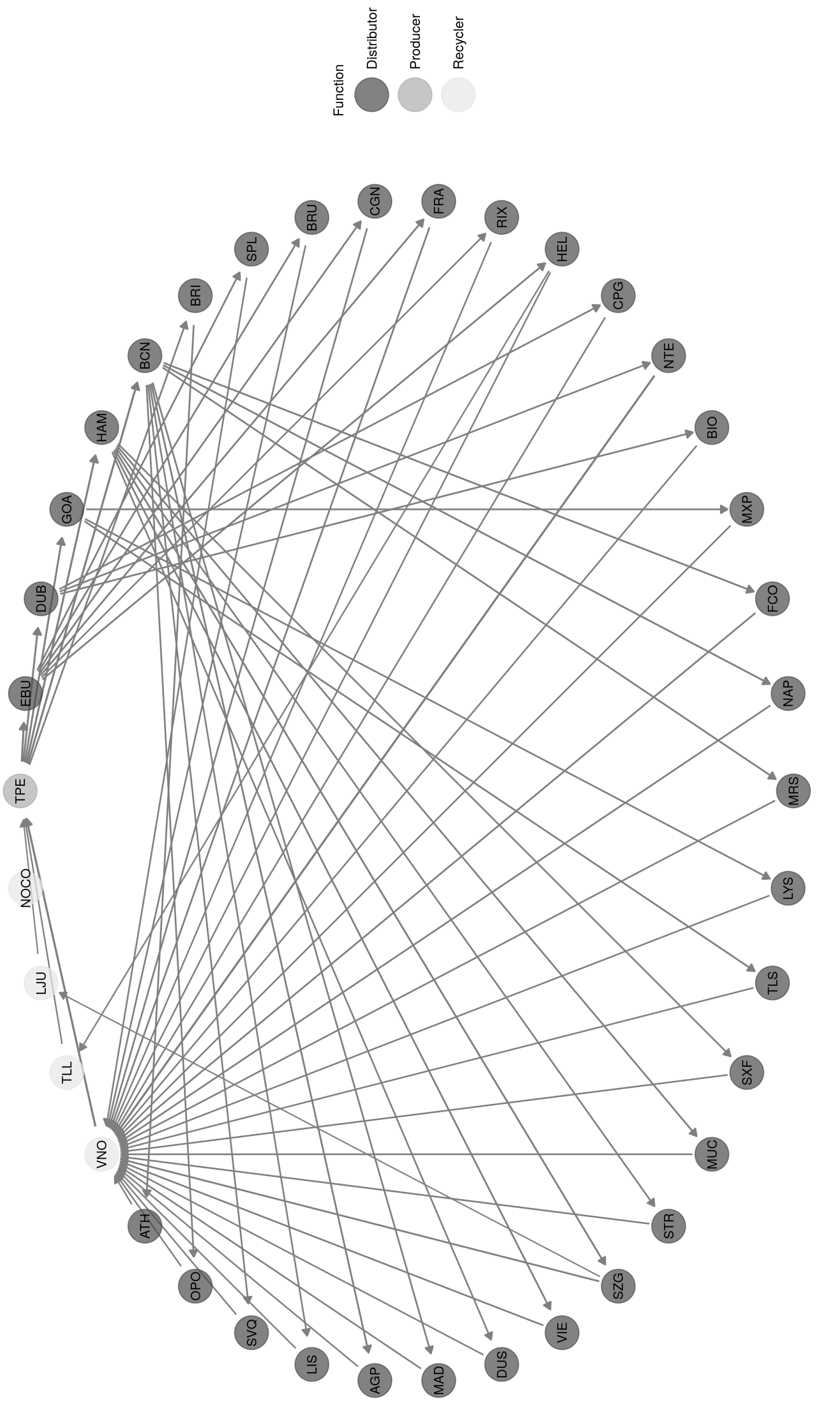

Figure 2.6: Graphical interpretation of the Green Supply Chain network

Conclusion

As highlighted by the models proposed, the Goal Programming approach may indeed turn out to be a great tool in the hands of the Decision Maker; because of that is largely applied by Supply Chain professionals and academics to model different problems they may face. Apart from the conclusion exposed previously about each model, from the cross conclusion of both the models proposed a series of eight facts may be identified that range from the advantages of multicriteria analysis to the pitfalls that GP has if implemented badly. In more detail such facts are:

- Multicriteria analysis and Goal Programming, in particular, is a sound tool for decision making in multinational context;
- Goal Programming is very versatile and can be implemented in almost any situation involving linear programming or mixed integer linear programming;
- The software base to solve GP problems can scale with extreme simplicity;
- Its simplicity may incur in bad modeling;
- The fields of research are not homogeneously developed leaving grey zones that find difficulties to be up to date with the latest changes in the environment;

- Operational related fields result in great expansion;
- Law related fields result in abandon.

Developing the third point, the scalability may be seen as the advantage that such approach has in its implementation given the software base a Decision Maker has; such advantage may be defined in terms the great number of capabilities that such software base can achieve. An example of such feature can be shown in the difference between the software base used in both the first and the second model to solve the problem given. In the first model we had the LINGO software which comes with a built-in Graphical User Interface (GUI) and with a limited degree of automation, meaning that is not possible to insert such tool in a fully automated workflow although the data gathering process can be automated with certain source of data, such as spreadsheets, which however works only with Excell and on Windows, leaving the problem of implementing such approach in UNIX based system without any use of virtual machines. A more scalable result would have been obtained with the LINDO API (or using directly the solvers API such as the GLPK[Sot09]), providing bindings for all the major programming languages available such as R and Python. In the second model the potential for scalability was higher because we keep separated each step and we used a flexible programming language such as R to handle all the sending process of the model on the solver (in our case the CPLEX in the NEOS server) as well as the process of reading the result an build useful dashboards out of it. However an even more scalable workflow would have been possible if the data related process was even more defined and not just based only on spread spreadsheets, a tentative workflow is given in the following list:

- Data filling process with a relational database;
- Data parsing with a scripting language such R using packages like sqldf[Gro17] or dplyr[Wic+17] in order to SQL query the database;
- Model data file filling using R scripting;
- Model (with data an instructions) sending to a solver, that can be both an in form of SaaS or a built-in solver accessed through its API;
- Result gathering and further analysis;
- Graphical rendering with specific plotting libraries such as ggplot2[Wic09] or the plotly[Sie+17] API (the last one should be intended for a more interactive purpose).

Speaking about the last three facts highlighted previously a lot of attention is given to operational problems however the same cannot be said when the topics shifts, and from Supply Chain we start dealing with international tax planning problems, as suggested before this may be due to the specific skills that such practitioner has on this field. Because of that is important to renew the call to action to model in a greater way these problems, which in most of the cases boils down to multi-objective problems that can be solved through Goal Programming.

Last but not least, is also important to highlight as done before that with such a versatile tool the skills of the modeller are much more needed when the situation gets very complex, leading to unplanned situations that may result in unfeasible solutions or even worse, sub-optimal ones, in such cases a technique that may turn out to be useful for the modeller could be starting with a minimum viable model and then build it up in terms of horizontal complexity (more variables) and vertical complexity (more constraints).

Aknowledgements

This thesis wouldn't have been possible without the R project, their packages provided a good link between models built in LINGO and AMPL[FGK97] and solved (in case of the Green Supply Chain model) using a cloud server provider of solvers such as NEOS, plus the ease ofuse of such language mixed with the great community supporting it makes it probalby one of the most powerfull language ever created.
The author of this thesis is also grateful to both the Supervisor and Co-Supervisor because of the assistance given to understand the problems faced in a better mathematical perspective, and also for the provision with tips and tricks in modeling some of the occurrences faced along this journey.
A special thanks goes also to the practitioners that helped me in shaping the model of international taxation; their help was so much usefull as the information and insights they provided me for the case study proposed in the first chapter.

Last but not least I would like to thank personally the people that helped me and supported me along this incredible journey, without your support I wouldn't have been here. Form these people I would really like to thank two of them, namely Vittoria, my partner that supported an suffered me for all this time and turned out to be a lighthouse in periods where my thoughts were not so clear, and Bruno for his true friendship and vivid curiosity which helped me gain a different perspective on this long but fulfilling journey; thank you again.

Appendices

Appendix A

Profit allocation model code

The following code snippet represent the model as defined in Chapter 1, the model was written in LINGO proprietary language for which file extention is the *.lng:

```
!Name: GP entity allocation model;
!Note: PLI constraints linearized and FMCU transformed as a function of ROS;

MODEL:

!Define the sets;

SETS:
DEVIATION_SET_SHORT / 1..2/: P;
DEVIATION_SET / 1..3/: NM,PM;

DECISION_SET / 1..142/:XC,XR;
DATA_SET/1..142/:TX,CE,LQ,UQ,MQ,PLI;

ENDSETS

DATA:

rev=@OLE('ExLingo.xlsx', 'rev');
emp=@OLE('ExLingo.xlsx', 'emp');

PLI=@OLE('ExLingo.xlsx', 'pli');
TX=@OLE('ExLingo.xlsx', 'ct');
CE=@OLE('ExLingo.xlsx', 'gni');
LQ=@OLE('ExLingo.xlsx', 'pl');
```

```
UQ=@OLE('ExLingo.xlsx', 'pu');
MQ=@OLE('ExLingo.xlsx', 'pm');

w1=0.16;
w2=0.30;
w3=0.54;

ENDDATA

MIN = (P(1)*w1)+(P(2)*w2)
+ (@SUM(DEVIATION_SET(I): (NM(I)+PM(I)))*w3);

SUM = (P(1))+(P(2))
+ (@SUM(DEVIATION_SET(I): (NM(I)+PM(I))));


!Cost minimization;
@SUM( DECISION_SET (I) :
 (XC(I)*CE(I))
) - P(1) =0;

!Tx base min;
@SUM( DECISION_SET (I) :
 ((XR(I) - (XC(I)*CE(I))) * TX(I))
) - P(2) =0;

!PLI allocation Linearized;
@FOR(DECISION_SET(I):
((XR(I) - (XC(I)*CE(I))))
>= LQ(I) * XR(I));


@FOR(DECISION_SET(I):
((XR(I) - (XC(I)*CE(I))))
<= UQ(I) * XR(I));

!Value chain;

0.13*(rev-@SUM(DECISION_SET(I) : XC(I)*CE(I)))=@SUM(DECISION_SET(I) :
@IF(PLI(I) #EQ# 1, XR(I)-XC(I), 0
```

```
))
+NM(1)-PM(1);

0.19*(rev-@SUM(DECISION_SET(I) : XC(I)*CE(I)))=@SUM(DECISION_SET(I) :
@IF(PLI(I) #EQ# 2, XR(I)-XC(I), 0
))
+NM(2)-PM(2);

0.68*(rev-@SUM(DECISION_SET(I) : XC(I)*CE(I)))=@SUM(DECISION_SET(I) :
@IF(PLI(I) #EQ# 3, XR(I)-XC(I), 0
))
+NM(3)-PM(3);

@FOR(DEVIATION_SET_SHORT(I) : P(I)>=0);
@FOR(DEVIATION_SET(I) : NM(I)>=0);
@FOR(DEVIATION_SET(I) : PM(I)>=0);

rev = @SUM(DECISION_SET(I) : XR(I));
emp = @SUM(DECISION_SET(I) : XC(I));
```

Appendix B

Green Supply Chain model code

The following code snippet represent the model as defined in Chapter 2, the model was written in AMPL proprietary language for which file extention, specifically for the model part, is the *.mod:

```
set D_CITY; #declare the set of distribution center
set W_CITY; #declare the set of retail center
set R_CITY; #declare the set of recycling cente

set DW_LINKS within (D_CITY cross W_CITY); #declare the links distribution vs retail;
set WR_LINKS within (W_CITY cross R_CITY); #declare the links retail vs recycling
set WW_LINKS within (W_CITY cross W_CITY);

set WEIGHTS = 1..5;

param p_supply >= 0; #amount produced by the plant in Taipei
param w_demand {W_CITY} >= 0; #amount requred at the retail centers
param r_demand >= 0;
param we{WEIGHTS} >=0, <=1;

#check: p_supply = sum{j in W_CITY} w_demand[j]; #check that demand do not overflow supply
#check: sum{j in W_CITY} w_demand[j] = r_demand;

param pd_cost {D_CITY} >= 0; #shipment cost from plant to distribution
param dw_cost {DW_LINKS} >= 0; #shipment cost from distribution to retail
param wr_cost {WR_LINKS} >= 0; #shipment cost from retail to recycling
param rr_cost {R_CITY} >= 0; #shipment cost from recycling to plant
```

```

param pd_cap {D_CITY} >= 0; #capacities for each entity
param dw_cap {DW_LINKS} >= 0;
param wr_cap {WR_LINKS} >= 0;
param rr_cap {R_CITY} >= 0;
#cost parameters (node part)
param production_cost >= 0;
param distribution_cost{D_CITY} >= 0;
param retail_cost{W_CITY} >= 0;
param recycle_cost{R_CITY} >= 0;
param reuse_cost >= 0;
#recycling part
param return_coefficient{W_CITY} >= 0;

#Fuzzy membership function
param limit1 {R_CITY} > 0;
param goal {R_CITY} >= 0;

#Opportunity cost of not using the waste
param waste_cost >= 0;

#Goalprogramming deviational variables
var pd_pdcost{D_CITY} >= 0;
var pd_dwcost{DW_LINKS} >= 0;
var pd_wrcost{WR_LINKS} >= 0;
var pd_rrcost{R_CITY} >= 0;
var nd_fuzzy{R_CITY} >= 0;

var pd_production >= 0;
var pd_distribution{D_CITY} >= 0;
var pd_retail{W_CITY} >= 0;
var pd_recycle{R_CITY} >= 0;
var pd_reuse >= 0;

var pd_waste >= 0;

var waste >=0;

var nd_retail_demand{W_CITY} >=0;
#
```

```
var collected {W_CITY} >= 0; #variable indicating the collected units per retail

var mu{R_CITY} >= 0, <= 1;

var obj{WEIGHTS};

minimize z: we[1] * sum {i in D_CITY} pd_pdcost[i] +
            we[1] * sum {(i,j) in DW_LINKS} pd_dwcost[i,j] +
            we[1] * sum {(i,j) in WR_LINKS} pd_wrcost[i,j] +
            we[1] * sum {i in R_CITY} pd_rrcost[i] +
            we[2] * pd_production +
            we[2] * sum {i in D_CITY} pd_distribution[i] +
            we[2] * sum {i in W_CITY} pd_retail[i] +
            we[2] * sum {i in R_CITY} pd_recycle[i] +
            we[2] * pd_reuse +
            we[3] * sum {i in R_CITY} nd_fuzzy[i] +
            we[4] * sum {i in W_CITY} nd_retail_demand[i] +
            we[5] * pd_waste;

node Plant: net_out = p_supply;
node Dist {i in D_CITY};
node Whse {j in W_CITY};
node Whse_collection {j in W_CITY}; #specific nodes for the collection
node Recy {k in R_CITY};
node Retu: net_in = r_demand + waste ;

arc PD_Ship {i in D_CITY} >= 0, <= pd_cap[i],
  from Plant, to Dist[i];

arc DW_Ship {(i,j) in DW_LINKS} >= 0,  <= dw_cap[i,j],
  from Dist[i], to Whse [j];

arc WW_Ship {(i,j) in WW_LINKS} >= 0,
  from Whse[i], to Whse_collection[i] return_coefficient[i];

arc WR_Ship {(i,j) in WR_LINKS} >= 0,  <= wr_cap[i,j],
  from Whse_collection[i], to Recy[j];

arc RR_Ship {i in R_CITY} >= 0,  <= rr_cap[i],
```

```
  from Recy[i], to Retu;

#Soft constraints of the arcs in the network
subject to pd_obj{i in D_CITY}:
        PD_Ship[i]*pd_cost[i] - pd_pdcost[i] = 0;
subject to dw_obj{(i,j) in DW_LINKS}:
        DW_Ship[i,j]*dw_cost[i,j] - pd_dwcost[i,j] = 0;
subject to wr_obj{(i,j) in WR_LINKS}:
        WR_Ship[i,j]*wr_cost[i,j] - pd_wrcost[i,j] = 0;
subject to rr_obj{i in R_CITY}:
        RR_Ship[i]*rr_cost[i] - pd_rrcost[i] = 0;
#Soft constraints of the node (operation costs)
subject to production:
        p_supply * production_cost - pd_production = 0;
subject to distribution{i in D_CITY}:
        PD_Ship[i] * distribution_cost[i] - pd_distribution[i] = 0;
subject to retail{j in W_CITY}:
        sum {(i,j) in DW_LINKS} DW_Ship[i,j] * retail_cost[j] -
 ↪  pd_retail[j] = 0;
subject to recycle{j in R_CITY}:
        sum {(i,j) in WR_LINKS} WR_Ship[i,j] * recycle_cost[j] -
 ↪  pd_recycle[j] = 0;
subject to reuse:
        r_demand * reuse_cost - pd_reuse = 0;
#Soft constraint waste minimization
subject to wastecontroll: (RR_Ship["NOCO"] * waste_cost) - pd_waste = 0;
#Collection variable (just for showing how many units are collected per
 ↪  retail)
subject to collection{j in W_CITY}:
        sum {(i,j) in DW_LINKS} DW_Ship[i,j] * return_coefficient [j] -
 ↪  collected[j] = 0;

#Fuzzy goal programming part -not working-
subject to fuzzy_recy{j in R_CITY}:
        sum {(i,j) in WR_LINKS} WR_Ship [i,j] + nd_fuzzy[j] >= goal[j];
subject to fuzzy_recy2{j in R_CITY}:
        sum {(i,j) in WR_LINKS} mu[j] + (nd_fuzzy[j]/limit1[j]) = 1;

subject to dw_obj_flow{j in W_CITY}:
        sum {(i,j) in DW_LINKS} DW_Ship[i,j] + nd_retail_demand[j] =
 ↪  w_demand[j];
```

```

#OBJECTIVE definition
subject to obj1:
        sum {i in D_CITY} pd_pdcost[i]        +
        sum {(i,j) in DW_LINKS} pd_dwcost[i,j] +
        sum {(i,j) in WR_LINKS} pd_wrcost[i,j] +
        sum {i in R_CITY} pd_rrcost[i] = obj[1];
subject to obj2:
        pd_production +
        sum {i in D_CITY} pd_distribution[i] +
        sum {i in W_CITY} pd_retail[i] +
        sum {i in R_CITY} pd_recycle[i] +
        pd_reuse = obj[2];
subject to obj3:
        sum {i in R_CITY} nd_fuzzy[i] = obj[3];
subject to obj4:
        sum {i in W_CITY} nd_retail_demand[i] = obj[4];
subject to obj5:
        pd_waste = obj[5];
```

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