Conceptualizing Organizational Growth by Biomimicking the Growth of Genetically Modified Trees

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Abstract

The development of human-based organizations for the purpose of surviving during the transitional crisis periods is always faced with continuous challenges concurrently with the deployment of new technologies, with new competitors entering the market, with changes in customers' needs, with new regulations enforced, etc. As a result of not successfully passing transitional crisis periods, many businesses go bankrupt every year, and therefore organizational developers need to consider new approaches for development. Biomimicry is one of the rising approaches that has not been studied well for organizational development purposes. Biomimicking trees inspire organizational developers in recent years. However, there is still no much information about biomimicking genetically modified trees since GMOs played a significant role in many industries. This research is trying to mathematically determine whether biomimicking genetically modified trees are a better representation than normal trees for organizational development purposes. The research did mathematically find that GM trees are superior over their normal version on relevant econometrics of human-based organizations. However, the connection between trees and human-based organizations could not be considered in the mathematical model due to the finding of this research that the connection is based on the universal growth pattern of all natures processes "S-curve" that is not quantifiable per up to date findings in this research.

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1. Introduction

Organizational development is targeted by researchers and specialists; a lot of advancement and success have been achieved, as a result. However, continuous improvement and development for an organization to remain sustainable and competent require new methods and approaches. One of the old and ongoing business strategies to improve a specific area of an organization is to mimic another organization that has been successful in a similar targeted area. This procedure of organizational change is called isomorphism. Mimicking a successful cluster of competitors or a specific successful competitor can be a good isomorphic example to follow for improvement purposes (DiMaggio & Powell, 1983). However, the utilization of isomorphism is not limited to successful competitors. Utilizing nature, too, is one of the new rising approaches in the 21st century for isomorphic organizational change (Woolley-Barker, 2016). It is generally believed that nature's processes are good candidates as they are believed to follow the same growth pattern. The natural growth pattern is a universal one, as shown in figure 1.1, in which all natural systems follow including human-based organizations as human is the natural and organic component of organizations. This is supported by *Benjan* and *Lorente* in the following exert from a 2011 publication.

> "When something spreads on a territory, the curve of territory size versus time is S-shaped: slow initial growth is followed by much faster growth, and finally by slow growth again. The corresponding

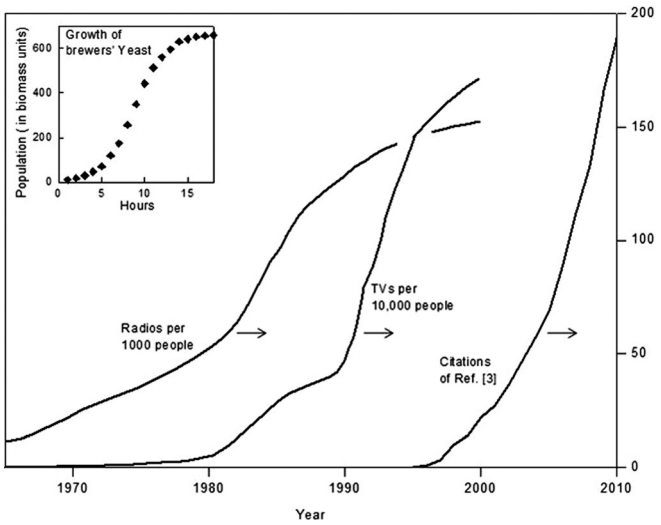


Figure 1.1: Examples of S-curve phenomena: the growth of brewer's yeast, the spreading of radios and TVs, and the growth of the readership of scientific publications (Bejan & Lorente, 2011)

curve of the rate of spreading versus time is bell-shaped. This phenomenon is so common that it has generated entire fields of research that seem unrelated: the spreading of biological populations, tumors, chemical reactions, contaminants, languages, news, information, innovations, technologies, infrastructure, and economic activity. The natural phenomenon is not a particular mathematical expression for the S-shaped curve." "We have shown that this pattern can be predicted entirely as a natural flow design." (Bejan & Lorente, 2011)

This further supported by *Accenture's* research, human-based organization in particular also follow the same natural growth pattern; and no wonder since human is the natural and organic component that makes an organization a nature's subsystem. (*Nunes* & *Breene*, 2011).

It is also believed that nature is one of the most successful systems to imitate as it successfully remained existent and sustainable in providing all biological needs for billions of years from nanoscale to solar scale (Benyus, 2002). In 1962, the term biomimicry was used for the first time to describe the “science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems” (*Benyus*, 2002).

Nature, including the ecological system in general, is a very complex system that has countless subsystems. Over the past years, environmental and business researchers have tried to make a connection between natural processes and human-based organizations, but they faced substantial obstacles in biomimicking natural systems, including complexity (*Woolley-Barker*, 2016). At the atomic level, nature’s processes follow unknown sophisticated rules so that the outcomes of nature’s processes are unforeseen and uncontrollable and look random per up-to-date technology (*Bensaude* et al., 2002). Moreover, per up-to-date knowledge, the practice of using biomimicry of naturally occurring trees for projecting organizational development and growth is inhibited by naturally occurring randomness and complexity. For example, the Chinese reforestation plan for the *Gobi* Desert at the northern border with Mongolia has been successful. It was found that the behavior of “GM” genetically modified trees was not as random or unpredictable as the normal trees in the research. As a result, GM trees can be used to achieve more narrow targets as they are well controlled, and their behavior is well known (*Bensaude* et al., 2002). From this standpoint, the reduction in randomness and complexity makes the GM trees more suitable for use in exploring

biomimicry of GM trees and organizational growth. From another standpoint, trees in particular share the same S-curve growth pattern with human-based organizations where the natural growth of trees can be represented as three phases. The system grows slowly in the early years, followed by a sharp rise in growth in the second phase. Then the system experiences a slowdown in the growth rate in the third phase in the later years (*Murarka*, 2013). The initial impression is that the outcomes of biomimicry might not be ultimate where GM trees could be more successful or representative to organizational growth than normal trees, within certain parameters.

1.1. Purpose of research

The purpose of this research is to help organizational developers, who consider taking inspiration from the growth of trees as a successful nature's model, to choose either genetically modified trees or normal trees as a better growth model for human-based organizations. It is not the purpose of this work to suggest that by observing GM plants that an organization can plan for the future. It is, however, believed that a great deal could be learned from making direct comparisons between two seemingly dissimilar organic-based groups when it comes to structuring an organization to be more resilient and, therefore, more successful. This is supported by an earlier work of *Rothschild*; they had the same conclusion that organizations have a similar mechanism as the one in natural systems but from an economic standpoint. *Rothschild* stated in his book "Bionomics: The Inevitability of Capitalism" that "a capitalist economy can best be comprehended as a living ecosystem. Key phenomena observed in nature –

competition, specialization, co-operation, exploitation, learning, growth, and several others – are also central to business life." *Rothschild* named this finding as economics bionics. The main idea of his finding is that an organism is defined by the information in its gene and its relationships with its prey, competitors, and predators. In the same way, an economic organization is also defined by its technology and by its associations with its suppliers, competitors, and customers.

In another work, *Korhonen* thinks that the 'voice of nature' will always be indirect in a human's processes such as that of corporate or industrial systems, so that our knowledge about the ecosystem functions will always be based on uncertainty. This, exactly, is the introductory approach appreciated by this research that supports the idea of encouraging to find an ecosystem that somehow tends to be more controlled and stable, such as GMOs, for organizational development purposes and through the use of biomimicry.

The current state of the art in this area is that many successful natural processes and designs, including the growth of trees and bio-diversity, have been inspiring organizational developers in their dedicated practices for decades. However, the natural growth of genetically modified trees as a superior organism over the normal trees has never been investigated or taken into consideration before for the sake of improving organizational growth.

This research will particularly fill a void in the current body of knowledge in which an investigation will be conducted to figure out if the growth of genetically

modified trees is a better representation of generalized organizational growth than non-GM trees.

1.2. Problem statement

It is hypothesized that the utilization of GM trees will help to reduce the influences of complexity and apparent randomness than does ordinary non-GM trees do when making the connection to organizational growth. This reduction in randomness and complexity is the basis for this research into the relationship of variables associated with GM plants of their relationship to organizational growth.

Organizational growth can be characterized by having several phases of transitional crisis periods. These phases of transitional crisis periods can be described as a series of developmental phases through which organizations aspire to pass as they grow. Each phase starts with a period of evolution, with steady growth and stability, and ends up with a crisis period where a revolutionary transition is required (*Greiner*, 1998.) Further explanations are detailed in sections 2.6.2 and 2.6.3.

It is not suggested that any organization could simply watch a set of trees and know what to do next. The general purpose of this research is to utilize analytical techniques to explore the relationship between a less random and complex set of GM modified organisms, such as GM trees, and organizational growth during crisis periods or periods of transition. The results of this research were not intended to be prescriptive in nature but more in line with a predictive tool. It is hypothesized that the analysis conducted will provide insight into the research

question proposed: "Is the growth of genetically modified trees a better representation of generalized organizational growth than past attempts using natural growth cycles of non-GM trees?”

1.3. Framework

The quantitative method of data analysis was used to determine the results from the data gathered. The result of this study should be useful to organizational developers who consider biomimicry as a tool for development and identification of systemic architectural characteristics. Biomimicry, in general, is not limited to just organizational change. It has been a successful tool for all fields, including architectural design (*Mortice*, 2016) and product improvement (*Hennighausen* and *Roston*, 2015), etc.

1.4. Basic assumptions

Information contained in articles are representative and correct. Since the basic assumption that articles are correct, it would be a logical assumption that using data found in less variable GMO trees would improve the ability to model this phenomenon.

2. Literature reviews

2.1. Organizational growth

When discussing organization growth, there are numerous different measures available. These measures are dependent on the definition of organizational growth that is being used; thus, they can be contradictory in nature. These measures include accounting-based measures such as return on investment, stock market, cash flows, sales, number of employees, assets, etc. These traditional ways of measuring organizational growth are inherently a dynamic measure of change over time. Organizational growth is also dependent on the type of organization being measured. The results measure being used will differ for new ventures versus fortune 500 corps, from manufacturing companies versus service firms, public to private companies, and for-profit versus nonprofits.

The different concepts of “growth” makes the actual assessment of organizational growth more complex and sometimes contradictory. Most growth studies concentrate on three basic areas: sales growth, number of employees, and assets. The vast majority of organizations utilize sales as their only measure of growth. This is usually taking a comparison of one time period to the next or some other predetermined time frame to measure short and long-term growth.

Other variables that have been considered in projecting organizational growth range from top management’s influence, organizational strategies, and industry characteristics, size, and age. For example, in 1990, *Eisenhardt* and *Schoonhoven* found that the size of the top management team is positively

affecting organizational growth. This supports the same result found by *Freeser* and *Willard* in 1990. In contrast, in 1992, *Hamilton* and *Shergill* found a good connection between diversity and organizational growth while it was not found in the 1987 investigation carried out by *Varadarajan* and *Ramanujam*. Therefore, the sheer number of variables that can be included in the assessment of organizational growth leads to a very complex and cumbersome process that their results are questionable. There is the need for a conceptualized comparison that develops a more basic approach to organizational growth. One that can be adapted and utilized in a location or business classification specific manner (*Weinzimmer* et al., 1998).

2.2. Genetically modified organism "GMO"

An organism is an open system that exhibits any form of life; it can be a system that is consisted of a cluster of cells such as animals, plants, and fungus or even micro-organism that is consisted of a singular cell such as bacteria. The gene is the very small component of the cell in any organism. Genes "Genome" carry the specifications of all the organism traits and functions. Each specification is stored in a DNA where every sequence of DNAs is a different gene. Modifying an organism gene results in altering one of or some of the organism's functions or traits (Phillips, 2008). Modification of organism genes aims to develop organisms and make them more efficient and fitted to harsh environmental conditions including drought, freezing, diseases, and pests. Genetic modification is different than selective breeding or crossbreeding of species where genetic modification is performed in laboratories, while others are not.

Transgenic technology, biotechnology, genetic make-up, and genetic engineering are all synonyms for genetic modification “GM.” They are the process of manipulating an organism’s genome “genes” by processes of biotechnology. The organism’s genetic make-up of cells is changed because new DNA has been added. The goal of genetic engineering is usually to add DNA with one or more traits that are not found in the organism (*Häggman* et al., 2016). Genetic engineers alter genetic make-ups of organisms by using techniques that remove heritable materials from the organism’s genome, or those that introduce new DNA prepared outside, in genetic laboratories, into the destined organism’s body (*Reguera* & *Blumwald*, 2012). For example, it has been suggested that the removal of lignin content from trees would reduce pulping costs incurred by paper companies by 15%. Removal of lignin from wood fibers by conventional industrial methods has proven costly, uses environmentally hazardous chemicals, and consumes large amounts of energy (*Rasala* et al., 2013). Through the use of genetic engineering techniques, to reduce lignin in the pulp, mills supplied with low-lignin timbers will ecologically help a great deal in reducing hazardous chemical releases in the environment and lessening the amount of energy needed to break lignin structure (*Reguera* et al., 2012). In addition, when it comes to food, the use of genetic modification is more ideal for the uses of land, herbicides, and other pesticides. Also, GM can create an essential sustainable way to feed the world by extending shelf life for easier shipping and enhancing crops’ texture, flavor, and nutritional value.

2.2.1. Applications of genetic modifications

Since genes exist only in organisms, genetic modification is applicable only to organisms so that anything contains any sort of organism or consists of organisms can be genetically modified. As a result, genetic modification can be applied to many products including, but not limited to, agricultural crops, food, animals, meat, medications, natural leather in apparels, and trees. Genetic modification was first introduced in food in the mid-1990s, then expanded to include the vast majority of processed food in the US.

Genetic engineering is underway to generate genetic modifications that will allow trees to cope with geographic stresses. For instance, frost tolerance *Eucalyptus* trees that are predominantly grown in the southern parts of the US are now being genetically modified to acquire traits that will allow them to be grown in the northern part of the country (*Porth* & *El-Kassaby*, 2014). Genetic modification "GM" is also currently underway to accelerate tree growths for commercialization purposes. For that purpose, trees are intended to grow thicker and faster. Such trees will increase in height and thickness in reduced harvest cycles (*Porth* & *El-Kassaby*, 2014). However, for the harvest to be economical, the trees have to grow in areas with limited soil nutrients and water. Ecologically conscious research in genetic engineering to foster tree resistances to diseases has been stepped up. Given that some known traditional trees are becoming extinct due to specific diseases; gene modification can be introduced to save emblematic trees in the ecosystem (*Polle* et al., 2013).

There is a debate about whether the GM growth process is considered natural or not as it evolves laboratory modifications. In one recent study conducted in 2015, scientists from Peru and Belgium discovered that genetic modification sometimes happens quite naturally (*Kyndt* et al., 2015). In addition, there is no doubt that GMOs are processed by nature, constituting that it is natural. Even if GM trees are not natural, they still can be compared to the natural growth of normal trees and bio-mimicked. Moreover, a study on GM crops found that there is no significant natural variability by using GM except changes in targeted traits (*Clarke* et al., 2013.)

2.2.1.1. Benefits of genetic modification for the Industrial Sector

Over some six decades, scientists and researchers have been inventing new ways to add value to tree crops. Some of these strategies are those focusing on increasing the frequency of those genes that are favorable for the commercial planting stocks. According to *Owusu* (1999), it is the laborious and time-consuming approaches that can help achieve these developments as explained by the classical Mendelian genetics (*Owusu*, 1999). Biomimicry, as furtherly discussed in the next section 2.3, and the extensive research advances that have been achieved over the last four decades have led to the introduction of vegetative propagation approaches applied in forest nurseries. The resultant effect has been the production of large quantities of trees. Despite these advancements, breeding of genetically modified trees has been slowed by the uncertainty that exists in their sexual reproduction as provided by nature (*Gartland* et al., 2003). At times, desired

traits of trees are rare or are non-existent to help in breeding; however, this trend is being reversed by biotechnology.

It is argued by various reports in 2008 that the use of biotechnology is still behind in the development of genetically modified trees due to the lack of technical and regulatory capacity to assess the benefits and costs of modern biotechnology (*FAO* 2009). However, there has been a limited commercialization of GM products due to the inability of the biotechnology organizations to invent a massive amount of genetically modified trees at low cost and over a short span of time. Somatic embryogenesis, which is a cloning technique, has been helpful in the production of large quantities of seedlings mostly from small contents of plant's tissue (Food and Agriculture Organization of the United Nations, 2010). Though at first, the technique was too costly for the breeders because they had to pluck every group of differentiated tree shoots manually from the source tissues before they are put in the growth medium. With the effort of an Australian plant biotechnology company, *ForBio*, it is possible to produce large quantities of both genetically modified and non-genetically modified trees from the plant tissue culture, thus making the process commercially viable.

2.2.1.2. Benefits of modifying trees genetics for industries

Any prospective benefits from genetically modified trees as a result of biomimicry come to play after a well-coordinated and complementary development of the two processes, that is, the genetic engineering and traditional breeding. As a result, it is expected that the developed desired traits provide the assurance of those traits that increase product quality, increase productivity and expand the

types and range of the climatic and land conditions where the trees thrive (International Service for Acquisition of Agri-Biotech Applications, 2017). Indeed, the trees are more suited for industrial purposes as the desired traits allow them to be more suitable for processing and sometimes increase the volume by changing the wood fibers to make them better for paper production and conversion into wood pulp (*FuturaGene*). In most cases, the goal of many manufacturers is to reduce the ecological demands and minimize the costs when applying high reactive chemicals to remove the lignin. As aforementioned, many innovations through biomimicry have aimed at reducing lignin and increasing the amount of fiber per volume in trees. It, therefore, becomes less costly and easier to remove lignin, make juvenile fiber usable by improving its characteristics among other aspects. Additionally, it has been found that GM trees form an essential component for saw timber and pulpwood, more than conventional trees, that make it possible for the manufacturers to produce desired products. Indeed, genetically modified trees mostly have thin limbs, adequate density, and straight trunks that are desirable for industrial purposes.

Mostly, biotechnology innovations on trees that are meant for industrial purposes are associated with operating costs and financial gains recorded by these industries. Some of these innovations are those associated with the improvement of lumber strength; then, there is that of using trees that have herbicide resistance gene; and the one related to the low-cost pine cloning technique (Food and Agriculture Organization of the United Nations). All these innovations play a significant role in enhancing the volume or quality of the wood

fibers and can minimize the costs of production of these contents while in the pulping digester. The table 2.1 in the next page shows the possible financial gains made from some of the future Biotech innovations.

Furthermore, the cropping mode of genetically modified trees has today surpassed harvests of second growth and natural trees because they are fast-growing. Indeed, it is cheap to harvest these trees because most of their plantation are well-located, making them easily accessible. Additionally, genetically modified trees are associated with remarkable growth rates, which relieve the manufacturers the costs of switching to other new plantation locations. Also, there is an aspect of greater stringency associated to harvest guidelines and the setting-aside of numerous natural old-growth forests that make harvesting them more expensive compared to plantations that have genetically modified trees (*Kanowski*, 2012).

Because of such benefits that are linked to planted tree plantations, especially for genetically modified trees, have replaced the natural ones as the main source of the industrial wood. In essence, tree plantations that are intensively managed like those with genetically modified trees have shown their ability to give substantially improved biological yields and potentially an essential source of timber for industrial wood production (*Boerjan*, 2005). Unlike more than 50 years ago, today, an estimate of the total timber harvested from forests is sourced from planted plantations.

Table 2.1: Possible financial gains made from some of the future Biotech innovations (Sedjo, 2004)

Additional Innovation	Benefits	Operating Costs
Clone superior pine	20% yield increase after 20 years	$100/hectare or 15–20% increase
Wood density gene	Improved lumber strength	None
Herbicide tolerance gene in eucalyptus (Brazil)	Reduce herbicide and weeding costs potentially saving $350 or 45% per hectare	None
Improve fiber characteristic	Reduce digester cost potential savings of $10 per Cubic meter	None
Reduced amount of juvenile wood	Increase value $15 per m^3 (more useable wood)	None
Reduce lignin	Reduce pulping costs potential of $15 per m^3	None

2.3. Biomimicry

The word biomimicry has the prefix “bio” that refers to biology, in which it means the “science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems” (*Benyus,* 2002). To avoid confusion, biomimicry, at least in the context of this research, focuses only on the economic output of natural processes consistently with the economic output of human-based organizations such as return on investment, time to maturity, production potential, etc. That is different than the bio-based economy or bio-techonomy that deals with the mechanisms of natural processes at the genetic and molecular levels and applying this understanding to creating or improving industrial processes. In addition, whenever the words biomimicry, bio-mimicking, bio-mimic, and bio-mimicked are used in the context of this research, they mean that human-based organizations biomimic trees.

2.3.1. Why biomimicry

What makes nature exceptional and ideal for mimicry is that it successfully remained existent and sustainable in providing all biological and ecological needs for billions of years from nanoscale to solar scale (*Benyus,* 2002). The philosophy behind biomimicry is that if humans get the advantage of nature’s designs that successfully operate and maintain life, then human problems can be solved, as well.

From another philosophical perspective, Human beings, many times, have been forced to strive whenever they try to improve their abilities to survive through numerous innovations and modifications for countless millennia. From hunting and

gathering to primitive farming and herding and later to domestication, humans have had to do all these through making significant accomplishments in innovation. Arguably, through biomimicry, humans have been able to invent genetically modified trees that are associated with high yields produced within a short span of time (*Boerjan*, 2005). High-yield plantations of trees can be able to satisfy the global wood needs of industries and at the same time help in protecting and preserving the existing natural trees together with their social and environmental values (*Mole*, 2008). The continual use of biomimicry to develop genetically modified trees in intensively managed tree plantations can be a conceivable way to stabilize the global natural forest cover and maintain it to at least the present level for many decades to come despite the increasing human population. As far as their industrial functions are concerned, trees (woods) form the raw material for packaging, paper, pulp, and lumber (*FuturaGene*, 2014). Apart from being a source of fuel, trees also act as a feedstock for biomaterials, biofuels, and bioenergy (*Voosen*, 2010).

2.3.2. Case studies of biomimicry

The term “biomimetics” was first mentioned by *Otto Schmitt* in the 1960s (*Harkness,* 2001) and then became popularized by *Janine Benyus* in her book in 1997, Biomimicry: Innovation Inspired by Nature (*Benyus,* 2002). Even Earlier, the idea of mimicking nature or biological processes can be seen. In his letter he wrote some time in the 1480s, *Leonardo da Vinci* documented his theories of flight in more than 100 drawings to be considered as one of the early experiments in human history that was simulating birds by flapping wings in order to help invent a

flying object that can carry a human in the sky (*Fuller*, 2008). Even though it failed, it was one of the earliest considerations of biomimicry. Nowadays, biomimicry can be widely and globally applied to almost everything.

Being a language of science and art, biomimicry is used in industries for manufacturing applications. For example, industrial designs and architecture techniques learned through biomimicry are mostly applied in manufacturing processes (*Aziz* & *Sherif*, 2016). Also, the genetically modified trees, most of which have been produced through biomimicry techniques, have found good uses in industrial manufacturing (*Radwan* & *Osama*, 2016). Through observation, modeling, and analysis of the genetically modified trees features, for example, their figural and structural properties, resistance to static and dynamic loads, lightness and stability have made the industrial researchers prefer them as they enable self-repairing, silent and energy-saving qualities when building (*Drake*, 2011). Apart from their uses in design and architecture, genetically modified trees are used in paper and pulp industries to manufacture paper products. At the same time, some trees are used in biochemical and energy industries as raw materials (*Voosen*, 2010). The following case studies explain in detail more about biomimicking trees and the benefits of doing so:

2.3.2.1. *Oak*s of New Orleans

In 2005, when hurricane Katrina hit New Orleans, the high-speed winds devastated the whole city and displaced more than a million people. But New Orleans' live *oak*s were surprisingly resistant. It was found that the leaves, branches, and trunk are designed like a Fibonacci sequence to aerodynamically

flex in the wind while strong root systems of all *Oak* trees are connected with each other so that the whole community serves as a countermeasure to the wind's sideways force (*Leu*, 2015). In this case, many lessons can be learned including how to design cultural foundations and how to form a teamwork that acts jointly as a single super employee. In addition, organizations inspired by the natural spiral design of leaves and branches can survive with limited resources by being willing to try new approaches or refine policies instead of standing rigid against challenges.

2.3.2.2. Palm tree

Another good example is the Palm tree. In addition to trunk flexibility mentioned in the previous example, it has a well-designed consolidated network of roots that have access to all existed resources in the surroundings. This trait gives the Palm tree the unique ability to access deep water so that it can grow in environments from the rainforest to desert conditions. So, it can be learned from the Palm tree that having the ability to make all possible resources available when they are needed is the driver behind survival in harsh work environments such as low-income jobs or more robotics taking over employees' jobs (*Beckford,* 2017). Even more, considering trees' traits that are beneficial to organizations can provide even more development such as combining connected roots in the *Oak* tree with the deep roots of the Palm tree.

2.3.2.3. *FuturaGene* company

Worldwide, massive plantations are stretching across China, Indonesia, and South Africa that contain mostly genetically modified eucalyptus trees.

According to various sources, these trees are growing 40 percent faster and are mostly used as fuel for cars, pellets for power stations and sometimes as a raw material in paper industries (*Vidal*, 2012). The *FuturaGene* Company has been one of the companies for more than eleven years that has planted both the poplar trees and eucalyptus trees in Brazil, China, and Israel on about 100-hectare portions of land for commercial purposes. These trees contain genes that have been extracted from common fast-growing Arabidopsis weed.

Indeed, *FuturaGene* has a new method of altering the composition of the trees walls that assist in stimulating their natural growth processes (*Vidal*, 2012). According to the information from this company, their genetically modified eucalyptus trees have the ability to grow five meters yearly with 20 to 30 percent additional mass than the other regular eucalyptus trees. These trees take only 5.5 years to reach 27 meters high (*Vidal*, 2012). It has been claimed that the gene-altering approach used by the company is no doubt an industrial game-changer not only in the current economy but economies to come (*Sedjo*, 2004). The company benefits from the trees that grow thicker and faster and eventually increase the yields for use in fuel industries (International Service for Acquisition of Agri-Biotech Applications, 2017). Currently, the company's aim is to increase the trees' yields. It is estimated that its transgenic eucalyptus plants can produce approximately 104 cubic meters of wood planted in one hectare in every year as compared with those trees planted for energy purposes in *Brazil* that gives an average of eighty cubic meters of wood. It is argued that the estimated increase in the yields by 40 percent can greatly help in cutting down the trees` prices (*Vidal*,

2012). Also, the company is planning to cut the harvesting period of eucalyptus in Brazil from seven to 5.5 years (*Vidal*, 2012).

FuturaGene, which is owned by *Suzano,* is a large Brazilian plantation group plants over 500 thousand hectares of eucalyptus trees every year. With these and other energy crops, the company is exporting majorly to the European countries (*Vidal*, 2012). Moreover, the company has partnered with other organizations located in Thailand, South Africa, and China, which together produce almost half of the global eucalyptus plantations.

2.3.2.4. *International Paper* Co. and *MeadWestvaco* Corp

International Paper Co. and *MeadWestvaco* Corp are two giant industries that are investing in plantation forests to replace the native *pine* in the southeastern parts of the United States (*Voosen*, 2010). The companies are planning to plant the engineered *eucalyptus* trees that can proliferate even in their conventional strains. Today, these trees are the ones dominating the tropical timber industries. By planting these genetically modified trees together with *ArborGen* LLC as the joint biotech venture, they intend to cover the shortage of timber that is being experienced globally. The companies are planning to use the engineered trees in energy applications, for example, biomass and the next-generation biofuels (*Voosen*, 2010). The genetically modified trees which can grow on marginal spaces, given hardiness and be harvested when there is a need to do so, can also be planted to produce cellulosic ethanol (*Mole*, 2008).

These *eucalyptus* trees can form a full canopy of leaves in a short span of time. Also, being greedy for carbon, the plant takes only twenty-seven months to reach 55 feet in height (*Rao*, 2010). As a matter of fact, its rapid growth rate can allow the companies to harvest a lot of wood on a limited piece of land (Institute for Agriculture and Trade Policy). This way, the companies can make a lot of revenue from exporting these timbers (*Lang*, 2004). Currently, *ArborGen* has been allowed to operate in seven states, with a total of 28 sites covering 330 acres (*Voosen*, 2010).

The *ArborGen* has come up with a type of *eucalyptus* that is able to resist freezing temperature, and therefore its growth rate cannot be altered whatever the physical condition. *International Paper* Co. and *MeadWestvaco* Corp are utilizing the *ArborGen* expensive *eucalyptus* seeds to benefit from their guaranteed gains in productivity and therefore become the most sought-after tree stock to serve the increasing bioenergy refineries. Additionally, the companies aim to produce timbers that will be used as coal. Interestingly, the German utility *RWE AG* is planning to come up with a massive wood-pellet plant that will be located in *Georgia* to help in supplementing its coal habits.

2.3.2.5. Brazilian transgenic eucalyptus trees

Brazil is one of the countries worldwide that are producing genetically modified trees on a large scale. The nation has *eucalyptus* trees planted in an orderly manner as they surround the hurly-burly plantations of native trees. The trees which cover about 3.5 million hectares countrywide were bred for a number of decades to increase their growth rates (*Ledford*, 2014). As compared to other

conventional trees, the genetically modified *eucalyptus* trees that grow in this nation produce 20% more woods. Also, unlike the native trees that take seven years to mature, these trees take five years and six months to be ready for harvesting. Indeed, it is estimated that the genetically modified *eucalyptus* trees are covering 20 million hectares in both the subtropics and tropics (*Ledford*, 2014). As soon as the trees are released for commercial use, the move will encourage the use of the trees elsewhere.

These breeds of trees are not only resistant to insect pests but can also retain the inserted genes for a long time. The trees are an essential resource in both the pulp and paper industries as well as the emerging biofuel industries (Institute for Agriculture and Trade Policy, 2002). It is important to understand that there is a ready market for many genetically modified trees, particularly in China, where the regulations are favorable. It is a matter of time before the United States let loose the strict measures it has put in place to prevent the use of the plants in the country.

Indeed, the rapid rise in the global population is increasing the demand for products sourced from the forests. It is estimated that the total wood use globally was about 2.9 billion m^3 and 3.4 billion m^3 in 1980 and 2010, respectively. It was also found that half of these wood products are utilized for industrial use while the rest are mostly applied for heating and cooking. Arguably, wood use is projected to continue rising as the population expands and the standard of living improves, and more application for woods in biomaterials and bioenergy is being developed

(*Harfouche* et al., 2011). It is, therefore, necessary for the world to think of a more sustainable strategy to maintain the needed supply of wood.

2.3.2.6. Corvallis, Oregon

In Oregon State University, the forest geneticists invented the genetically modified poplar trees that have the ability to grow rapidly. In addition, these trees are highly resistant to the insect pests as it was reported by the Canadian Journal of Forest Research. The trees developed by the institution are considered the best as far as the genetic modification of trees grown in forests is concerned. These genetically modified poplar trees are mostly used in both pulp and paper industries as well as in modern industries of biofuel (*Strauss* et al., 2001). Indeed, poplars used for commercial purposes are mostly sterile to prevent any possible spread of features of these trees to natural forests.

Arguably, these trees are preferred because of their high wood yield that is guaranteed from their associated healthy and productive plantations. Given their improved growth and high production, genetically modified poplar trees promise more value for the same quantity of trees planted as those in natural forests. Also, after two growing seasons, artificial poplar trees can increase in size by 13% as compared to the native trees, thus increasing the size of the wood further for use in industries (*Strauss* et al., 2001).

The purpose of this section is to convey that trees can be biomimicked rather than presenting new discoveries in the field of biomimicry. Even though there are no specific studies or cases of biomimicking GM trees for organization

development purposes, it is found after a deep search that there are only a few case studies, including the presented case studies above, about conventional trees.

2.4. Organizations' key performance indicators (KPIs)

At the outset, key performance indicators (KPIs), also known as the key success indicators (KSIs), are measurable values demonstrating how a firm achieves its key business goals. Firms utilize these indicators in order to assess their success at arriving at targets. That is, via these indicators, both managers and employees evaluate how effective a number of pre-set processes, as well as functions in an organization, are in helping the firm achieve its set goals. In most cases, success is usually consistent progress towards a set goal. As such, organizations are encouraged to focus only on the key objectives. Thus, the organization needs to carefully identify why it exists and focus on delivering such goals to all of its stakeholders. This implies that there is science as well as art to the establishment of appropriate indicators, particularly in the case of manufacturing firms (*Ward* et al., 1994). The goal in both cases is to ensure that measures that profoundly lead to the accomplishment of progress towards main objectives are identified. By so doing, the indicators will only be utilized in monitoring how close the firm is in achieving its major objective. The KPI's for an organization can be considered similar to the desirable traits scientists are addressing when they genetically modify plants. Such traits include growth rates, resistance to certain diseases, the economics of operation, environmental impacts, etc.

Generally, there are two types of performance indicators – lagging and leading. Lagging performance indicators are utilized in assessing how the firm has performed. That is, they only display how the past campaigns and programs have performed. Financial metrics constitute such measures since they will simply display the results of the previous operations. On the other hand, leading performance measures tend to provide direction on how future results can be achieved. So, the issue that arises here is how and when to choose one of or both of the two groups. In as much as leading metrics are direly needed, it is prudent to evaluate whether already established measures are achieving their goals. Thus, striking the right balance between the two groups of performance measures is necessary for the manufacturing firms. This is the very same approach adopted in the case of GM trees since a number of measures have been established to ensure increased future productivity. As well, measures have been put in place so as to assess the very same anticipated productivity. That is, output/production has increased, and costs related to producing the needed quantity declined in the process.

In the manufacturing sector, every key objective characteristically needs several performance measures or "traits." Furthermore, the performance indicators in this case must be sustainable (*Amrina* & *Vilsi*, 2015). However, this requires that a continuous improvement approach be instituted, a cycle which is hardly complete; progress evaluation must be continuously carried out based on the set targets as well as the established action plan(s). Thus, a commitment must be made, set goals as well as performance assessed, action plan(s) created and

implemented, progress evaluated, and finally, achievements recognized. This cycle must continuously be re-assessed. The key reason for the aforementioned reassessment is the dynamic nature of the manufacturing environment. That is, technological invention and innovation is an ever-changing process, and thus firms' ways of manufacturing must ensure they align accordingly to such processes. At the core of this cycle are the key performance indicators as they provide a basis upon which the aforesaid measurement and evaluation can be executed. This is the same aspect that the development of GM trees has adopted. The desired goals on production, cost reduction, field areas needed, and resistance to diseases are set, and appropriate action plans such as the kind of genes to use created and implemented. The goals will later be assessed based on the lagging metrics to measure progress.

Specifically, in manufacturing setups, several groups of KPIs can be identified. The first one is customer responsiveness as well as experience. Changeover time, manufacturing cycle time, and on-time delivery are key metrics under this category. The next category is concerned with quality improvement and under which yield, supplier quality, and customer returns are key metrics. Efficiency improvement is the next category, and throughput, production attainment, capacity utilization, and overall equipment utilization constitute the key metrics. Other leading performance measures include inventory reduction, ensuring compliance, increasing innovation and flexibility, and reduction of maintenance. The lagging metrics for manufacturing firms are basically concerned with cost reduction and profitability increment. Key KPIs under this category

include: total production cost per unit, production cost as a ratio of revenue, net operating profit, revenue per employee productivity, average unit contribution margin, return on assets (ROA) or return on net assets, energy cost per unit, cash-to-cash cycle time, earnings before interest, taxes, depreciation, and amortization (EBITDA), and customer fill rate (*Davidson*, 2013).

Most, if not all, of the above-listed metrics, can be directly correlated to the key metrics that the developers of GM trees utilize. Just like in the case of genetically modified eucalyptus, savings in the resources used in production, an increased in the wood produced, reduction in the number of hectares needed to meet the desired wood demand, increase in the amount of carbon dioxide capture, creation of jobs, and increased profits to all sorts of growers are some of the key performance indicators. This implies that there exists a platform over which plant performance can be correlated to the production performance of businesses. The next section attempts to make a probable link between the development strategies deployed in GM trees and some of the aforementioned KPIs.

2.5. The connection between trees and organizations' KPIs

Over the past years, environmental and business researchers have tried to make a connection between natural processes and industrial organizations, but they faced substantial obstacles in biomimicking natural systems, including complexity (*Woolley-Barker*, 2016) and randomness. Even though there is no randomness in nature as every atom in theory follows specific rules and behave according to natural laws, some of the natural processes are still not known how

they work and why they work the way they are. This is why some natural processes look random while they are not in theory.

The *Woolley-Barker* study focuses on some of the ways in which organizations can biomimic trees so as to obtain a different point of view to utilize for improving their overall productivity. The review that has been done has considered both types of trees, the reason being that it is easier to see what has been deployed in the case of GM trees and inject the same in manufacturing in order to stand out from the ordinary rest.

However, it is worth understanding the hypothesized connection between trees and organizational growth. Nature as a whole is a very big and sophisticated open system consisting of a tremendous number of interconnected subsystems that are dependent on other subsystems in the upper level in nature's hierarchy. The human species, as an open system, is an example of nature's subsystem that is successful and has become bigger and bigger over the previous hundreds of centuries. As a result, according to *General Systems Theory* by *Von Bertalanffy* (1969), such a system turns out to be more complex and moves toward independence. For example, humans connect with each other, and then they form social life. This dynamic of collaboration results in social and economic organizations. Moreover, when dominating behaviors appear in growing human-based organizations, they act independently as a whole, where their components subdivide into interdependent specialized subsystems. These breakdown processes can continue to develop new independent hierarchical systems in the future so that the state of equilibrium can be achieved.

However, in order for an organization to reach the state of equilibrium, the organization as an open system needs to be dependent on the higher organization for adjustment before reaching a steady state. For this purpose, a feedback system between a human-based organization and the growth of trees, as a higher or adjacent level in the natural hierarchy, can be a good learning loop to reactively developing human-based organizations by learning from the natural growth of trees whether they are normal or genetically modified. Several examples of what can be learned from trees are explained in section 2.3.2. In the following section is some explanations on how the growth of GM trees may be similar to crisis or transitional periods in organizations in many aspects. Also, the following explains how organizations and natural open systems are similar in which a learning loop can be formed to generate an understanding model to learn more about organizational development. So, not to be confused with the field of industrial ecology that is meant to seek green supply management practices where this section of this research focuses only on the differences and similarities between the natural process and human-based organizations for the purpose of answer the research question.

2.5.1. Similarities

In terms of simple inputs, there are several similarities including workforce and natural resources, finance, time, and policies as follows:

2.5.1.1. Workforce and natural resources

In order for a tree to grow and survive, it needs the four basic energy components (LAWN): light, air, water, and nutrients, and then to process these

inputs (*Tilley,* 2015). The tree can obtain this energy from the surrounding environment with the help of the ecological system that deals with the relations of organisms to one another and to their physical surroundings while the biological system of organisms is meant to process this energy. Both systems together play the similar role of the workforce in organizations where the biological system are employees, the ecological systems are the operational environment, where related suppliers, customers, and regulatory. Moreover, the required energy for trees as natural resources can be subdivided for comparative purposes as well. As energy components provide vital functions in botanic growth, they also do so in organizations.

In the workplace, good lighting is associated with reduced risk of occupational accidents and health problems, better concentration and accuracy in work, a brighter and cleaner workplace resulting in a more active, cheerful environment, improved work performance, and better visibility, improved accuracy, and increased work speed-enhancing production (*Bommel* et al., 2002) as set forth by “Standardize (*Seiketsu*)”, the fourth element of the lean process. When it comes to air, this energy component includes air purity, circulation, and thermal comfort, which are all needed in any workplace. The availability of these elements saves employees from the consequences of bad air quality such as headaches, fatigue, trouble concentrating, and irritation of the eyes, nose, throat, and lungs (*OSHA*, 2011). On the other hand, the lack of air quality will negatively affect the productivity in organizations. Water and nutrients in botanic growth are equivalent to employees who supply the energy need to grow the organization. It’s known that

what humans eat affects their productivity. The more good food employees consume, the happier, more engaged, more motivated, more curious, and more creative they tend to be (*Freidman,* 2014). So, energy components play a key role in achieving top performance in organizations, in a similar way as they do to GM tree growth and as both humans and plants are organic systems

2.5.1.2. Finance

In drawing a parallel with the growth in GM trees, the top three comparable financial elements are capital, assets, and expenses. Capital is money and relates to both industries as it is needed to start any organization and is required to start GMO plantations, as well. Assets in organizations can be facilities, equipment, inventory, technologies, and experiences while assets in GM trees can be land, genetic engineering, stored nutrients, and crops. In the same way, expenses are incurred in both industries as the purchase of assets, which is another similarity. So, running an organization is similar to planting a GM tree in terms of financial considerations.

2.5.1.3. Time

Time means money in any organization. In GM trees as an organization, the growth cycle period is important. The shorter the harvest cycle period is, the more profits are generated, as a result of increasing production and sales. In the same way, the inventory turnover time in an organization shortens the return of investment, which then consequently maximizes profits with more emphasis on product development, marketing, and innovation.

2.5.1.4. Regulatory

Every state has its own regulations and policies to operate an organization such as land use and zoning laws that specify the nature of the permitted activity performed in targeted locations. These regulations affect organizations by limiting some activities for the general interest and sometimes by providing incentives for the same purpose. For example, achieving environmental goals is highly appreciated by governments and environmental agencies. Such achievements bring financial incentives like tax exemptions and other privileges and facilities. A rewarding achievement in organizations can include hiring additional employees, reducing the emissions of greenhouse gases, or manufacturing recyclable products. On the other hand, the plantation of GM trees can be rewarded by regulations for implementing healthy practices such as reforestation, increasing the capture of carbon dioxide, or decreasing the required area for plantation. So, planting GM trees and operating organizations are similar in terms of benefiting from rewarding policies. In addition, the similarity even extends to limitation policies. So, obstructing residential programs, destabilizing the soil, or threatening wildlife and biodiversity can be penalized by regulations as a result of an unresponsive GM trees plantation. Additionally, organizations can also be similarly penalized if negative practices are observed, such as violating employees' human rights, over-consuming natural resources, or illegally monopolizing a product in a particular market.

2.5.1.5. Outputs

In terms of outputs, the similarity between GM tree and organizations continue to share similar outputs. As mentioned previously, both organizations participate in achieving environmental benefits like performing energy-saving practices and consuming natural resources economically and wisely or even being limited to renewable resources. An additional similarity is that both organizations produce their own goods. Organizations provide goods and services while GM trees provide crops and lumber. As illustrated earlier in section 2.5.1.2, profits and time are tied together as time is money and both organizations can make profits. Also, production capacity is important in both sides to maximize profits. After all, this comparison is only valid in the context of showing the similarities because, of course, a human-based organization is not a tree, and trees cannot produce lumber nor corps by itself.

2.5.2. Concerns

Accordingly, GM trees might be a good candidate system to learn from when addressing system similarities. This is due to the fact that organizations can be isomorphically developed as they are similar to the successful environmental growth of GM trees, in many aspects. However, there are some concerns shared between GM trees and organizations. For example, biodiversity can be threatened as a result of an excessive uncontrolled plantation of GM trees, while cultural and geographical stresses can affect the diversity of human-based organizations in general. Moreover, diversity is vital for an organization to be sustainable because diversity increases adaptability and a variety of resources (*Smith*, 2017). One of

the big challenges is to preserve natural resources as over-consumption is threatening human survival by causing climate change and using up the resources of future generations. These concerns should be considered when performing an isomorphic mimetic change. There are a lot of physical differences between organizations and GM trees, but these differences don't stop the feasibility of a feedback system to perform a learning loop between the two systems.

2.5.3. Findings by other researchers

There are also several works that suggest that natural systems, in general or sometimes in particular including the growth of trees, are similar to the development of organizations in which these natural systems are mimicable and can serve as successful models to learn from. Table 1 in section 2.5.3.3. summarizes the works other researchers performed in the past concluding that organizational development is sufficiently similar to the natural growth of trees. However, no one has published particularly about the biomimicry of GM natural processes when looking into the similarities or differences in the growth between both sides, which clearly means that there is a gap of knowledge in this area. The classification of comparison elements in the following works are not always the same as to what is suggested by this research; they differ from a study to another as follows.

2.5.3.1. Ecosystem principles for an industrial ecosystem

In a peer-reviewed paper published by *Jouni Korhonen* in the *Journal of Cleaner Production* in 2000 about the four ecosystem principles for an industrial ecosystem, *Korhonen* suggests that the industrial system, which is equivalent to

the growth of organizations in the context of this research, is similar to the ecosystem during the operation based on the case study on the *Jyväskylä* regional energy supply system in Finland. The driver behind the *Korhonen*'s suggestion is to facilitate the development of industrial systems by imitating the principles of system development of ecosystems. *Korhonen* found out a different classification of similarities between the nature of industrial-based organizational development and the growth of natural systems, in general. Even though the elements of similarities in *Korhonen*'s paper are different than the elements of similarities suggested in this research in section 2.5.1, both sets of similarities support the idea of the analogy in different measures. Moreover, *Korhonen* stepped up a little by showing how similarities are beneficial for biomimicry.

The similarities are not limited only to the main four elements of roundput, diversity, locality, and gradual change, but also includes other less important aspects such as waste and energy. The first element is roundput which is the utilization of waste or output as a resource or an input in the life cycle of both organizations. In ecosystems, plants produce oxygen in return for consuming carbon dioxide, while animals, on the other hand, require oxygen to live and produce carbon dioxide. In terms of industrial systems, fossil fuel is, most possibly, consumed to produce goods while the same goods can be recycled and reused to produce new goods. So, a closed loop of the lifecycle is more sustainable and better than an open-loop system with an unlimited growth paradigm.

The second element, diversity in terms of species, organisms, and interdependency between open ecosystems, is set forth for ecosystems to survive.

The existence of diversity in ecosystems, as a natural strategy, can explain the long-term survival even in harsh conditions permanently changing of environmental conditions and the fluctuation of resource availability. In the past, the manufacturing industry tended to be less diverse, especially when studying the system under one single denominator such as monetary value or mass production. Nowadays, the increasing emphasis on quality, variety, and diversity in the industrial output structure of products is challenging. Also, in terms of policy and management, the existence of diverse and interdependent cooperation systems such as large manufacturers, small to medium-sized enterprises, the public municipal organizations, waste management companies, consumers, etc. could, for example, facilitate the existence of ecosystems.

The third element is locality. Ecosystems evolved to adapt to the local environmental conditions and to their surroundings in diverse interdependent relationships. On the other, organizations are not doing well in this scenario. They still rely on imported energy such as fossil fuel and ignoring local natural resources. Therefore, *Korhonen* suggests that organizations need to try and replace imported resources with local renewables and with local waste material and energy sources to achieve the state of equilibrium and the required balance for sustainability.

The fourth element is gradual change from an evolutionary standpoint where the survival of botanic open systems, for example, rely on the flow resource from the sun and the evolution respects the renewal rate of these systems. Further, as evolution happens through the gene as the information storage medium, the information moves through reproduction. This process can also be found in

industrial systems as they are subsystems of the cultural evolution (*Fuchs,* 2012). Moreover, culture in an industrial system serves as the information storage medium including oral, written, video, internet, and so on. Even more, such records and development happen much more rapidly than in natural systems.

However, the author thinks that the 'voice of nature' will always be indirect in a human's processes such as that of corporate or industrial systems, so that our knowledge about the ecosystem functions will always be based on uncertainty. This, exactly, is the introductory approach appreciated by this research that supports the idea of encouraging to find an ecosystem that somehow tends to be more controlled and stable, such as GMOs, for organizational development purposes and through the use of biomimicry.

2.5.3.2. Economy as an ecosystem

Rothschild has the same conclusion that organizations has a similar mechanism as the one in natural systems but from an economic standpoint. *Rothschild* stated in his book "*Bionomics: The Inevitability of Capitalism"* that "a capitalist economy can best be comprehended as a living ecosystem. Key phenomena observed in nature – competition, specialization, co-operation, exploitation, learning, growth, and several others – are also central at business life." *Rothschild* named this finding as economics bionics. The main idea of his finding is that an organism is defined by the information in its gene and its relationships with its prey, competitors, and predators. In the same way, an economic organization is also defined by its technology and by its associations with its suppliers, competitors, and customers. For example, organizations behave

as biological organisms and industries as species. “Like the organisms and species that make up the global ecosystem, the world’s firms and industries have spontaneously coevolved to form a vast living ecosystem.” (*Rothschild* 1990, 337.) Consequently, organizational efficiency is rewarded by survival and organizational inefficiency, on the other hand, is punished by extinction (*Rothschild* 1990, 224).

2.5.3.3. Other works

Ralf Isenmann, a researcher at the University of Kaiserslautern, Germany, compiled many works, as summarized in table 2.2, in which all of them support the idea of analogy between organizations and natural systems. *Ralf’s* work “Further Efforts to Clarify Industrial Ecology's Hidden Philosophy of Nature” is published in the Journal of Industrial Ecology.

2.6. Organizational growth vs. tree natural growth

In this section, it is intended to show that the growth phases of human-based organizations are similar to the natural growth phases of trees. In a paper published by Harvard Business Reviews in 2011, the Accenture research center started in 2003 to test the premise that all performances are relative. The researchers studied 800 companies that represent about 80% of the market capitalization, per Russell 3000 index. They tested 13 econometrics to evaluate organizational growth over the past ten years at the time of the study. The research team found out that organizations that successfully passed the transitional crisis periods have implemented new sub-S-curves to manage their sustainability (*Nunes* & *Breene*, 2011).

Table 2.2: The use of natural images in industrial ecology

Authors	References
Frosch and Gallopoulos (1989)	Industrial ecology would function “as an analogue of the biological system”
Tibbs (1992)	Industrial ecology “takes the pattern of the natural environment as a model”
Allenby and Cooper (1994)	“Sustainable structure will resemble a mature ecological community”
Andrews et al. (1994)	Nature is “instructive to explore in some detail what an industrial ecosystem could involve”
Ayres and Ayres (1996) and Ayres (2002)	“Industrial ecosystems, designed from ‘scratch’ to imitate nature”
Erkman (1997)	The “industrial system can be seen as a certain kind of ecosystem”
Wernick and Ausubel (1997)	Industrial ecology “implies that models of non-human biological systems ... are instructive for industrial systems”
Allenby (1999)	“The concept of industrial ecology ... [is] based here on the biological analogy”
Cleveland (1999)	It is characteristic of industrial ecology to “look to the natural world for models of ... efficient use of resources”
Manahan (1999)	“Industrial ecology mimics natural ecosystems”
Chertow (2000)	“The underlying concept of industrial symbiosis is the metaphor of an industrial ecosystem that mimics a natural ecosystem” “Famously, industrial ecologists look to biological ecosystems as analogies or metaphors in the study of production and consumption”
Côte (2000)	“In biological systems, materials are cycled by a complex web of species that includes not only producers and consumers, but also scavengers and decomposers”
Cohen-Rosenthal (2003)	“Industrial ecology dream that, as in natural systems, waste equals food and that linking one company’s ‘throw-aways’ to another’s need will provide better environmental and business outcomes”
Deutz and Gibbs (2004)	“Industrial Ecology is a strategy to promote the reduction of the environmental impact of industry by learning from an analogy with natural systems”
Journal of Industrial Ecology (2005)	Industrial ecology “looks to the natural world for models”

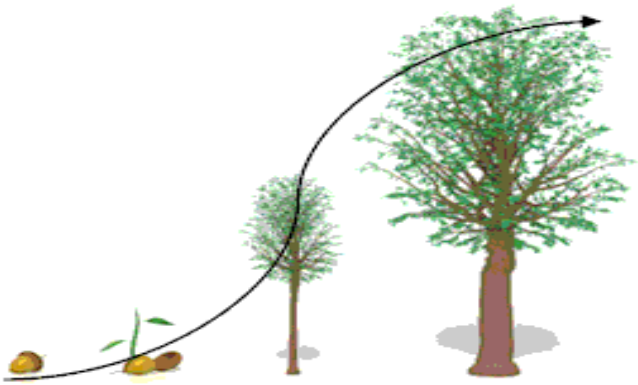


Figure 2.1: Natural growth of trees (Murarka 2013)

What is important from Accenture's research is that all studied human-based organizations had elements that followed the S-curve growth that is the same pattern as the natural growth of trees. This is taken into consideration when utilizing GM trees that are known to be less variable. It is logically expected that a reduction in variability would make the relationship more prominent.

The natural growth of trees can be represented as three phases, as depicted by the black curve in figure 2.1. In the first phase, the system grows slowly in the early years, followed by a sharp rise in growth in the second phase. Then the system experiences a slowdown in the growth rate in the third phase in the later years. As well, organizational growth is also similar to trees' natural growth in the same manner, as shown in figure 2.2 (Wrexin, 2015). In the first phase, the organization builds itself up, creates a market value, and develops capabilities. In the second phase, the organization grows rapidly and reaches out to its customers, followed by growth slow-down and consistent operation in the third phase as old products become mature and the market becomes saturated. This steady operation continues unless a major innovation and development take place in the

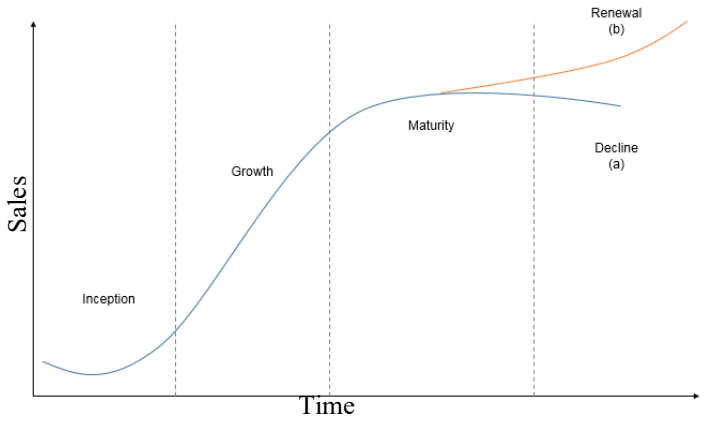


Figure 2.2: Organization growth (Wrexin, 2015)

organization. After all, it seems that the organizational growth cycle is similar to trees' natural growth, and they share the same S-curve.

2.6.1. The origin and the universality of the S-curve

This shared process of growth between human-based organizations and trees sounds simple; it is fortunately found in all other natural systems, including animals, humans, and companies, as shown in figure 2.3 (*Murarka*, 2013).

The natural growth pattern is a universal one, as shown in figure 2.4, in which all natural systems follow, including human-based organizations as human is the natural and organic component of organizations. According to a paper published by the Journal of Applied Physics, the authors from *Duke* University and the University of *Toulouse*, *France*, suggest that the shape of the S-curve is the natural flow and growth pattern of all nature's processes.

> "When something spreads on a territory, the curve of territory size versus time is S-shaped: slow initial growth is followed by much faster growth, and finally by slow growth again. The corresponding

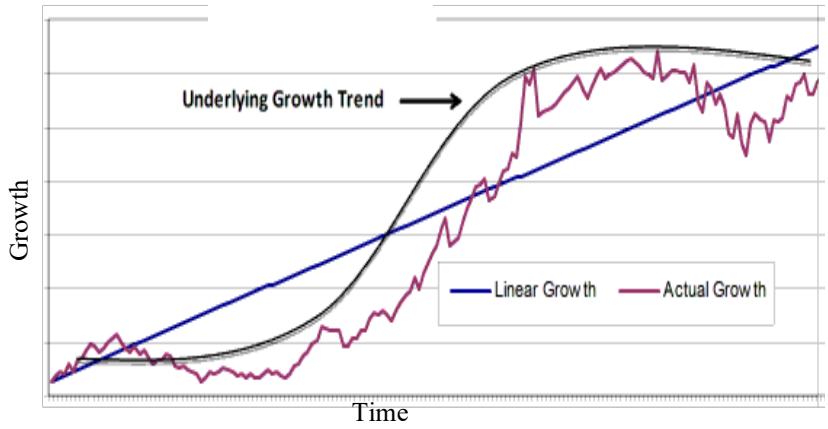


Figure 2.3: Normal growth of all natural systems (Murarka 2013)

curve of the rate of spreading versus time is bell shaped. This phenomenon is so common that it has generated entire fields of research that seem unrelated: the spreading of biological populations, tumors, chemical reactions, contaminants, languages, news, information, innovations, technologies, infrastructure, and economic activity. The natural phenomenon is not a particular mathematical expression for the S-shaped curve. The natural phenomenon is the very frequent observation that in many flow systems". (Bejan & Lorente, 2011)

2.6.1.1. Mathematical S-curve

Logistic function or Sigmoid function is the mathematical version of the S-curve; the Sigmoid model offers the ability to quantify the classical S-curve by toggling the curve when using the following equation:

$$f(x) = \frac{1}{1 + e^{-k(x-x_0)}}$$

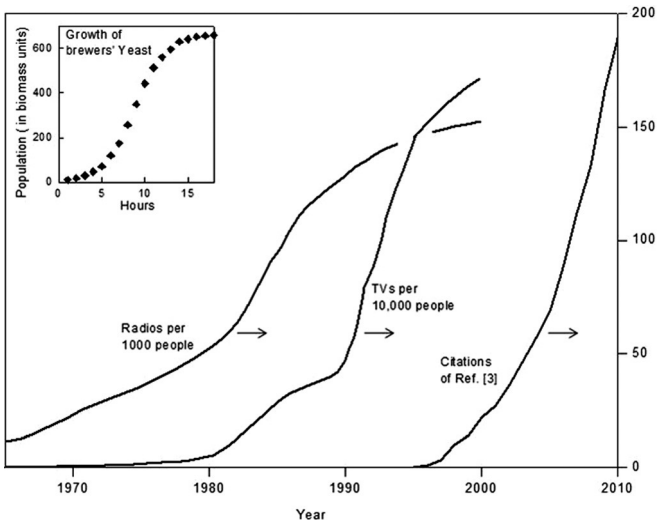


Figure 2.4: Examples of S-curve phenomena: the growth of brewer's yeast, the spreading of radios and TVs, and the growth of the readership of scientific publications (Bejan & Lorente, 2011)

Where:

- $e =$ the natural logarithm base.
- $x_0 =$ the x-value of the sigmoid's midpoint,
- $L =$ the curve's maximum value, and
- $k =$ the logistic growth rate or steepness of the curve.

The inputs to the function do not build the curve rather than toggling the curve, so that the steeper the curve, the faster the growth. This property of the function makes limited to logistic applications as it is named and might not be as representative as it should be in the context of this research. This idea will be furtherly explained in section 4.5.2

The *Sigmoid* function is not the only S-curve function in the field. There is the Lim's S-curve that seeks to provide utilizable solutions to poverty alleviation and economic development. Lim's S-curve provides a mathematical function for economic development that can help developing countries. However, *Hui Sng*, a

professor in economics at the Nanyang Technological University (NTU) in Singapore, suggested in her book “Economic Growth and Transition: Econometric Analysis of Lim's S-Curve Hypothesis” that the Lim’s S-curve has a mathematical and econometrical sophistication and here are some serious limitations of the S-curve applications as a mathematical tool.

> “The main weakness of the S-Curve hypothesis is that it lacks quantitative rigor. There is a lack of empirical proof of the S-Curve hypothesis and there is a lack of empirical analysis on the growth paths of economies at different stages of development. In addition, the completeness of the S- Curve hypothesis as a growth model is also hindered by its lack of micro-economic foundation.” (Sng, 2010)

2.6.2. Natural phases of organizational and business growth

The Greiner Curve (1998) identifies the five phases organizations go through as they mature. There are five accepted evolutionary phases of organizational and business growth: creativity, direction, delegation, coordination, and collaboration (*Greiner*, 1998). When an organization is within one of the stages, it is relatively stable. However, every stage inevitably leads to a crisis point, which is a forcing function that causes the organization to transform.

Just as in trees, an organization grows from humble beginnings. If it is nurtured correctly, it will continue its growth. The problem area of this continued growth is in the transitional areas between the five evolutionary phases. These transitional areas are sometimes referred to as the revolutionary phases or areas

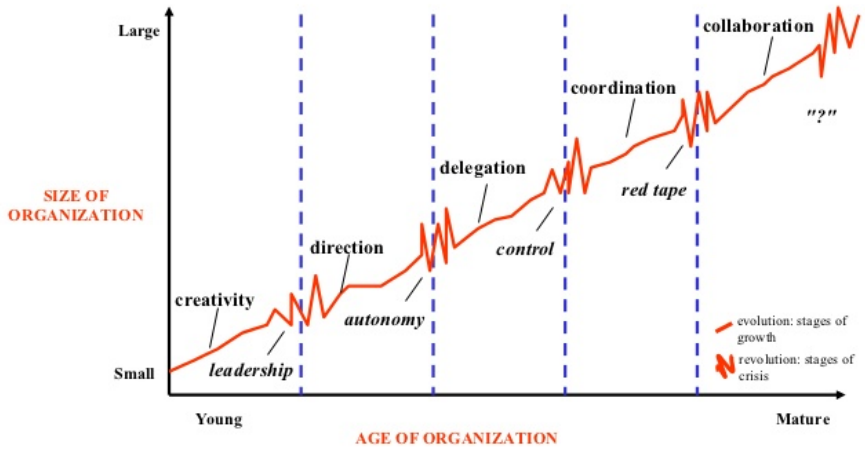


Figure 2.5: The five phases of growth

of crisis (*Greiner*, 1998.) The biomimicry analysis being performed has the possibility of opening a new area of research and understanding in the highly volatile revolutionary phase or areas of crisis. Organizational growth is not a linear function, especially in these transitional areas of crisis. The growth can be steady but with intermittent areas of positive or negative growth. The areas of crisis can determine the success or even survival of an organization.

The figure 2.5 shows the five phases, along with their evolutionary and revolutionary components. The three phases of breakpoint change are another example of natural phases of organizational growth (Kamal, 2016). The model suggests that natural systems, including human-based organizations, experience three phases of development passing through two transitional periods named breakpoints. *Kamal* suggests that natural systems are exemplary models to learn from due to the historical record of how nature's processes had successfully changed itself during the breakpoint. The philosophy behind his approach is

coming from an evolutionary standpoint that is “nature knows change best, she’s been in this business the longest,” so that “we can plan for tomorrow by frequently looking at past results” (Kamal, 2016). Basically, this fundamental is in-line with the Greiner curve in terms of the idea of phases of growth and transitional periods that an organization experience a challenging time to survive. In figure 2.6, *Kamal* shows similar work to *Greiner* of the growth of natural systems.

2.6.3. What can be learned from phases of growth

Understanding the growth cycle of GM trees may be very helpful in the understanding of organizational growth during times of crisis for two main reasons. First, it has been suggested that organizational growth and the natural growth of GM trees follow the relative cycle. Second, the goal for organizations is to exist and persist through these difficult times of crisis with positive growth, as opposed to negative growth. With regard to the natural world, times of crisis are associated with the external forces of weather, water, drought, etc. GM trees are designed to help reduce the negative impact of these external forces, and in this way, they may provide a better model of organizations going through similarly difficult times as compared with normal trees. This idea could then be adapted to organizations experiencing these times of crisis and allows them to think about crises and periods of crisis in this different way. Specifically, organizations can be prepared in a way similar to that of GMOs, and this study may help to understand external forces or stressors better. By being able to prepare themselves before times of crisis happen, organizations may be able to reduce their losses and endure these difficult periods with less disruption.

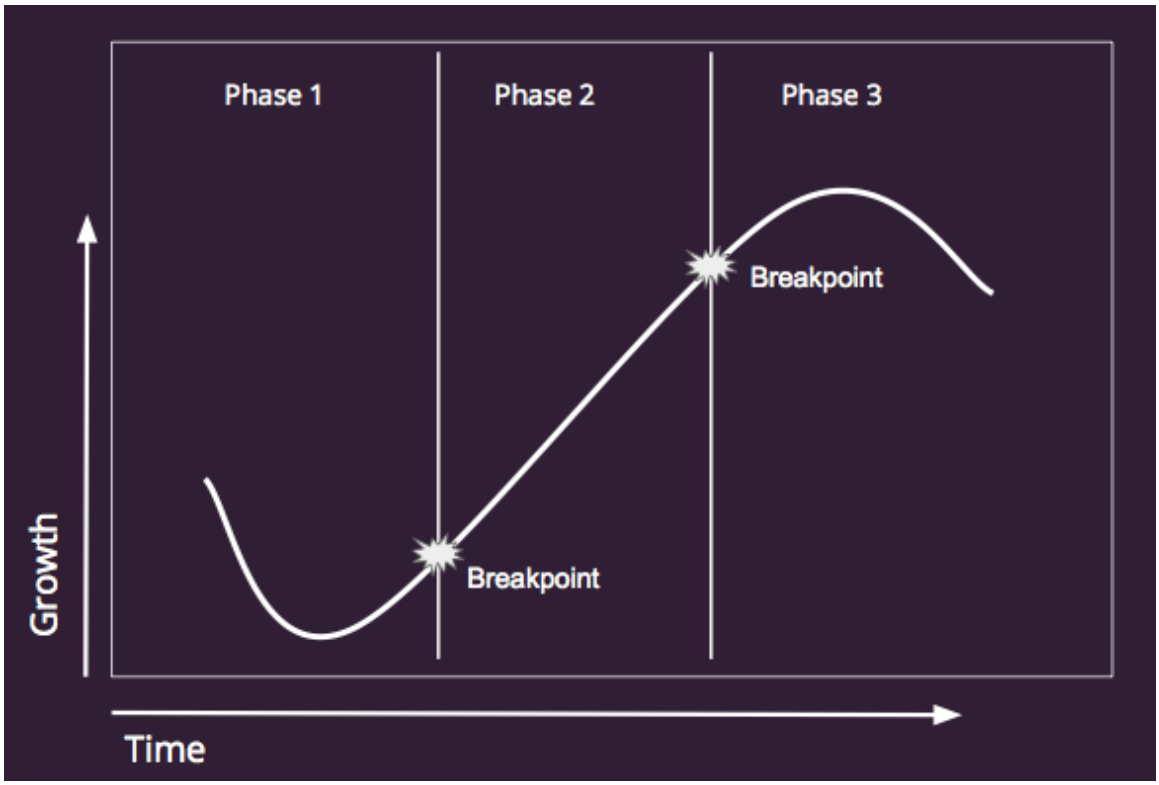


Figure 2.6: The three phases of Breakpoint Change

2.7. Normal trees vs. GM trees

There are only a few GM tree species approved by governmental agencies around the world, with many still under study. One of the best examples officially approved is the *Eucalyptus* tree in Brazil. It is developed and genetically modified by *FuturaGene.* As depicted in the following infographic, figure 2.7 (*FuturaGene*, 2014) and the bar graph, figure 2.8, the current advantages of GM *Eucalyptus* are time savings of 18 months to maturity, a 15% increase in production, 13% less area required to meet demand, a 12% increase in carbon-dioxide capture, 16% additional jobs, a 28% increase in profit for rural growers when they have free access to the technology, and a 20% reduction in production cost. In addition, the

GM *Eucalyptus* can contribute to the pulp and paper, furniture, steel, civil construction, bioenergy, and bio-products industries (*FuturaGene,* 2014).

Statistical analysis is conducted on the available statistical information in the infographic, as shown in the bar figure 2.8. The yellow line shows the linear regression of improvements on different independent economic variables between GM Eucalyptus and non-GM eucalyptus. The analysis in this example shows around 15% of total improvement on some econometrics that are similarly used by economy-based organizations such as production cost, profits, and number of job creation.

2.8. Summary

As stated before, this research will be focusing on human-based organizations by emphasizing the role of biomimicking successful natural processes as a way to learn from nature how problems can be solved. Trees were picked as a good candidate from successful natural processes because, in addition to the sharing of the S-curve growth pattern, it almost shares the same economic metrics with human-based organizations such as time to maturity, production potential, return on investment, etc. In this research, GM tree is hypothesized to be favored over the conventional tree in the context of achieving economic improvements to organizations through the use of biomimicry. If the hypothesis is not econometrically rejected in chapter four, then the results will be beneficial to the advocates of organizational development.

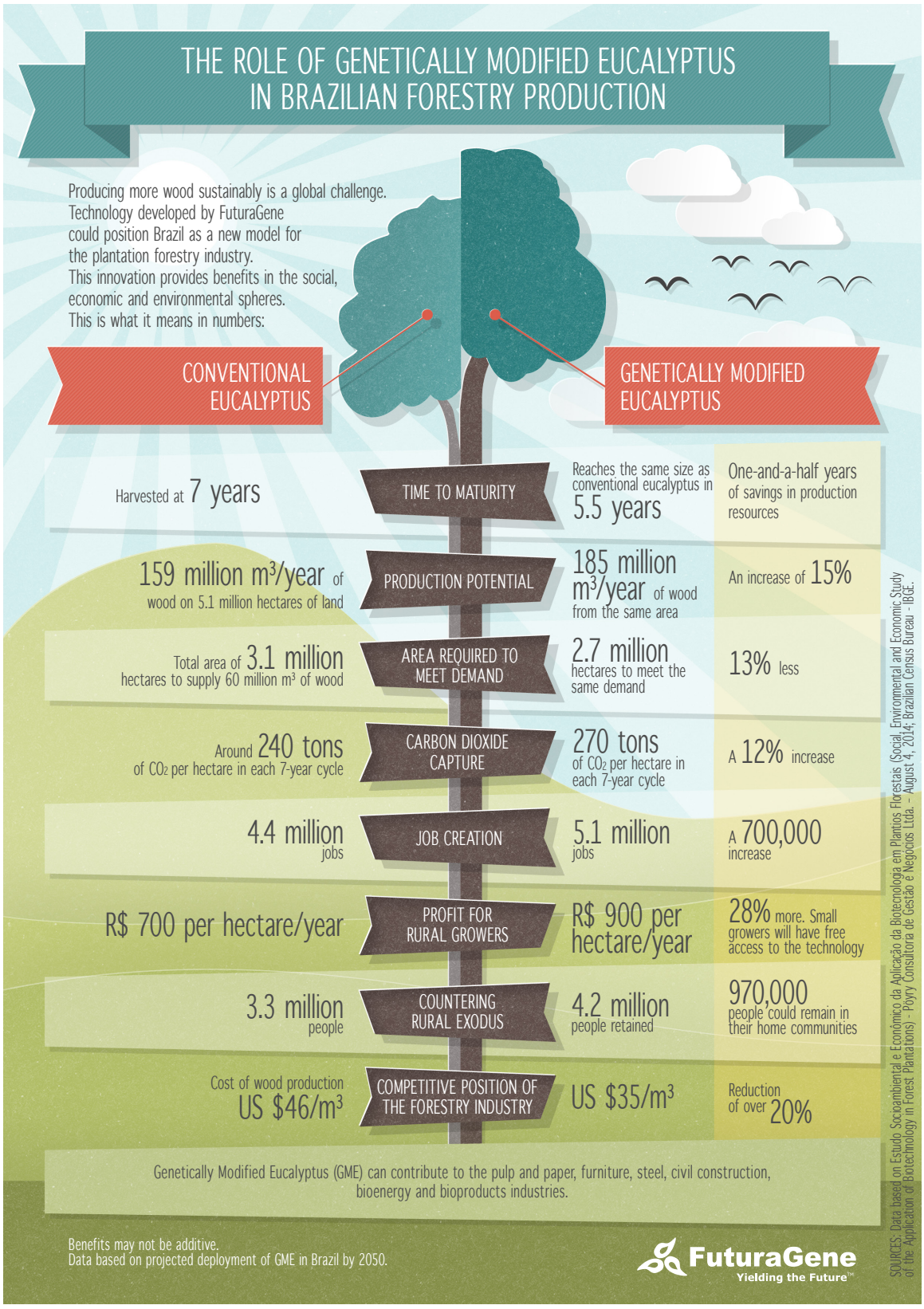


Figure 2.7: The role of GM Eucalyptus in Brazilian forestry production (FuturaGene 2014)

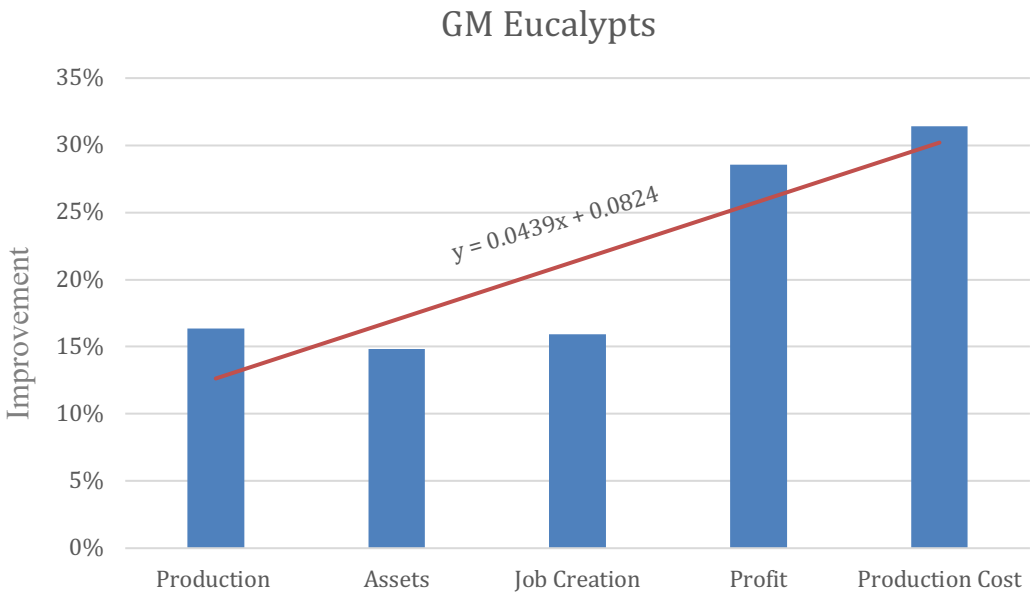


Figure 2.8: Linear regression of GM Eucalyptus improvement over non-GM type

3. Methodology

3.1. Introduction

In this chapter, the methodology proposed for this study is presented and discussed. This includes the research question and hypothesis proposed for this study along with a discussion of the data proposed for use and the associated variables under study, and the data analysis plan.

3.2. Research question and hypotheses

The research question proposed in the present study consists of the following:

Research Question: "Is the growth of Genetically Modified trees a better representation of organizational than past attempts using natural growth cycles of normal trees?"

The analysis planned for this study, as it will be explained later in section 3.4. Data analysis plan, along with the interpretation of its results, will aim to answer this research question. Additionally, the following hypothesis was developed on the basis of this research question:

$H0_1$: The growth of Genetically Modified trees is not a better representation of organizational growth than past attempts using natural growth cycles of normal trees.

Ha_1: The growth of Genetically Modified trees is a better representation of organizational growth than past attempts using natural growth cycles of normal trees.

3.3. Conceptual framework

The following figure presents the conceptual framework of variables that will be tested by the aforementioned hypothesis, with this figure illustrating a single independent variable, along with three dependent variables. The independent variable is the type of tree under observation, with the dependent variables consisting of survivability, volume growth, viability, and production. These econometrics were picked as they 1) are found to be similar to the metrics found in many organizations, and 2) have their empirical information published by different researchers. Also, these dependent variables are consistent with the dependent variables of GM *Eucalyptus* mentioned in figure 3.1, which are production, assets, job creation, profits, and production cost.

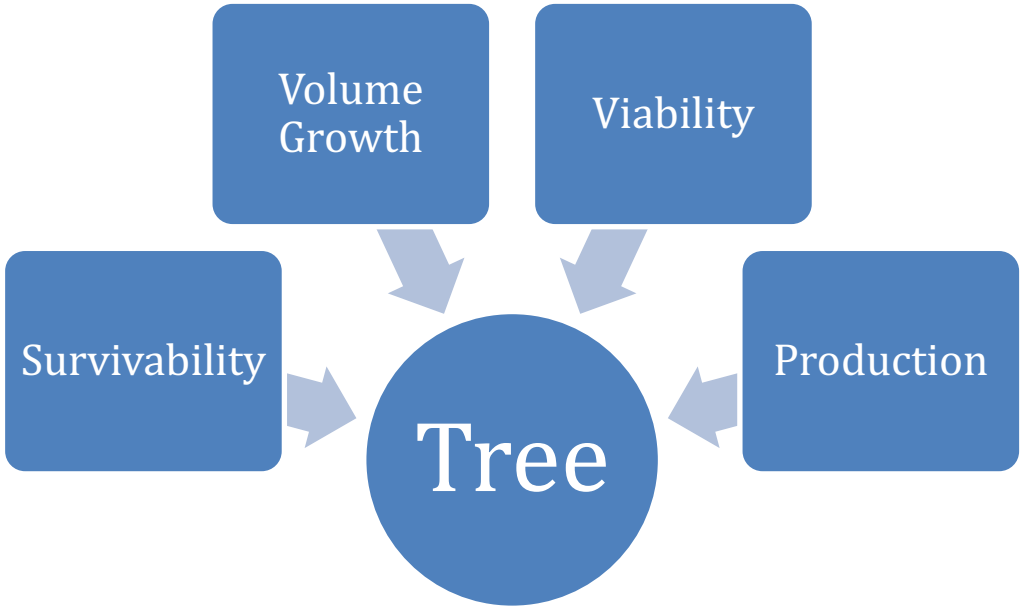


Figure 3.1: The targeted variables intended to be tested by the model

3.4. Analysis plan

The analysis plan is developed based on the validity of the basic assumptions given in chapter 1. The above set of hypotheses will be tested statistically. The hypothesis proposed for this study will be tested through the use of a meta-analysis. Specifically, a meta-analysis will be conducted using Stata 13.0 software in order to determine the size of the effect of the differences between conventionally grown and GM trees to confirm a difference actually exist. A random-effects model and a fixed-effects model will then be used, in which the true treatment difference is assumed to consist of a single random variable which is normally distributed. This produces larger standard errors based on this greater degree of variation being present between the groups being examined. The greater the variation, the greater the differences between the test groups.

3.4.1. Selection criteria

A random-effects model was felt to be the most appropriate in this case due to the fact that the studies identified for inclusion in this meta-analysis generally studied different effects or differences between conventional and GM trees, so it was felt by the researcher that a random-effects model and a fixed-effect model would more appropriately cover this scenario as compared with a fixed-effects model.

There are many studies that provide their outcomes in different statistical measurements. The selection criterion will pick the studies that their results and outcomes are compatible with the measurements required by the calculation of the meta-analysis. Moreover, the criterion of selecting a study to participate in the

meta-analyses will require the results of the studies 1) to be quantitative and 2) to directly compare a GM tree to its non-GM type tree. In addition, at least one of the aforementioned variables to be tested by the hypotheses has 3) to be a comparison element of the elected study for inclusion in the meta-analyses.

3.4.2. Step-by-step analysis

1) A literature search was conducted in order to find relevant studies comparing conventionally grown with GM trees in order to determine a list of studies that can be used in this study's meta-analysis.
2) These studies will be reviewed, and the relevant effect sizes extracted, or data which can be used to calculate an effect size, if no relevant effect size is included in the paper. A number of studies have already been identified which appear to be strong candidates for inclusion in this study's meta-analysis (*Fernandez-Cornejo* et al., 2014; *Lagnaoui* et al., 2001; *Lojewski* et al., 2009; *Pilate* et al., 2002; and *Jing* et al., 2004).
3) With respect to the process by which this meta-analysis will be conducted, initially, each of the studies selected for inclusion will be reviewed in order to determine a statistical result which will be appropriate for use in this study's meta-analysis.
4) These results will be added to an *Excel* file, which will include the study title, the first author's last name, the year of publication, along with the associated excerpted statistical results and notes, as needed, describing the result in question in additional detail.

5) Once this process has been completed, each of the results taken from the studies included in this meta-analysis will then be transformed into a single measure of effect size for the purposes of the meta-analysis.
6) Specifically, Pearson's r is selected for use as this effect size can be easily used to conduct the meta-analysis in Stata, as detailed in section 3.5. Pearson's r will be calculated to measure the strength of the linear relationship between the GM tree and its non-GM type, followed by the associated standard errors, which are also required for the purposes of conducting a meta-analysis using effect size in Stata.
7) Once this is complete, the meta-analysis itself will be conducted in Stata 13.0, using the *metaan* command. These results will then be interpreted and applied in order to test this study's hypothesis and to answer its research question.
8) In addition to the results of the meta-analysis, a funnel plot with superimposed pseudo-95% confidence intervals will also be created in order to determine whether studies with more average effect sizes have a greater standard error and whether studies having effect sizes substantially above or below this average have reduced standard error, which is expected.
9) In addition, a contour-enhanced funnel plot will also be conducted in order to assess whether small-study reporting bias or publication bias was present in the meta-analysis.

With regard to the data proposed for analysis in this study, this study proposes the analysis of secondary data or data that has already been collected by other researchers, as opposed to the use of primary data or original data, which

would be collected directly by the researcher. Literature searches have already been conducted in order to ensure that studies appropriate for use in this study's meta-analysis exist and can be used for the purposes of this study's analysis. These data will be collected, compiled, and analyzed in order to test this study's hypothesis.

3.5. Overview of meta-analysis

Meta-analysis is a mathematical tool that mathematically compares the outcomes and the results of scientific studies. The driver behind selecting meta-analysis is to find the common truth resulted from involved similar scientific studies, excluding studies or data with certain or significant errors. This approach aims to pull out the nearest estimate to the unknown supported common truth, depending on how errors are perceived. During the process of meta-analysis, weighted averages are yielded from the outcomes of participated studies so that they differ in which they can be allocated and, then, uncertainty can be computed around the point estimate thus generated. Moreover, meta-analysis as a mathematical tool has the ability to contrast results from a variety of studies and recognize patterns among studies, origins of variances between targeted results, or any other factor attracts attention within participated studies (*Rothman* et al., 2008).

The main benefit of using this tool is the aggregation of data along with possible information resulting in a higher level of statistical power and a more robust point estimate than what is possible through a conventional individual study. However, during the process of performing meta-analysis, the researcher choices significantly affect the results. These choices include how studies are searched,

based on what set of objective criteria the studies are selected, how to analyze and deal with incomplete data, how to avoid publication bias (*Walker* et al., 2008). Meta-analysis usually plays a vital role in the systematic review procedure. For example, it can be conducted on clinical trials of medical treatment in order to get a comprehensive understanding of treatment and how it works. This is where meta-analysis got its name as it refers to the statistical approach that collects needed pieces of evidence from studies while it leaves qualitative evidence.

3.5.1. History

The historical roots of the meta-analysis are often back to 1904 when the statistician *Karl Pearson* published a paper in the *British Medical Journal* about the typhoid vaccine. In his paper, he compared data from several studies so that it is believed to be the first case ever known to use meta-analysis (*Nordmann* et al., 2012). However, in 1940, the first known application of meta-analysis concerning a particular research issue was conducted by *Duke University* psychologists *J. G. Pratt, J. B. Rhine*, and associates in their book named: *Extrasensory Perception After Sixty Years*. In this book, the authors investigated 145 reports of the sixth sense experiments performed from 1882 through 1939. Even though meta-analysis is mostly used in the medical sector, nowadays, it had not been applied in the medical sector until 1955. Then, in the 1970s, the techniques of the meta-analysis were widely introduced to other sectors such as education by *Gene V. Glass, Frank L. Schmidt,* and *John E. Hunter*, and other works in other sectors. *Gene V. Glass* was the first statistician to formalize the term by linking it to his work (*Glass*, 1976). Particularly, he stated that: *"my major interest currently is in what*

we have come to call ...the meta-analysis of research. The term is a bit grand, but it is precise and apt ... Meta-analysis refers to the analysis of analyses".

3.5.2. Advantages

Meta-analysis uses the mathematical approach to compare the results between several studies in an effort to exceed the quality over single studies, improve estimates of the size of the effect, and or to resolve uncertainty and contradictions, if any, between the results of individual studies. Moreover, meta-analysis generates a weighted average of the participating study results in which it gets the following advantages:

- Results can be expanded to encompass a larger population,
- As more data is used, final results can achieve more precision and accuracy. As a result, the statistical power to detect an effect may be increased.
- The ability to measure and analyze the inconsistency of results among the participating studies. For example, errors caused by sampling or even publication bias can be identified and resolved.
- Moderators can be involved to explain variation between studies,

3.5.3. Risks

There are risks and disadvantages of utilizing meta-analysis. Conducting meta-analysis on small studies does not predict the result of one single large study (*LeLorier* et al., 1997). Some experts express their concerns that meta-analysis does not correct the publication bias in the original sources and references in the

participating studies. That means only high credible studies with sources of the same level of quality can be good candidates to conduct a meta-analysis in a practice called “best evidence synthesis” (*Slavin*, 1986). Moreover, relying on publicly available studies may lead to exaggerated results because of publication bias in the original studies or their sources, in which studies that show insignificant results or negative results are less likely to be published or used. If such implications exist, it is difficult to know if researchers in pharmaceutical companies, for example, hide negative studies or overlook unpublished studies such as conference abstracts that did not reach publication. Also, if some publication biases are discovered, it is also not easy to know the number of such hidden studies stay hidden (*Rosenthal*, 1979).

According to a study performed in 2012 in the sake of identifying publication bias, an examination of a sample of 91 recent meta-analyses, published in American Psychological Association and Association for Psychological Science journals, found that 64 studies out of 91 (70%) made some effort to identify and analyze publication bias and 26 studies (41%) reported evidence of publication bias. The final indication was that 25% of meta-analyses in the psychological sciences might have suffered from publication bias (*Ferguson* & *Brannick*, 2012). There are other problems less important than publication bias such as problems arising from agenda-driven bias or studies do not report non-statistically significant effects. However, other investigators think that in the worst scenario, weak studies can be used if a study-level predictor indicator is added to reflect the methodological quality of candidate studies to investigate the effect of the study

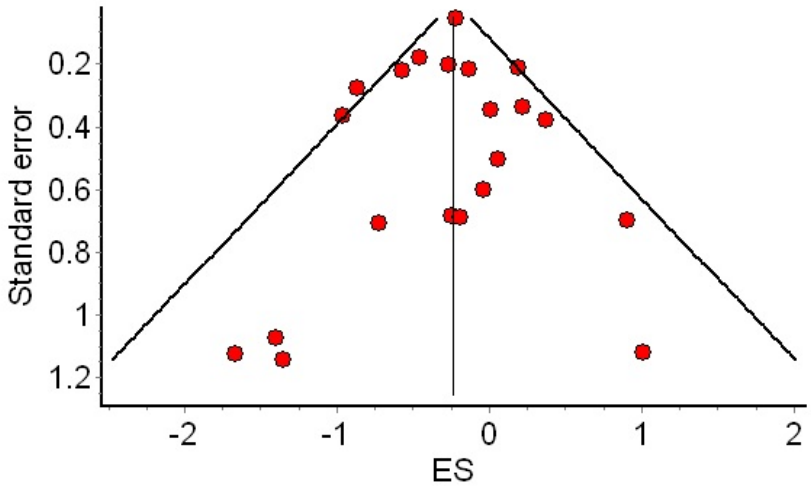


Figure 3.2: Funnel plot scatters largest studies at the top while smaller studies with higher standard errors are scattered at the base

quality on the effect size (*Hunter,* 1982). While others suggested that a better approach is to keep the information about the variance in the study sample, then unwanted subjectivity can be introduced by methodological selection criteria to defeat the purpose of the approach. (*Glass* et al., 1981).

There is a statistical approach to solve the publication bias when it comes to the point where researchers overestimate the results of desired studies and hide the results of studies not supporting the research hypothesis or goal. This approach, called funnel plot, visualizes the effect sizes among participating studies by plotting standard errors versus effect sizes. As shown in figure 3.2, funnel plot shows large studies with lower standard errors as a less scatter in the top of the funnel while other small studies with higher standard errors are clear to be less unjustified (*Light* & *Pillemer 1984*).

For the purpose of making sure that participating studies do not have publication biases, and as stated before at the end of section 3.4. Data analysis plan, a contour-enhanced funnel plot will also be conducted in order to assess whether small-study reporting bias or publication bias was present in the meta-analysis.

3.5.4. Conducting meta-analysis

There are two approaches to conduct the meta-analysis. Deciding what approach is appropriate depends on data provided by participating studies. Data can be either first data or secondary data. In statistics, first data is an individual participant data that is raw and needs to go through statistical processes first to generate some statistical results such as odds ratios or relative risks. These results are already calculated in secondary data that is also called aggregate data; and that is the basic difference between the two types of data. The meta-analysis that is to be conducted in this research will be using the direct secondary data provided by participating studies, as previously summarized in section 3.4. Data analysis plan. In chapter 4, the steps of conducting the meta-analysis will be explained in detail after evaluating the data provided by participating studies.

3.6. The mathematical model of the meta-analysis

With respect to the meta-analysis proposed for use in this study, *Pearson's* correlation coefficient is proposed as the effect size that will be used. The process of the meta-analysis itself will involve the conversion of all effect sizes found in the studies incorporated into this meta-analysis to *Pearson's* correlation coefficients, with the meta-analysis then being conducted on these converted data.

Regarding the *Pearson's* correlation coefficient, this measure of effect size can be transformed through the use of the *Fisher z*-transform to a *z*-score:

$$z = \frac{1}{2} log\left(\frac{1+r}{1-r}\right)$$

The sampling uncertainty of the correlation's *z*-transformation can be defined by its variance, as follows:

$$v = \frac{1}{n-3}$$

Where n is equal to the study's sample size.

With respect to the equations relevant to the meta-analysis itself, these methods and equations are largely independent of the effect size used. Using the generic effect size T_i, the initial assumption can be made that T_i is normally distributed around θ_i with a variance v_i. This assumption can be illustrated as follows:

$$T_i - N(\theta_i, v_i) = 1, \dots, \mathrm{k}$$

The extent to which this assumption is upheld depends upon the effect size in question. For example, this assumption is nearly upheld in the case of the *Fisher z*-transformed correlation coefficient, while this is less true in the cases of the untransformed correlation coefficient as well as the log-odds ratio.

The primary function of the meta-analysis is to combine effect size estimates across studies in order to derive an estimate of the average effect size. Here, θ_i represents the unobserved effect size parameter, or the true effect size,

in the i^{th} study, with T_i representing the corresponding observed effect size estimate from the i^{th} study, with v_i its variance. Effect size data derived from k studies can then be represented as effect size estimates $T_1, \ldots \ldots, T_k$ with variances $v_1, \ldots \ldots, v_k$.

Study data used in a meta-analysis can be described as a two-level hierarchical model with one model used for the study-level data, and a second model used for the between-study variation in effects. Regarding the within-study level, the estimate of the effect size T_i consists of the effect size parameter along with the addition of sampling error, as follows:

$$T_i = \theta_i + \varepsilon_i, \text{ where, } \varepsilon_i \sim N(0, v_i)$$

Here, θ represents the mean effect size parameter associated with all studies or can be defined as the distribution mean associated with the sampled specific-study effect size parameters $(\theta_1, \theta_2, \ldots, \theta_k)$.

The effect size parameters at the between-study level are based on a mean effect size plus a random-effect which is specific to each study in question as follows:

$$\theta_i = \beta_0 + \eta_i, \text{ where } \eta_i \sim N(0, \tau^2)$$

Here, η_i represents differences between study-to-study effect sizes, where τ^2, termed the between-studies variance component, measures the level of variation across studies with respect to their random-effects (or the η_i values), and more broadly, their effect parameters (or the θ_i values). While this model, in its

general form, is identical to that of the hierarchical linear model, in this present case, the level one variance is not the same across level one units, with this instead varying from study to study. Additionally, the level one variance is known with regard to the meta-analysis, while generally it is instead unknown, needing to be estimated from the data collected.

This two-level model can be represented as a one-level model in the following way:

$$T_i = \beta_0 + \eta_i + \varepsilon_i = \beta_0 + \xi_i$$

Here, ξ_i represents a composite error, whereby $\xi_i = \eta_i + \varepsilon_i$. With the equation presented as a one-level model, it can be determined that the effect size associated with each study is an estimate of the measure β_0 and having a variance that is dependent upon v_i and τ^2. Additionally, the distinction between the variance of T_i in which θ_i is fixed (termed the "conditional sampling variance" of T_i, and denoted as v_i), and the variance of T_i in which the variance of θ_i is incorporated as well (termed the "unconditional sampling variance" of T_i, and denoted as v_i^*), should be made. As the sampling error ε_i is independent of the random-effect η_i, and as the variance of η_i is τ^2, the unconditional sampling variance of T_i is then equal to the following:

$$v_i^* = v_i + \tau^2$$

The maximum likelihood and least squares estimate of the parameter β_0 can then be calculated as the following:

$$\hat{\beta}_0 = \frac{\sum_{i=1}^{k} w_i T_i}{\sum_{i=1}^{k} w_i}$$

Where:

$$w_i = \frac{1}{(v_i + \tau^2)} = \frac{1}{v_i}$$

And where τ^2 represents the estimate of the between-subjects variance component. As this corresponds to a weighted mean of T_i, more weight is then given to studies in which their estimates have a smaller unconditional variance – meaning that they are more precise (*Konstantopoulos* & *Hedges*.)

3.7. Summary

For the purpose of developing relationships between generalized organizations during phase transitional crisis periods through biomimicking trees as a natural successful process, it is hypothesized that GM tree is favored over the conventional one in terms of the economic output such as return on investment, production potential, time to maturity, etc. In order to test the hypothesis econometrically, the statistical tool of meta-analysis is the candidate to conduct the test. This tool is selected based on the fact that it can use the econometric data collected from several studies. In addition, such a statistical comparison, using meta-analysis, has not been done before, where other researchers only compare a specific species of tree with its GM model in different singular studies. The aforementioned studies have been found eligible to participate in this research as they provide the effect of the sizes of several econometrics between GM and

conventional tree. All further investigations, beyond the step-by-step analysis plan detailed in section 3.4. Data analysis plan, will be performed in chapter four.

For the purpose of avoiding any consequence of publication bias, as aforementioned in section 3.5.3. Risks, that could exist in participating studies especially in small ones, a funnel plot with superimposed confidence intervals of 95% will be created and a contour-enhanced funnel plot will also be conducted in order to determine associated standard errors and to assess whether small-study reporting bias or publication bias was present in the meta-analysis.

4. Results

4.1. Introduction

In this section, the results of the analyses conducted for this study are presented and discussed. These analyses consisted of two meta-analyses, one incorporating fixed-effects, and one incorporating random-effects, such that both of these assumptions were covered. Descriptive statistics along with descriptions of the effects used in these meta-analyses are presented, along with a presentation and discussion of the results of the meta-analyses themselves.

4.2. Meta-analysis

First, a literature review was conducted in this area in order to initially find a set of studies that could be used for this study's meta-analysis. This incorporated, generally, any previous research which compared GM with normal trees on some relevant outcome, including growth, yield, and related measures. This literature search proved challenging as while a body of literature does exist comparing GM with normal trees, the majority of the researchers who publish in this area do not include the necessary data or statistical results which would be required in order to calculate an effect size for the purposes of a meta-analysis. For this reason, the majority of the studies found and reviewed could not be used and needed to be discarded. In the end, a series of results taken from a total of two papers were used in this study's meta-analyses.

The studies whose results were incorporated into this study's meta-analyses consisted of a paper by *Klocko* et al. (2014), titled "Bt-Cry3Aa transgene

expression reduces insect damage and improves growth in field-grown hybrid poplar," along with a paper by Axelsson et al. (2011), titled "Leaf ontogeny interacts with Bt modification to affect innate resistance in GM aspens". Due to the small number of studies incorporating useable data or results for the purposes of a meta-analysis, multiple results were derived from these papers and were included as separate effect sizes in this current study's meta-analyses, as possible. While Klocko et al. (2014) presented several results, only one could be used:

1. It consisted of a t-test conducted focusing on a comparison between GM *Poplar* tree and its non-GM type. They had found that the average volume growth of the GM *type* was significantly larger, $t(215) = -2.80$, $p = .006$, with $n = 215$ within each group.

Following this, Axelsson et al. (2011) incorporated a series of results which could be incorporated into this study's meta-analyses. These consisted of five results analyze the viability and the survivability of GM Aspen tree as follow:

2. The effect of the GM line on leaf consumption by slugs, which did not achieve statistical significance, $F(1, 188) = 1.883$, $p = .172$; Wt line $n = 48$, Bt17 line $n = 46$;
3. The effect of the leaf position on the leaf consumption by slugs, $F(1, 188) = 6.448$, $p = .012$, same sample sizes,
4. The effect of the GM line on leaf consumption by slugs in a 10-day feeding trial, $F(1, 43) = 16.149$, $p < .001$, same sample sizes,

5. Comparing Wt and Bt17 lines in terms of biomass production with a new t-test being run on their data for the purposes of these meta-analyses,
6. Comparing the Wt and Bt27 lines in terms of biomass production, using an estimated sample size of 46.

Table 4.1 summarizes all results included in these meta-analyses as well as the results of the calculations made in aid of the meta-analyses. Following the collection of the various results from these two papers, Cohen's d was calculated in relation to each result using a variety of appropriate equations and calculators (see Appendix A). Cohen's d measures the sizes of associations or the size of the difference. As a rule of thumb: if d= 0.2 the effect is small, if d= 0.5 the effect is said to medium, and if d = 0.8 the effect is large. For example: if d= 0.8 then the groups being compared do not differ by 0.2 standard deviations or more, this difference is statistically trivial. Following this, Pearson's r, along with its associated standard error, were calculated from each Cohen's d. The Pearson's r values along with the associated standard errors were then used for the meta-analyses conducted in Stata. Pearson's r is a measure of the strength of the linear relationship between variables. With a Pearson's r = 1.0, there is a perfect positive relationship between variables and with r =-1.0 perfect negative relationship.

Table 4.1: Original data

Study	Original Results	Cohen's d	Pearson's r (SE)
Klocko	$t(215) = -2.80$, $p = .006$	-.3810	-.1872 (.0672)
Axelsson	$F(1, 188) = 1.883$, $p = .172$	.2831	.1401 (.0677)
Axelsson	$F(1, 188) = 6.448$, $p = .012$	.5239	.2533 (.0661)
Axelsson	$F(1, 43) = 16.149$, $p < .001$	.8292	.3829 (.0631)
Axelsson	Wt = 52.3g +/- 8.4, Bt17 = 21.6g +/- 7.0	3.9706	.8931 (.0308)
Axelsson	Wt = 52.3g +/- 8.4, Bt27 = 28.9g +/- 16.5	1.7873	.6663 (.0510)

Table 4.2: interpreted data

Study	Result	Cohen's d	Pearson's r	P-value
Klocko	Average volume growth of the GMO compared to non-GMO	Small	Small	Significant
Axelsson	The effect of GMO on leaf consumption by slugs	Small	Small	Not Significant
Axelsson	The effect of GMO on leaf consumption by slugs	Medium	Small	Significant
Axelsson	The effect of GMO on leaf consumption by slugs	Large	Medium	Significant
Axelsson	The effect of GMO on leaf consumption by slugs	Large	Large	Negative
Axelsson	Biomass production of GMO^2 over non-GMO	Large	Large	Negative

An r = 0 indicates no relationship between variables. The closer r approaches 0, the greater the variation around the line of best fit. Rules of Thumb for Pearson's r for Strength of Association: With an r value (positive or negative values) of 0.1 to 0.3 the strength of the relationship is small, from 0.3 to 0.5 the strength of the relationship is medium, and an r of 0.5 to 1.0 indicates a large strength of relationship, as furtherly explained in table 4.2.

Table 4.3 presents the results of the fixed-effects meta-analysis conducted on these data. Effect sizes were found to vary from a minimum of -.187 to a maximum of .893. Weight was highest in relation to effect 5, which was weighted as 44.77%, with effects one through three weighted as less than 10%, effect 4 weighted as slightly above 10%, and with effect 6 weighted as 16.30%. The overall effect was found to be equal to .569, with the associated 95% confidence interval ranging from .529 to .609. This result indicates a moderate and positive effect when comparing GM with normal trees. The effects percentage weight indicates

Table 4.3: Fixed-effects meta-analysis results

Effect	Effect size	95% Confidence Interval Lower	Upper	% Weight
1	0.187	-0.319	-0.056	9.39
2	0.140	0.007	0.273	9.24
3	0.253	0.124	0.383	9.68
4	0.383	0.259	0.507	10.62
5	0.893	0.833	0.953	44.77
6	0.666	0.566	0.766	16.30
Overall effect (fe)	0.569	0.529	0.609	100

that the original data taken from the case studies shows that the samples differ. One basic assumption that the samples are the same is important to note. The weighting differences among the six case studies indicate they are different when comparing single fixed-effects.

Figure 4.1 presents the forest plot associated with this analysis. As shown, effect 1 had the smallest effect size, with effects two through four having more moderate effect sizes, and with effects five and six having larger effect sizes. The line demarcated by the diamond represents the overall effect of .569, with the sides of this diamond representing the 95% confidence interval of this effect. This associated confidence interval was quite narrow.

Next, Table 4.4 presents the results of the random-effects meta-analysis conducted on these data. This method weights each effect nearly equally. The results of this analysis produced a small positive effect of 0.360, with the 95% confidence interval ranging from a minimum of .020 to a maximum of 0.701.

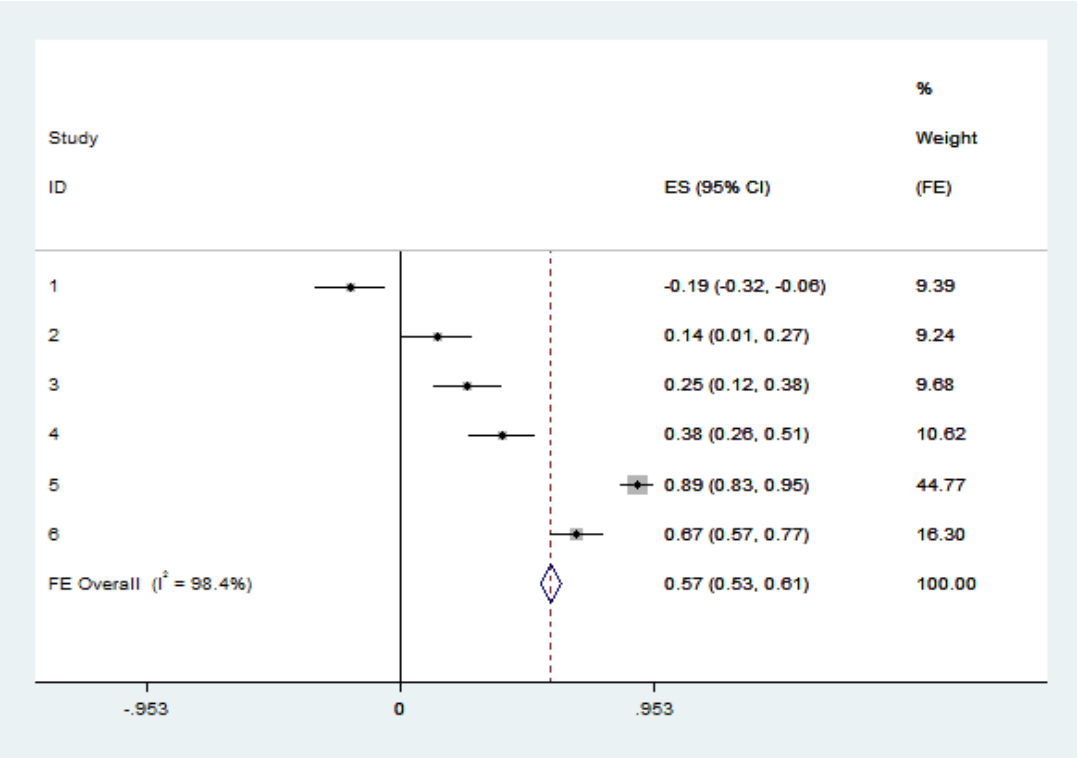


Figure 4.1: Forest plot associated with fixed-effects meta-analysis

The effects percentage weight indicates that the original data taken from the case studies shows that the samples are relatively the same. One basic assumption that the samples are different important to note. The slight weighting differences among the six case studies indicate they are different when compared to the single fixed-effects.

Figure 4.2 presents the forest plot associated with this analysis. The effect sizes are identical, with the differences present consisting of the effect weights, as well as the diamond, representing the overall effect along with its 95% confidence interval. While substantially smaller, the 95% confidence interval associated with this overall effect was also much larger as compared with the 95% confidence interval associated with the fixed-effects meta-analysis.

Table 4.4: Random-effects meta-analysis results

Effect	Effect size	95% Confidence Interval		% Weight
		Lower	Upper	
1	-0.187	-0.319	-0.056	16.57
2	0.140	0.007	0.273	16.57
3	0.253	0.124	0.383	16.59
4	0.383	0.259	0.507	16.62
5	0.893	0.833	0.953	16.90
6	0.666	0.566	0.766	16.75
Overall effect (fe)	0.360	0.020	0.701	100

Figure 4.3 presents a funnel plot of these effects with superimposed 95% confidence limits. This consists of a simple scatterplot of the effect sizes with their associated standard errors, with asymmetry having a number of possible causes. Causes of asymmetry include that of heterogeneity, reporting bias, and chance, with heterogeneity being the likely culprit due to the large degree of heterogeneity associated with these six effects.

Finally, Figure 4.4 presents a contour-enhanced funnel plot associated with this analysis. This is similar to the funnel plot presented in Figure 4.3 but includes the addition of lines representing different probability levels; namely, the 1% probability level, the 5% level, and the 10% level. This allows for a further illustration of effect heterogeneity while also incorporating the issue of statistical significance. The plotted effects are, except for one effect, in areas of non-significance. This would also suggest the possibility of publication bias.

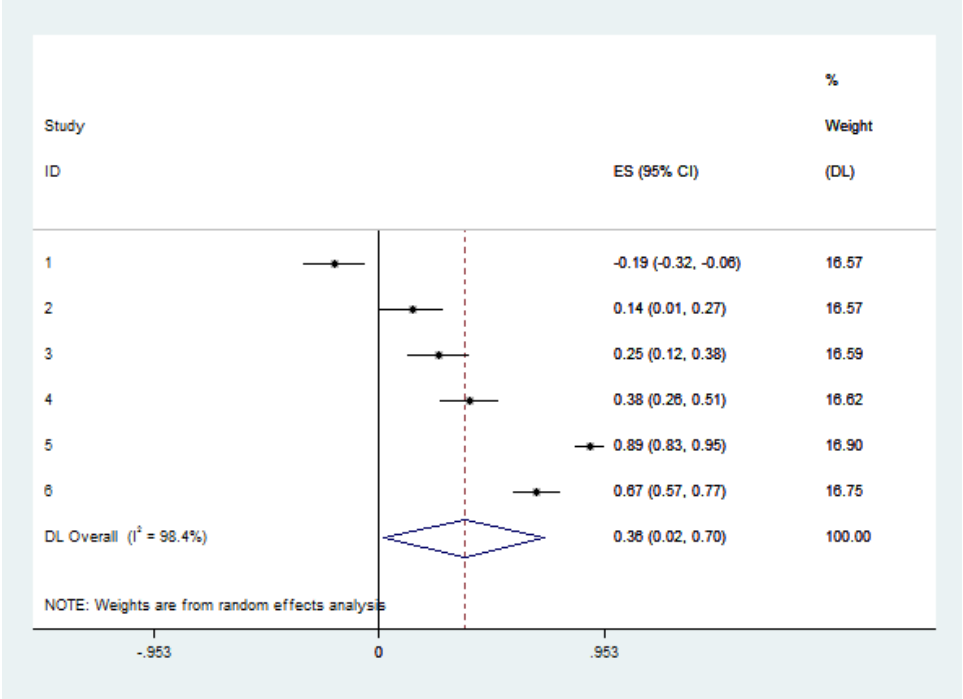


Figure 4.2: Forest plot associated with random-effects meta-analysis

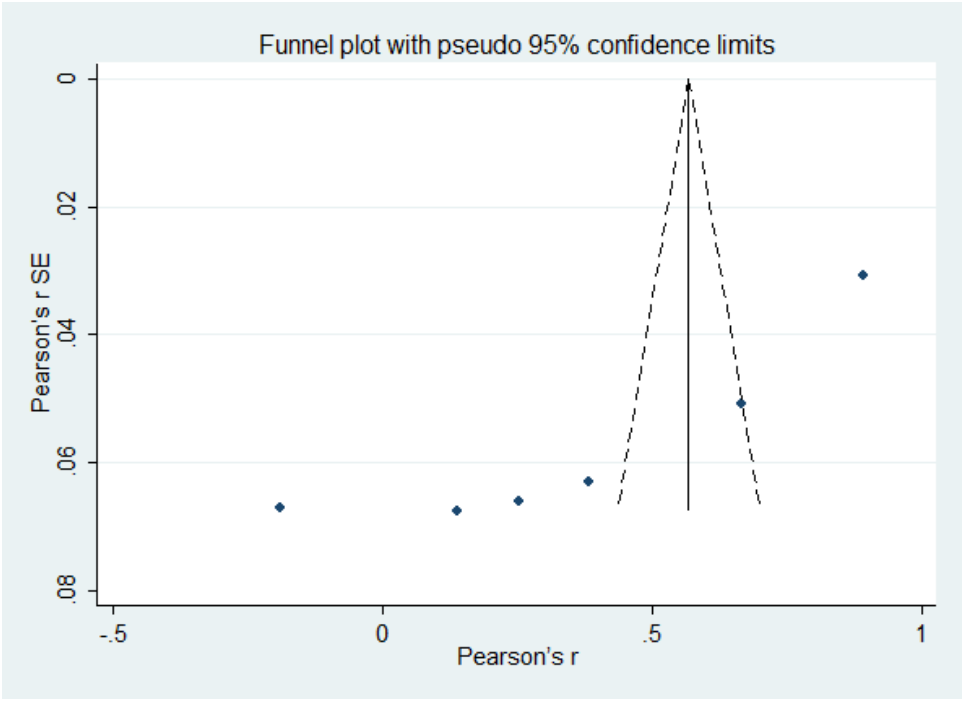


Figure 4.3: Funnel plot with pseudo 95% confidence limits

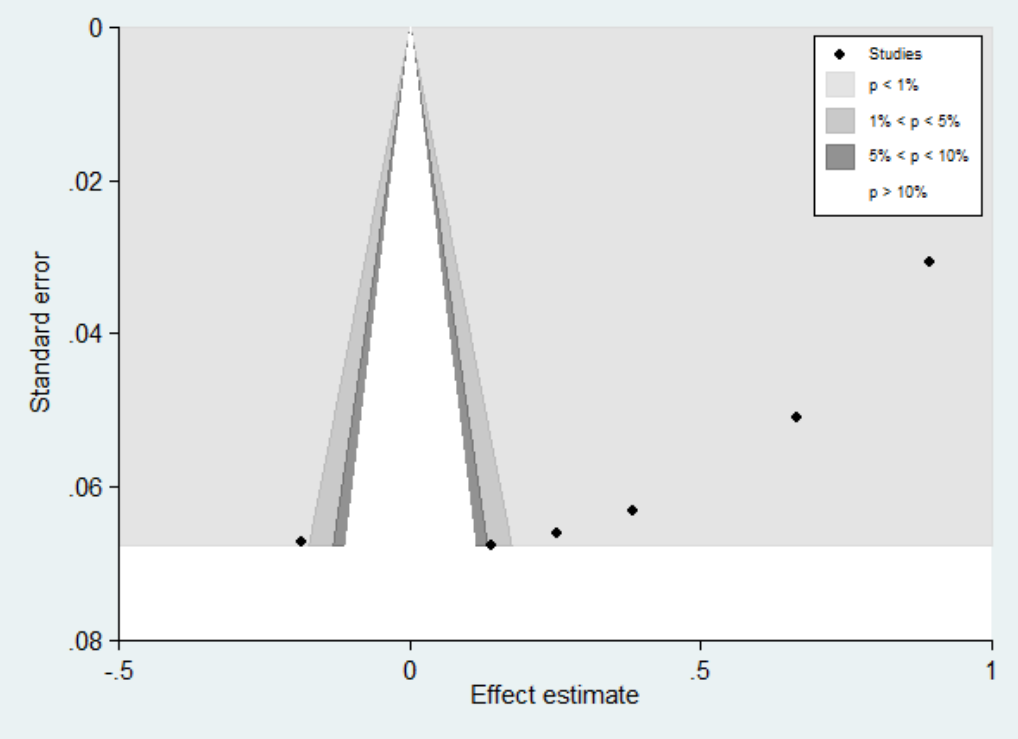


Figure 4.4: Contour-enhanced funnel plot

4.3. Simulating the dataset

A second set of two meta-analyses was then conducted after first generating a simulated dataset in Stata. First, descriptive statistics were conducted on the Pearson's r values associated with the data collected for the original meta-analyses conducted. These analyses indicated a mean Pearson's r of .358 along with a standard deviation of .384. A simulated dataset of 250 cases were then generated using these same values for the mean and standard deviation and using the normal distribution. Sample sizes were then generated using a mean sample size of 200 with a standard deviation of 50, which is representative of the sample sizes found in the studies reviewed.

The standard error of Pearson's r was then calculated as the square root of Pearson's r subtracted from one, divided by two subtracted from the sample size. This produced a small number of missing cases which reduced the total valid sample size from 250 to 241. Following these calculations, these meta-analyses were conducted.

Table 4.5 presents the results of the fixed-effects meta-analysis conducted on these simulated data. Effect sizes were found to vary from a minimum of -.750 to a maximum of .977. Weight was highest in relation to simulated study 34, which was weighted as 5.60%, and was lowest with regard to study 219, which was weighted as .07%. The overall effect was found to be equal to .512, with the associated 95% confidence interval ranging from .505 to .518. This result indicates a strong and positive effect when comparing GM with normal trees.

The fixed-effect Meta-analysis results provide a percentage weighting range from 0.07 to 5.6 that indicates, just as with the original work with the case studies, that weighting percentages are heterogenous in nature and they cannot be the same weighting for each simulated case study. This indicates more variability between case simulated case studies.

Table 4.6 presents the results of the random-effects meta-analysis conducted on these simulated data. Effect sizes were found to vary from a minimum of -.750 to a maximum of .977. Weight was highest in relation to simulated study 34, which was weighted as .43%, and was lowest with regard to study 219, which was weighted as .39%.

Table 4.5: Meta-analysis on simulated data: fixed-effects

Study	Effect	95% Confidence Interval		% Weight
1	0.189	0.015	0.362	0.15
2	0.721	0.622	0.819	0.47
3	0.785	0.711	0.860	0.83
4	-0.271	-0.422	-0.119	0.20
5	-0.419	-0.536	-0.301	0.34
6	-0.048	-0.194	0.099	0.21
7	0.219	0.097	0.341	0.31
8	-0.271	-0.411	-0.131	0.24
9	0.409	0.289	0.529	0.32
10	0.560	0.456	0.665	0.42
11	0.517	0.406	0.627	0.38
12	0.275	0.161	0.389	0.35
13	-0.387	-0.516	-0.259	0.28
14	0.419	0.314	0.525	0.41
15	0.191	0.010	0.372	0.14
16	0.173	0.016	0.330	0.19
17	0.095	-0.030	0.220	0.29
18	0.478	0.378	0.578	0.46
19	0.108	-0.011	0.227	0.33
20	0.560	0.460	0.659	0.47
21	0.721	0.602	0.840	0.32
22	0.916	0.855	0.977	1.25
23	0.058	-0.091	0.208	0.21
24	0.693	0.570	0.816	0.30
25	-0.750	-0.828	-0.672	0.76
26	-0.278	-0.420	-0.136	0.23
27	0.285	0.128	0.442	0.19
28	0.520	0.408	0.631	0.37
29	0.975	0.946	1.004	5.52
30	-0.080	-0.225	0.064	0.22
31	-0.058	-0.196	0.080	0.24
32	0.226	0.021	0.432	0.11
33	0.857	0.784	0.930	0.87
34	0.977	0.949	1.006	5.60
35	0.095	-0.040	0.230	0.25
36	0.692	0.590	0.794	0.44
37	-0.284	-0.408	-0.159	0.30
38	0.795	0.710	0.880	0.63
39	0.119	-0.009	0.248	0.28
40	0.904	0.839	0.970	1.07
41	0.536	0.441	0.632	0.51
42	0.751	0.671	0.830	0.73
43	-0.086	-0.206	0.034	0.32
44	0.747	0.650	0.843	0.49

Table 4.5. Continued.

Study	Effect	95% Confidence Interval		% Weight
45	0.238	0.061	0.415	0.15
46	0.495	0.395	0.594	0.47
47	0.522	0.415	0.630	0.40
48	-0.014	-0.118	0.091	0.42
49	0.303	0.182	0.425	0.31
50	-0.438	-0.557	-0.319	0.32
51	0.471	0.357	0.584	0.36
52	0.025	-0.099	0.148	0.30
53	-0.033	-0.180	0.114	0.21
54	0.589	0.455	0.724	0.25
55	-0.420	-0.582	-0.257	0.17
56	0.749	0.647	0.852	0.44
57	0.131	0.002	0.260	0.28
58	0.627	0.514	0.739	0.36
59	0.698	0.599	0.798	0.46
60	0.412	0.263	0.561	0.21
61	0.758	0.669	0.848	0.57
62	0.758	0.671	0.846	0.60
63	0.162	0.019	0.306	0.22
64	-0.236	-0.370	-0.101	0.25
65	0.449	0.322	0.577	0.28
66	-0.471	-0.594	-0.348	0.31
67	0.660	0.558	0.762	0.44
68	0.688	0.589	0.787	0.47
69	0.930	0.885	0.976	2.22
70	0.478	0.361	0.594	0.34
71	0.909	0.856	0.963	1.62
72	0.146	-0.022	0.314	0.16
73	0.208	0.095	0.320	0.36
74	0.668	0.584	0.752	0.65
75	0.172	0.024	0.320	0.21
76	0.656	0.563	0.748	0.54
77	0.526	0.425	0.628	0.45
78	-0.144	-0.286	-0.003	0.23
79	0.662	0.519	0.804	0.23
80	0.933	0.883	0.982	1.88
81	0.718	0.608	0.828	0.38
82	-0.418	-0.534	-0.302	0.34
83	0.303	0.188	0.417	0.35
84	0.506	0.331	0.681	0.15
85	0.860	0.794	0.927	1.05
86	0.405	0.271	0.539	0.26
87	0.611	0.502	0.720	0.39
88	0.309	0.153	0.466	0.19

Table 4.5. Continued.

Study	Effect	95% Confidence Interval		% Weight
89	0.253	0.097	0.408	0.19
90	0.384	0.272	0.495	0.37
91	0.249	0.103	0.396	0.21
92	0.930	0.878	0.982	1.73
93	0.092	-0.037	0.220	0.28
94	-0.190	-0.323	-0.056	0.26
95	0.713	0.618	0.808	0.51
96	0.476	0.331	0.620	0.22
97	0.247	0.111	0.382	0.25
98	0.407	0.282	0.533	0.29
99	-0.036	-0.190	0.118	0.19
100	0.148	-0.026	0.322	0.15
101	0.129	0.021	0.238	0.39
102	0.385	0.255	0.515	0.27
103	0.274	0.095	0.454	0.14
104	0.322	0.205	0.439	0.33
105	0.001	-0.131	0.134	0.26
106	0.242	0.118	0.365	0.30
107	0.162	0.028	0.297	0.25
108	0.073	-0.087	0.233	0.18
109	0.587	0.479	0.695	0.39
110	0.303	0.168	0.437	0.25
111	0.111	-0.069	0.290	0.14
112	0.633	0.511	0.755	0.31
113	0.282	0.152	0.411	0.27
114	-0.426	-0.544	-0.307	0.33
115	0.442	0.303	0.582	0.24
116	0.104	-0.035	0.242	0.24
117	-0.121	-0.319	0.076	0.12
118	0.368	0.217	0.519	0.20
119	0.623	0.506	0.739	0.34
120	0.238	0.123	0.353	0.35
121	0.419	0.228	0.610	0.13
122	-0.337	-0.477	-0.196	0.23
123	0.463	0.333	0.594	0.27
124	0.948	0.902	0.995	2.11
125	0.563	0.460	0.665	0.44
126	0.676	0.554	0.798	0.31
127	0.641	0.511	0.772	0.27
128	0.649	0.520	0.777	0.28
129	0.675	0.581	0.769	0.52
130	-0.043	-0.158	0.072	0.35
131	0.609	0.510	0.707	0.47
132	0.426	0.302	0.549	0.30

Table 4.5. Continued.

Study	Effect	95% Confidence Interval		% Weight
133	0.233	0.078	0.389	0.19
134	0.797	0.729	0.865	0.99
135	0.059	-0.074	0.193	0.26
136	-0.019	-0.172	0.133	0.20
137	0.839	0.776	0.903	1.13
138	-0.326	-0.453	-0.200	0.29
139	0.759	0.664	0.854	0.51
140	0.222	0.086	0.359	0.25
141	0.220	0.050	0.390	0.16
142	0.641	0.536	0.746	0.42
143	0.385	0.260	0.510	0.29
144	0.785	0.632	0.938	0.20
145	0.480	0.356	0.604	0.30
146	-0.460	-0.607	-0.313	0.21
147	-0.217	-0.344	-0.090	0.28
148	0.034	-0.122	0.190	0.19
149	0.255	0.140	0.370	0.35
150	-0.097	-0.212	0.017	0.35
151	0.716	0.631	0.801	0.64
152	0.580	0.480	0.680	0.46
153	-0.341	-0.499	-0.184	0.19
154	0.039	-0.110	0.188	0.21
155	0.388	0.237	0.538	0.20
156	0.483	0.372	0.594	0.37
157	0.696	0.588	0.804	0.40
158	0.552	0.443	0.660	0.39
159	0.669	0.570	0.768	0.47
160	0.451	0.331	0.572	0.32
161	-0.102	-0.247	0.042	0.22
162	-0.004	-0.143	0.134	0.24
163	0.400	0.280	0.519	0.32
164	0.770	0.681	0.858	0.59
165	0.393	0.228	0.559	0.17
166	0.395	0.268	0.522	0.29
167	0.525	0.393	0.656	0.27
168	0.187	0.070	0.304	0.33
169	-0.279	-0.416	-0.142	0.24
170	0.645	0.543	0.747	0.44
171	0.699	0.613	0.785	0.62
172	-0.055	-0.184	0.075	0.28
173	0.126	0.006	0.246	0.32
174	-0.285	-0.417	-0.153	0.26
175	0.157	0.007	0.308	0.20
176	0.701	0.614	0.787	0.62

Table 4.5. Continued.

Study	Effect	95% Confidence Interval		% Weight
177	0.752	0.659	0.845	0.53
178	-0.582	-0.712	-0.452	0.27
179	0.193	0.058	0.329	0.25
180	0.587	0.470	0.704	0.34
181	0.479	0.373	0.585	0.41
182	0.408	0.295	0.522	0.36
183	0.714	0.617	0.810	0.49
184	0.030	-0.089	0.149	0.33
185	0.755	0.656	0.854	0.47
186	-0.475	-0.612	-0.337	0.24
187	0.569	0.456	0.683	0.36
188	0.219	0.096	0.342	0.30
189	-0.159	-0.280	-0.038	0.31
190	0.267	0.115	0.418	0.20
191	0.614	0.499	0.729	0.35
192	0.225	0.101	0.350	0.30
193	0.186	0.020	0.351	0.17
194	0.193	0.073	0.312	0.32
195	0.819	0.738	0.899	0.71
196	-0.316	-0.462	-0.170	0.22
197	0.118	-0.010	0.247	0.28
198	0.346	0.215	0.477	0.27
199	0.790	0.701	0.880	0.57
200	0.579	0.479	0.679	0.46
201	0.269	0.141	0.398	0.28
202	0.258	0.128	0.387	0.27
203	0.042	-0.092	0.177	0.25
204	0.508	0.343	0.672	0.17
205	0.230	0.105	0.354	0.30
206	0.588	0.477	0.700	0.37
207	0.809	0.727	0.891	0.68
208	-0.121	-0.258	0.016	0.24
209	0.223	0.083	0.363	0.23
210	0.248	0.135	0.361	0.36
211	0.502	0.365	0.639	0.24
212	0.079	-0.094	0.252	0.15
213	0.477	0.324	0.631	0.20
214	0.502	0.370	0.634	0.26
215	0.600	0.492	0.708	0.39
216	-0.531	-0.633	-0.429	0.44
217	0.702	0.586	0.819	0.34
218	-0.203	-0.396	-0.009	0.12
219	0.051	-0.200	0.301	0.07
220	0.078	-0.063	0.219	0.23

Table 4.5. Continued.

Study	Effect	95% Confidence Interval		% Weight
221	-0.089	-0.246	0.068	0.19
222	0.040	-0.086	0.167	0.29
223	0.163	-0.012	0.338	0.15
224	0.503	0.397	0.609	0.41
225	0.520	0.396	0.645	0.30
226	0.218	0.089	0.347	0.28
227	-0.111	-0.239	0.017	0.28
228	0.779	0.698	0.859	0.71
229	0.075	-0.106	0.256	0.14
230	0.284	0.161	0.407	0.30
231	0.608	0.443	0.773	0.17
232	0.201	0.078	0.324	0.30
233	0.097	-0.051	0.246	0.21
234	0.151	-0.005	0.308	0.19
235	0.675	0.593	0.757	0.69
236	0.539	0.407	0.671	0.26
237	0.662	0.559	0.764	0.44
238	-0.060	-0.206	0.085	0.22
239	0.212	0.045	0.379	0.17
240	0.404	0.297	0.510	0.40
241	0.302	0.174	0.430	0.28
Overall effect (fe)	0.512	0.505	0.518	100.00

The overall effect was found to be equal to .318, with the associated 95% confidence interval ranging from .267 to .370. This result indicates a moderate and positive effect when comparing GM with normal trees.

The random-effect Meta-analysis results provide a percentage weighting range from 0.39 to 0.42 that indicates, just as with the original work with the case studies, that weighting percentages are homogenous in nature and possess relatively lower variance weighting for each simulated case study. This indicates a lower degree of variability.

Table 4.6: Meta-analysis on simulated data: random-effects

Study	Effect	95% Confidence Interval		% Weight
1	0.189	0.015	0.362	0.41
2	0.721	0.622	0.819	0.42
3	0.785	0.711	0.860	0.42
4	-0.271	-0.422	-0.119	0.41
5	-0.419	-0.536	-0.301	0.42
6	-0.048	-0.194	0.099	0.41
7	0.219	0.097	0.341	0.42
8	-0.271	-0.411	-0.131	0.41
9	0.409	0.289	0.529	0.42
10	0.560	0.456	0.665	0.42
11	0.517	0.406	0.627	0.42
12	0.275	0.161	0.389	0.42
13	-0.387	-0.516	-0.259	0.41
14	0.419	0.314	0.525	0.42
15	0.191	0.010	0.372	0.40
16	0.173	0.016	0.330	0.41
17	0.095	-0.030	0.220	0.42
18	0.478	0.378	0.578	0.42
19	0.108	-0.011	0.227	0.42
20	0.560	0.460	0.659	0.42
21	0.721	0.602	0.840	0.42
22	0.916	0.855	0.977	0.42
23	0.058	-0.091	0.208	0.41
24	0.693	0.570	0.816	0.42
25	-0.750	-0.828	-0.672	0.42
26	-0.278	-0.420	-0.136	0.41
27	0.285	0.128	0.442	0.41
28	0.520	0.408	0.631	0.42
29	0.975	0.946	1.004	0.43
30	-0.080	-0.225	0.064	0.41
31	-0.058	-0.196	0.080	0.41
32	0.226	0.021	0.432	0.40
33	0.857	0.784	0.930	0.42
34	0.977	0.949	1.006	0.43
35	0.095	-0.040	0.230	0.41
36	0.692	0.590	0.794	0.42
37	-0.284	-0.408	-0.159	0.42
38	0.795	0.710	0.880	0.42
39	0.119	-0.009	0.248	0.41
40	0.904	0.839	0.970	0.42
41	0.536	0.441	0.632	0.42
42	0.751	0.671	0.830	0.42
43	-0.086	-0.206	0.034	0.42
44	0.747	0.650	0.843	0.42

Table 4.6. Continued.

Study	Effect	95% Confidence Interval		% Weight
45	0.238	0.061	0.415	0.41
46	0.495	0.395	0.594	0.42
47	0.522	0.415	0.630	0.42
48	-0.014	-0.118	0.091	0.42
49	0.303	0.182	0.425	0.42
50	-0.438	-0.557	-0.319	0.42
51	0.471	0.357	0.584	0.42
52	0.025	-0.099	0.148	0.42
53	-0.033	-0.180	0.114	0.41
54	0.589	0.455	0.724	0.41
55	-0.420	-0.582	-0.257	0.41
56	0.749	0.647	0.852	0.42
57	0.131	0.002	0.260	0.41
58	0.627	0.514	0.739	0.42
59	0.698	0.599	0.798	0.42
60	0.412	0.263	0.561	0.41
61	0.758	0.669	0.848	0.42
62	0.758	0.671	0.846	0.42
63	0.162	0.019	0.306	0.41
64	-0.236	-0.370	-0.101	0.41
65	0.449	0.322	0.577	0.41
66	-0.471	-0.594	-0.348	0.42
67	0.660	0.558	0.762	0.42
68	0.688	0.589	0.787	0.42
69	0.930	0.885	0.976	0.42
70	0.478	0.361	0.594	0.42
71	0.909	0.856	0.963	0.42
72	0.146	-0.022	0.314	0.41
73	0.208	0.095	0.320	0.42
74	0.668	0.584	0.752	0.42
75	0.172	0.024	0.320	0.41
76	0.656	0.563	0.748	0.42
77	0.526	0.425	0.628	0.42
78	-0.144	-0.286	-0.003	0.41
79	0.662	0.519	0.804	0.41
80	0.933	0.883	0.982	0.42
81	0.718	0.608	0.828	0.42
82	-0.418	-0.534	-0.302	0.42
83	0.303	0.188	0.417	0.42
84	0.506	0.331	0.681	0.41
85	0.860	0.794	0.927	0.42
86	0.405	0.271	0.539	0.41
87	0.611	0.502	0.720	0.42
88	0.309	0.153	0.466	0.41

Table 4.6. Continued.

Study	Effect	95% Confidence Interval		% Weight
89	0.253	0.097	0.408	0.41
90	0.384	0.272	0.495	0.42
91	0.249	0.103	0.396	0.41
92	0.930	0.878	0.982	0.42
93	0.092	-0.037	0.220	0.41
94	-0.190	-0.323	-0.056	0.41
95	0.713	0.618	0.808	0.42
96	0.476	0.331	0.620	0.41
97	0.247	0.111	0.382	0.41
98	0.407	0.282	0.533	0.42
99	-0.036	-0.190	0.118	0.41
100	0.148	-0.026	0.322	0.41
101	0.129	0.021	0.238	0.42
102	0.385	0.255	0.515	0.41
103	0.274	0.095	0.454	0.40
104	0.322	0.205	0.439	0.42
105	0.001	-0.131	0.134	0.41
106	0.242	0.118	0.365	0.42
107	0.162	0.028	0.297	0.41
108	0.073	-0.087	0.233	0.41
109	0.587	0.479	0.695	0.42
110	0.303	0.168	0.437	0.41
111	0.111	-0.069	0.290	0.40
112	0.633	0.511	0.755	0.42
113	0.282	0.152	0.411	0.41
114	-0.426	-0.544	-0.307	0.42
115	0.442	0.303	0.582	0.41
116	0.104	-0.035	0.242	0.41
117	-0.121	-0.319	0.076	0.40
118	0.368	0.217	0.519	0.41
119	0.623	0.506	0.739	0.42
120	0.238	0.123	0.353	0.42
121	0.419	0.228	0.610	0.40
122	-0.337	-0.477	-0.196	0.41
123	0.463	0.333	0.594	0.41
124	0.948	0.902	0.995	0.42
125	0.563	0.460	0.665	0.42
126	0.676	0.554	0.798	0.42
127	0.641	0.511	0.772	0.41
128	0.649	0.520	0.777	0.41
129	0.675	0.581	0.769	0.42
130	-0.043	-0.158	0.072	0.42
131	0.609	0.510	0.707	0.42
132	0.426	0.302	0.549	0.42

Table 4.6. Continued.

Study	Effect	95% Confidence Interval		% Weight
133	0.233	0.078	0.389	0.41
134	0.797	0.729	0.865	0.42
135	0.059	-0.074	0.193	0.41
136	-0.019	-0.172	0.133	0.41
137	0.839	0.776	0.903	0.42
138	-0.326	-0.453	-0.200	0.42
139	0.759	0.664	0.854	0.42
140	0.222	0.086	0.359	0.41
141	0.220	0.050	0.390	0.41
142	0.641	0.536	0.746	0.42
143	0.385	0.260	0.510	0.42
144	0.785	0.632	0.938	0.41
145	0.480	0.356	0.604	0.42
146	-0.460	-0.607	-0.313	0.41
147	-0.217	-0.344	-0.090	0.41
148	0.034	-0.122	0.190	0.41
149	0.255	0.140	0.370	0.42
150	-0.097	-0.212	0.017	0.42
151	0.716	0.631	0.801	0.42
152	0.580	0.480	0.680	0.42
153	-0.341	-0.499	-0.184	0.41
154	0.039	-0.110	0.188	0.41
155	0.388	0.237	0.538	0.41
156	0.483	0.372	0.594	0.42
157	0.696	0.588	0.804	0.42
158	0.552	0.443	0.660	0.42
159	0.669	0.570	0.768	0.42
160	0.451	0.331	0.572	0.42
161	-0.102	-0.247	0.042	0.41
162	-0.004	-0.143	0.134	0.41
163	0.400	0.280	0.519	0.42
164	0.770	0.681	0.858	0.42
165	0.393	0.228	0.559	0.41
166	0.395	0.268	0.522	0.41
167	0.525	0.393	0.656	0.41
168	0.187	0.070	0.304	0.42
169	-0.279	-0.416	-0.142	0.41
170	0.645	0.543	0.747	0.42
171	0.699	0.613	0.785	0.42
172	-0.055	-0.184	0.075	0.41
173	0.126	0.006	0.246	0.42
174	-0.285	-0.417	-0.153	0.41
175	0.157	0.007	0.308	0.41
176	0.701	0.614	0.787	0.42

Table 4.6. Continued.

Study	Effect	95% Confidence Interval		% Weight
177	0.752	0.659	0.845	0.42
178	-0.582	-0.712	-0.452	0.41
179	0.193	0.058	0.329	0.41
180	0.587	0.470	0.704	0.42
181	0.479	0.373	0.585	0.42
182	0.408	0.295	0.522	0.42
183	0.714	0.617	0.810	0.42
184	0.030	-0.089	0.149	0.42
185	0.755	0.656	0.854	0.42
186	-0.475	-0.612	-0.337	0.41
187	0.569	0.456	0.683	0.42
188	0.219	0.096	0.342	0.42
189	-0.159	-0.280	-0.038	0.42
190	0.267	0.115	0.418	0.41
191	0.614	0.499	0.729	0.42
192	0.225	0.101	0.350	0.42
193	0.186	0.020	0.351	0.41
194	0.193	0.073	0.312	0.42
195	0.819	0.738	0.899	0.42
196	-0.316	-0.462	-0.170	0.41
197	0.118	-0.010	0.247	0.41
198	0.346	0.215	0.477	0.41
199	0.790	0.701	0.880	0.42
200	0.579	0.479	0.679	0.42
201	0.269	0.141	0.398	0.41
202	0.258	0.128	0.387	0.41
203	0.042	-0.092	0.177	0.41
204	0.508	0.343	0.672	0.41
205	0.230	0.105	0.354	0.42
206	0.588	0.477	0.700	0.42
207	0.809	0.727	0.891	0.42
208	-0.121	-0.258	0.016	0.41
209	0.223	0.083	0.363	0.41
210	0.248	0.135	0.361	0.42
211	0.502	0.365	0.639	0.41
212	0.079	-0.094	0.252	0.41
213	0.477	0.324	0.631	0.41
214	0.502	0.370	0.634	0.41
215	0.600	0.492	0.708	0.42
216	-0.531	-0.633	-0.429	0.42
217	0.702	0.586	0.819	0.42
218	-0.203	-0.396	-0.009	0.40
219	0.051	-0.200	0.301	0.39
220	0.078	-0.063	0.219	0.41

Table 4.6. Continued.

Study	Effect	95% Confidence Interval		% Weight
221	-0.089	-0.246	0.068	0.41
222	0.040	-0.086	0.167	0.42
223	0.163	-0.012	0.338	0.41
224	0.503	0.397	0.609	0.42
225	0.520	0.396	0.645	0.42
226	0.218	0.089	0.347	0.41
227	-0.111	-0.239	0.017	0.41
228	0.779	0.698	0.859	0.42
229	0.075	-0.106	0.256	0.40
230	0.284	0.161	0.407	0.42
231	0.608	0.443	0.773	0.41
232	0.201	0.078	0.324	0.42
233	0.097	-0.051	0.246	0.41
234	0.151	-0.005	0.308	0.41
235	0.675	0.593	0.757	0.42
236	0.539	0.407	0.671	0.41
237	0.662	0.559	0.764	0.42
238	-0.060	-0.206	0.085	0.41
239	0.212	0.045	0.379	0.41
240	0.404	0.297	0.510	0.42
241	0.302	0.174	0.430	0.41
Overall effect (dl)	0.318	0.267	0.370	100.00

Next, a series of plots were created in relation to these meta-analyses. While forest plots were created in relation to both the fixed-effects and the random-effects meta-analyses, these will not be reproduced here as the number of studies associated with the meta-analyses made these plots difficult to read due to all 241 studies being compacted into a single image. However, two funnel plots were created for diagnostic purposes, with Figure 4.5 presenting a funnel plot of the effects with superimposed 95% confidence limits. Here, asymmetry may have a number of possible causes, which include that of heterogeneity, reporting bias, and chance, with heterogeneity being the likely cause here due to the large degree of heterogeneity associated with these effects.

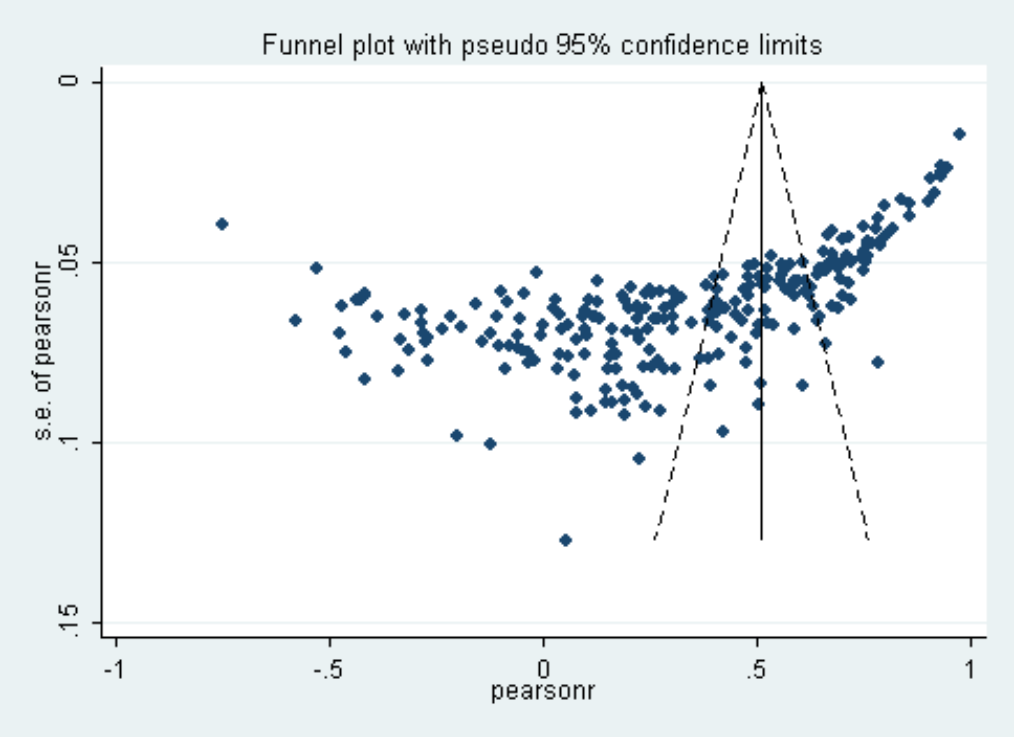


Figure 4.5: Funnel plot with pseudo 95% confidence limits

Additionally, it is important to remember that these data are simulated. Figure 4.6 presents a contour-enhanced funnel plot associated with these meta-analyses, with this plot including the addition of lines representing different probability levels. The plotted effects are largely in areas of non-significance, which would suggest the possibility of publication bias if these data were not simulated.

4.4. Organizational growth as it relates to GM tree growth

When discussing organization growth, there are different measures available. These measures are dependent on the definition of organizational growth that is being used, thus they can be contradictory in nature. These measures include accounting-based measures such as return on investment, stock market, cash flows, sales, number of employees, assets, etc. These

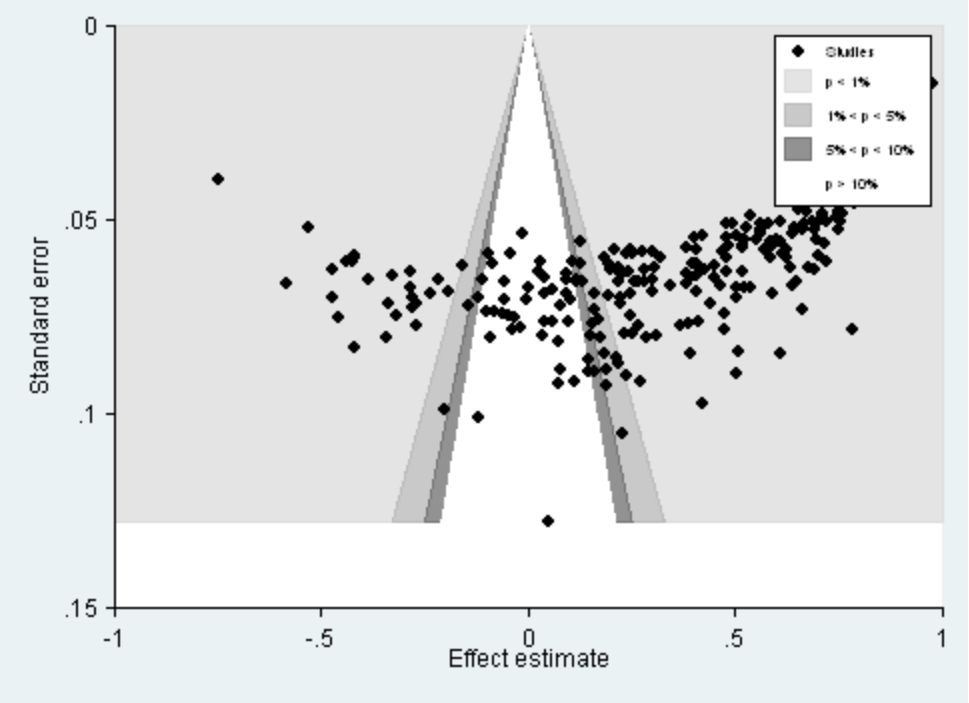


Figure 4.6: Contour-enhanced funnel plot.

traditional ways of measuring organizational growth are inherently a dynamic measure of change over time.

The different concepts of “growth” makes the actual assessment of organizational growth more complex and sometimes contradictory. Most growth studies concentrate on three basic areas: sales growth, number of employees, and assets. The vast majority of organizations utilize sales as their only measure of growth. This is usually taking a comparison of one time period to the next or some other predetermined time frame to measure short and long-term growth. For the reasons mentioned above, the measures in table 4.7 will be used to apply the GM tree growth to organizational growth.

Table 4.7: Comparisons between tested variables and variables of improvements of GM Eucalyptus

	GM *Eucalyptus* "Areas of improvements"	Tested measures from participating studies	Targeted Econometrics of organizational growth
Dependent Variables	Production	Average volume growth of the GM tree compared to the non-GM tree	Volume growth
	Assets		
	Job creation	The effect of GM tree on leaf consumption by slugs	Survivability
	Profits	The effect of leaf position of GM tree on leaf consumption	Viability
	Production Cost	Biomass production of GM tree over the non-GM tree	Production

The advancements in technology have helped the GM trees to grow faster, according to the conceptual framework, including more production and assets less time to maturity, better production, optimized growth cycle time, and reduced cost. These abilities allow the trees to overcome stress and inertia, and deal with a crisis during the transition from one phase to another. In the same way, modern-day organizations with improved internal capabilities, such as better technology, agile processes, and people with digital competencies, mature at a rapid pace.

It can also be asserted that technological advancements are modifying the way of working of people in a more positive way; thereby, enhancing the production potential of the organizations. Moreover, the adoption of Information Technology has also helped in decreasing the costs as, for example, the costs associated with labor. Therefore, the adoption of new technology could be considered helpful in improving the growth of a company and could facilitate in dealing with the phase

transitional crisis periods. Eventually, organizations with advanced technologies can also be considered as Smart factories, and they have several benefits, such as enhanced product quality, process efficiency, safety, sustainability, and reduced costs. Most of these benefits are equivalent to the conceptual framework of this research that is better represented by GM trees and the organizations of the modern world as compared to the normal trees.

4.5. Challenges of answering the research question

4.5.1. The mathematical approach

The quantitative methodology of this research intended to build a mathematical model that compares three elements together: human-based organizations, normal trees, and GM trees. The comparison can be performed in two steps. First, to mathematically compare the two types of trees considering the homogeneity. Second, to apply the results of the first step on human-based organizations. The Meta-analysis was promising since the simulated data set was based on actual research results. It was able to distinguish that GM trees were less variable than their natural counterparts. With the reduction in relative variability, it was hypothesized that the GMO growth could be used to form a relationship with organizational growth.

From a comparison standpoint, the second step has a limitation in terms of utilizing the quantitative approach. The cause of this limitation is that the suggested relationship and similarity between human-based organizations and trees is based on the application of biomimicry that is inherently qualitative. This similarity could

be established, but the need for data limits that possibility at the point in time. Biomimicry requires the existence of a relationship between the human-based model that is wanted to be developed and the candidate natural model by looking into the similarity in the targeted functions among the comparison elements. Also, the establishment of similarity does not have to be quantified to produce a specific percentage of similarity rather than just proving the existence of similarities as biomimicry is based on inspiration of nature, opinions, and skills of qualitative observations according to the institute of biomimicry, a non-profit organization co-founded by Janine Benyus who is a biologist and a faculty member in the University of Montana (Biomimicry Institute, 2019). Furthermore, the similarity in the context of this research cannot be quantified unless it compares a specific single organization with a specific clone or species of trees which is not a requirement in the application of biomimicry and not the purpose of this research. Even though, the suggested similarity in this research is heavily investigated from several perspectives to prove that it is fairly existed, as a justification to the intended theoretical application of the meta-analyses results on human-based organizations. As a result, the cited work and references in the literature reviews for biomimicry applications and similarities between the comparison elements don't have to meet the requirement of the quantitative methodology since it is based on opinions and observations.

Here lies a major; it appears to be common practice for business and consulting type publications to utilize the S-curve as a mathematical representation. They are not based on scientific mathematical derivation but more

in the representation of an event. At the outset of this research, it was assumed the publications, in very noteworthy ones like the Harvard Business Review, were based on sound scientific research procedures. It appears that this assumption is incorrect from a quantitative viewpoint. It became very apparent once the analysis portion of this research was almost complete, and it was found that the predictive relationship being searched for quantitatively does not exist. This is the reason this research pursued a quantitative relationship. In retrospect, many articles that were found during the literature review were discarded and not included in the bibliography of this work due to opinion-based findings. Some of these opinion-based articles were directly sighted in articles used to support the S-curve postulates presented by some of the more noteworthy ones.

The application of biomimicry including observing simple similarity is also widely accepted in the scientific society and by highly respected organizations such as Arizona State University's new Biomimicry Center (http://biomimicry.asu.edu/), Wyss Institute of Biologically Inspired Engineering at Harvard University (https://wyss.harvard.edu/), and NASA (Jet Propulsion Laboratory, 2019) in addition to the case studies mentioned in the literature reviews. It was only when the bibliographies of these publications and the articles they referenced were reviewed that a trend was noted that the basic assumption that the findings were all not based on quantitative results was discovered.

4.5.2. The mathematical representation of the S-curve

Even though there was an issue of mixing quantitative and qualitative data, it was decided to proceed to see if any quality information might be gained. Since this research is based on the use of a quantitative methodology, it was a concern that whether the mathematical model could include the human-based organizations and trees and whether they are mathematically homogenous in following the same pattern of the S-curve. In order to find out the possibility of quantifying the growth of human-based organizations, the financial metrics of top businesses in several sectors were compiled and looked into to generate data that can be used to initiate a mathematical model that may accommodate human-based organizations and trees. This process went over several steps. The process started with establishing a criterion to pick the appropriate financial metrics that can represent the comprehensive organizational growth without affecting the universal pattern of the S-curve.

The first financial metric that normally comes in mind is sales over time. Unfortunately, sales do not tell if the company is profiting, breakeven, or losing. Even though there is an ongoing history of sales for a company, that does not necessarily mean that the company did not collapse, file for bankruptcy, or restructure its debts. Therefore, sales as a financial metric does not meet the criterion. Another financial metric was earning per share (EPS). It was a good candidate in terms of respecting the universal shape of the S-curve but, however, it was not the best in representing human-based organizations, since it neglects

the value of intangible resources such as creativity of employees, the reputation of the organization, and how trustable its services and products.

After analyzing 40 financial metrics, considering the availability of data, it was found out that total-assets is the best in meeting the criterion. Also, the literature of the total-assets was reviewed to make sure that intangible assets are included when considering total-assets as a financial metric for better representation of human-based organizations. Here is a brief summary of the reviews in table 4.8

After that, the S-curve of the total-assets of several human-based organizations were collected and compiled, as shown in figures 4.7 through 4.20, as examples. Unfortunately, after analyzing all the curves, it was found that these curves can’t be combined into one representative curve for human-based organizations, even though that every single S-curve was a good representation of its organizational growth as it relates to total assets. This “visual” fit could be why there is such a desire to make the connection. Another publication in Harvard Business Reviews gives more emphasis on the same finding that the S-curve is a universal growth pattern for all natural systems, and the steepness of the curve is what makes each organization different. They broke down the S-curve into specialized S-curves for most basic subsets of operating parameters such as labor, material, market, etc.

Table 4.8: Summary of the literature reviews of the total-assets

Findings about intangible assets	Source
“The total assets are those things of dollar value that it owns tangibles such as land, buildings, equipment, or inventory, or intangibles such as trademarks, designs, and patents.”	(Ostwald & McLaren, 2003)
“Assets are anything capable of providing future benefits; otherwise they are expense.”	(Ostwald & McLaren, 2003)
“The assets of the company consist of all its property: what it owns and what is owed to it.”	(Park & Sharp-Bette, 1990)
Current assets, fixed assets, and other assets: “including investments made in other companies (to control their operations) and intangible assets such as goodwill, copyrights, and franchises.”	(Park & Sharp-Bette, 1990)
“Everything owned by a business is an asset” and “everything owing to a business is an asset.”	(Reitell & M.A., 1930)
“Assets are economic resources that are expected to benefit future activities.”	(Horngren, 1970)
“Franchises and trademarks are often called intangible assets because they are not physical in nature.”	(Horngren, 1970)
“Another intangible asset, goodwill,” “prepayment and deferred charges.”	(Horngren, 1970)
They are any expenses or investments in activities that are expected to bring future benefits such as training, research development, and advertisement (amortization.)	(Horngren, 1970)



Figure 4.7: Total-assets over time for Cisco Systems

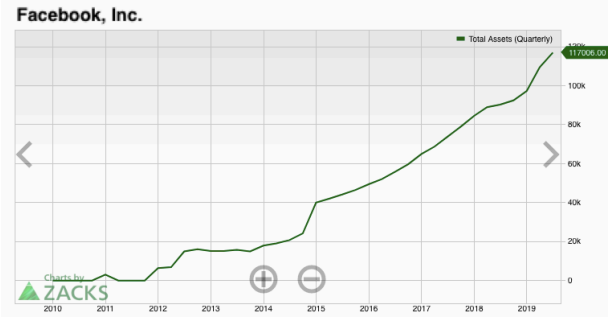


Figure 4.8: Total-assets over time for Facebook



Figure 4.9: Total-assets over time for Comcast



Figure 4.10: Total-assets over time for HHGregg



Figure 4.11: Total-assets over time for Expedia Group

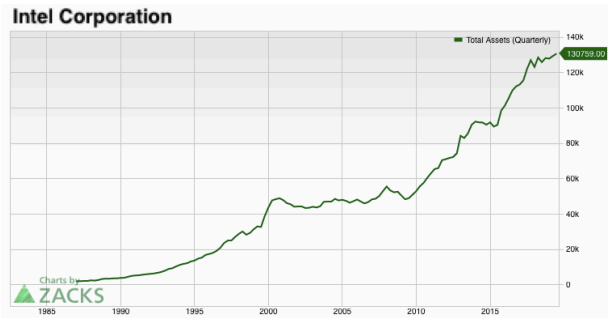


Figure 4.12: Total-assets over time for Intel

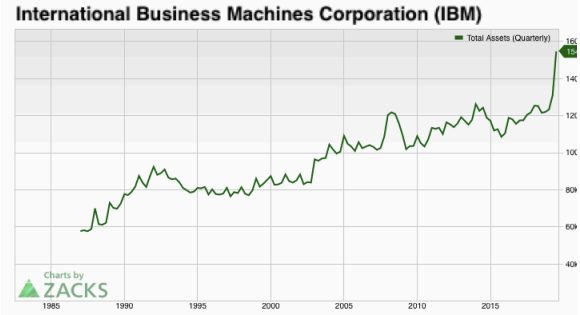


Figure 4.13: Total-assets over time for IBM

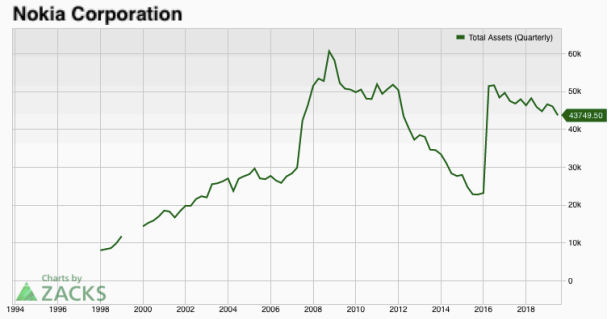


Figure 4.14: Total-assets over time for Nokia

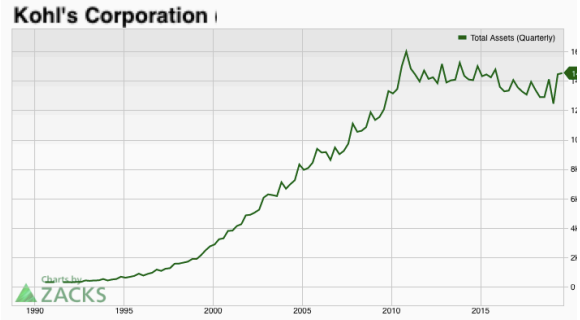


Figure 4.15: Total-assets over time for Kohl's



Figure 4.16: Total-assets over time for Pier 1 Imports

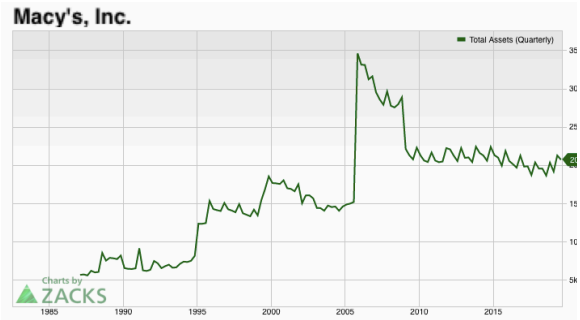


Figure 4.17: Total-assets over time for Macy's

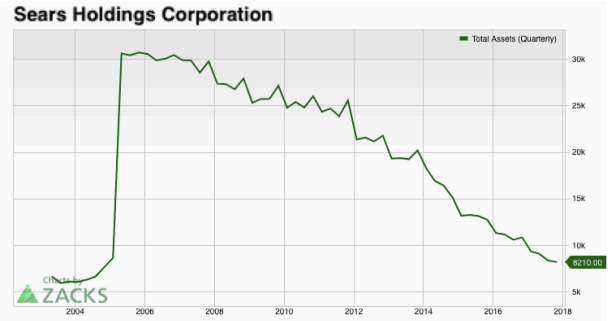


Figure 4.18: Total-assets over time for Sears

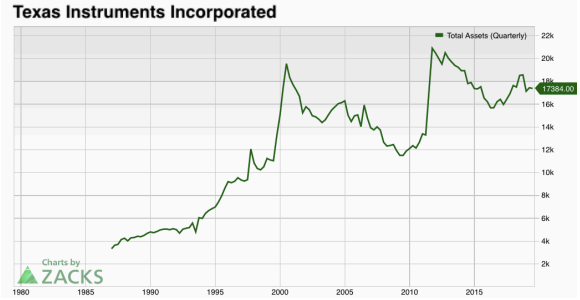


Figure 4.19: Total-assets over time for Texas Instruments

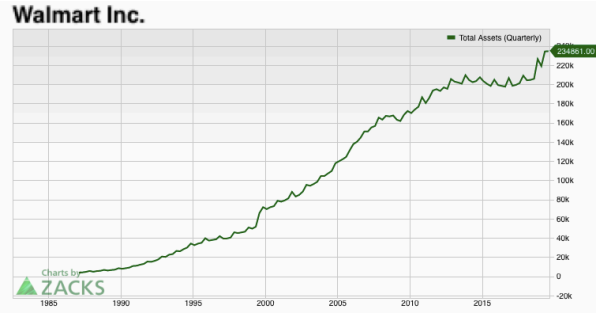


Figure 4.20: Total-assets over time for Walmart

According to what is reviewed in the literature in section 2.6.1.1 about the mathematical S-curve, It is found that the S-curve that has been used in some highly respected business publications for describing growth in organizations and their subsets is grossly misused or misunderstood by the authors. Using a highly generalized approach of fitting a curve to financial data is suspect at best. It was akin to correlations or simple distribution matching rather than a real mathematical representation. It is also found that the creation of an algorithm to address the growth of human-based organizations is not possible due to the fact that every organization is different, as well as every subsystem within that organization.

It was concluded that a mathematical model would not be the ideal approach to address the relationship between human-based organizations and trees, and there might be a different statistical tool that needs to be implemented by statistical experts to come up with such a model. It is not suggested that the S-curve has no real benefits or is wrong. It is suggested that the S-curve has no theoretical quantitative basis, unless otherwise proven. As a result, whatever is built or developed from the use of the S-curve cannot be an application of the

quantitative methodology. It seems like the S-curve was a discovery rather than an invention.

4.6. Summary

In summary, the results of the meta-analyses conducted for this study found a large effect size in the fixed-effects meta-analysis conducted, and a moderate effect size in the random-effects meta-analysis. Overall, a substantial and important difference was indicated between GM and normal trees. As a result, the conceptual framework of comparing less variable GM trees to the growth of organizations, especially the organizations of the modern world, was thought to be possible. In the original hypothesis, the reduced variation of GMO trees was thought to make them a better representation of the growth of human-based

organizations than ordinary unmodified trees turned out to be unprovable at this time with the methodology utilized in this research.

The articles are misleading in offering a tool that can be used to manage different parts of human-based organizations. For example, the authors of the articles in table 4.9 conceptualized the successful organizational growth by endorsing the utilization of the S-curve when they did not investigate the scientific origin of that curve and whether it is accordingly quantifiable or not.

It is consistent with the suggestion in this research that the S-curve has no theoretical quantitative base, *Hui Sng*, a professor in economics at the Nanyang Technological University (NTU) in Singapore, clearly stated the opposite about the

Table 4.9: Publications endorsing the S-curve for organizational growth

Article	Publisher	Year
Use Learning to Engage Your Team	Harvard Business Review	2008
Evolution and revolutions as organizations grow	Harvard Business Review	1998
Jumping the S-Curve. How to beat the growth cycle, get on top, and stay there	Accenture Institute for High Performance	2010

origin of an economic-based S-curve “the main weakness of the S-Curve hypothesis is that it lacks quantitative rigor. There is a lack of empirical proof of the S-Curve hypothesis and there is a lack of empirical analysis on the growth paths of economies at different stages of development.” (Sng, 2010).

5. Discussion

This study sought to answer the question of whether GM trees provide a better model of organizational growth during phase transitional crisis periods as compared with non-GM trees. First, this study did find that GM trees are significantly improved as compared with non-GM trees on relevant econometric outcomes, which supports previous findings (Boerjan, 2005; FuturaGene, 2014; Ledford, 2014; Mole, 2008; Strauss et al., 2001; Vidal, 2012). However, a direct comparison cannot be made between the results found in this study and those found in previous research, as previous research does not exist comparing GM and non-GM trees with respect to which would provide a superior model of organizational growth during phase transitional crisis periods. This study does, however, support previous work which served to draw a theoretical parallel between natural and organizational systems (Korhonen, 2000; Murarka, 2013; Rothschild, 1990; Wrexin, 2015).

The research did mathematically find that GM trees are superior over their non-GM counterparts on relevant econometrics of human-based organizations. However, the connection between trees and human-based organizations could not be considered in the mathematical model due to the finding of this research that the connection is based on the universal growth pattern of all natures processes “S-curve” that is not quantifiable per up to date findings in this research.

5.1. Limitations

A number of limitations exist with respect to this current study. First, and the most substantial limitation is associated with the fact that meta-analyses conducted on previous research comparing GM and non-GM trees on a number of outcomes is related to organizational growth in only an indirect way. It is difficult to make the argument that a meta-analysis in this area, regardless of these findings, would be able to provide any real implications as to whether GM trees or normal trees provide a better model of organizational growth during phase transitional crisis periods.

Second, the number of effects included in these meta-analyses were fairly limited. The inclusion of a more expansive literature review may have allowed for a larger number of effects, as well as a larger number of studies, to be included within the meta-analyses conducted here.

Third, the connection between GM trees and human-based organization cannot be quantified per up to date scientific findings. That makes a major limitation to the quantitative methodology.

5.2. Future Research

Drawing upon the limitations of this study, a number of possibilities for future research can be recommended. First, future research can take a more direct approach when attempting to determine appropriate models of business. More specifically, the comparison between GM and normal trees is very indirect, and similarly, it is difficult to mathematically make the argument that any differences

which may exist between GM and normal trees are relevant in relation to models of organizational growth during phase transitional crisis periods, and especially, with regard to how organizational growth during phase transitional crisis periods can be modeled most effectively and accurately. Future research could track the origin of the S-curve from a scientific perspective rather than an observational perspective; so that any outcome based on a scientific S-curve, if possible, could only then be an application of the quantitative methodology. Future research also could take a different approach by, for example, surveying corporate officers. The results of a well-designed survey could be used in order to form new models of organizational growth which allow for greater accuracy and which are better representative of organizational growth.

Additionally, if a meta-analytic approach was going to be taken in any future research conducted in this area, the inclusion of a greater number of effects and studies, if possible, would help strengthen the meta-analysis and would serve to produce results that would be more trustworthy as compared with one in which only a small number of effects or studies were included.

5.3. Conclusion

In summary, this study aimed to determine whether GM trees or non-GM trees would serve as a better model of human-based organizations by conducting meta-analyses using previous studies which have compared these two types of trees on relevant outcomes. The results of the analyses found that GM trees are superior to normal trees, with the effect being small to moderate. However, the connection between trees and human-based organizations could not be quantified,

and therefore that connection could not be quantitatively represented in the mathematical analyses of this research. Even though there was an issue of mixing quantitative and qualitative data, it was decided to proceed to see if any quality information might be gained.

This research found that the model of the universal growth pattern (S-curve) that represents the connection between human-based organizations and all natural processes, was akin to correlations or simple distribution matching rather than a real mathematical representation. It is also found that the creation of an algorithm to address the growth of human-based organizations is not possible due to the fact that every organization is different, as well as every subsystem within that organization.

Based on the quantitative methodology, it is concluded that the research question could not be answered and that a mathematical model would not be the ideal approach to address the relationship between human-based organizations and trees. Future studies could expand upon this area of research by expanding the meta-analyses conducted, or by taking a different approach to the determination of how to appropriately and accurately model organizational growth.

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Appendix

Equations and online calculators used in the calculation of effect sizes:

- http://www.campbellcollaboration.org/escalc/html/EffectSizeCalculator-SMD3.php
- http://www.campbellcollaboration.org/escalc/html/EffectSizeCalculator-SMD4.php
- https://www.socscistatistics.com/effectsize/default3.aspx
- https://www.meta-analysis.com/downloads/Meta-analysis%20Converting%20among%20effect%20sizes.pdf
- https://www.polyu.edu.hk/mm/effectsizefaqs/calculator/calculator.html
- https://stackoverflow.com/questions/16097453/how-to-compute-p-value-and-standard-error-from-correlation-analysis-of-rs-cor

Vita

Magdi Sindi was born in Saudi Arabia in 1983. In 2005, Sindi earned his Bachelor of engineering degree in Architectural Engineering from Umm Al-Qura University in Makkah, Saudi Arabia. After that, he worked as a site manager in the construction project of Al-Jamarat Bridge, that costed $1.2 billion, in Mena, Saudi Arabia. In the course of his work, Sindi actively participated in supervising subcontractors, analyzing working drawings and specifications, and estimating and performing computer-based quantity takeoff. Then, he moved to work in Makkah Municipality as an architect and a planning engineer for correcting and criticizing building designs, applying urban regulations, and solving urban problems. In 2010, Sindi left his country, Saudi Arabia, to complete his graduate education. In 2012, he earned his Master of Engineering degree in Construction Management from Vanderbilt University in Nashville, TN. Then, he earned his Doctor of Philosophy degree in Engineering Management from the University of Tennessee, Knoxville in 2019.