COULD CLIMBING UP MASLOW'S PYRAMID HELP US SOLVE THE WORLD'S ENVIRONMENTAL PROBLEMS?

A study of the impact of human development from material to non-material needs on the environment

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Executive summary

Our planet is witnessing an unprecedented increase in temperature that is causing frequent damages such as extreme weather conditions, acidification of oceans and extinction of species that may soon become irreparable. Various studies have reported that greenhouse gas emissions (GHG) from human activities in industries that produce 'material goods' like transportation, energy, manufacturing and agriculture have been the chief drivers of the climate change crisis. Even as greener and renewable energy technologies are increasingly being adopted, since consumption of material goods in the rich parts of the world continue to increase, it may not be enough to solve the environmental problems in time. However, we may be able to solve them by adopting a different way of living.

In order to do so, we need to understand the purpose of the economy. According to Aristotle, *Eudaimonia* or the 'good life' which is the full development of human capabilities or virtues is the ultimate end of human life and the purpose of the economy or the production and consumption of material goods by people are simply a *means* towards this ultimate end. A similar idea that human beings have an ultimate end towards which all actions are directed can also be found with the more popularly known Maslow's hierarchy of needs. This essentially means that human beings need material wealth only insofar that it supports the fulfilment of their non-material needs: the development of capacities/virtues. 'Non-material' can refer to needs such as enjoying a classical dance performance, or studying philosophy or engaging in therapy. This perspective allows us to rethink growth in terms of a shift from material to non-material needs, which could also help solve the world's environmental problems as long as non-material needs can be met in less polluting ways (as compared to how material needs are met).

Following this, economic activities are classified as physical (or goods-producing) or non-physical. Activities in the physical economy meet material needs and have a higher potential for productivity growth. Activities in the non-physical economy, including health care, education, research and arts, meet non-material needs and have a lower potential for productivity growth since human work is generally the final output. Based on this classification, it is observed that, in the advanced economies, the share of the physical economy in total demand is getting smaller, while the share of the non-physical economy is getting bigger over time, reflecting human development from material to non-material growth. If the non-physical economy − which consists mainly of human work such as a doctor's advice, a lesson, a concert − is relatively less polluting, such a shift could mean good news for the environment.

While this looks promising, a consequence of the lower potential for productivity growth in the non-physical economy is that their activities can be expensive. Baumol (1993), termed this the 'cost disease' and argued that people in the rich parts of the world *can afford* the expensive 'personal services' when funds resulting from the productivity gains in the physical economy (due to labour-saving innovations) are transferred to the non-physical economy. Yet, nowadays, the standard response to the 'cost disease' is to replace human work with technology through standardisation, computerisation and robotisation of hitherto human tasks as a way to minimise costs. Due to the nature of work in the non-physical economy, the growing technology/ material-intensity can affect the quality of the non-material value created, while it may also increase the pressure on the environment. This led me to investigate the impact of the rising technology-intensity in the non-physical economy on the quality of outcome and on the environment.

One of the main activities in the non-physical economy, health care, is 'an art and a science' in the sense that it takes care of the health of a human being in order to enable him to develop intellectually and psychologically and it is not just about 'fixing' what is broken. Doctors, therapists and nurses are people who possess besides clinical knowledge, interpersonal skills such as understanding and empathy to carry out complex human interactions with patients. Yet, in recent times, especially in the United States, technologies such as electronic health records (EHR), e-prescribing, tele-medicine and health apps are increasingly being adopted to displace some of the creative work performed by health care professionals. The main drivers of such trends identified are: the privatisation of health care, the systems of 'Managed Care' and government measures such as the American Recovery and Reinvestment Act (ARRA) of 2009 that allocated funds to incorporate health information technologies in health care facilities across the country. Some of the common experiences found with the adoption of technology in health care are: a supplier-induced demand for drugs and medical technologies due to a 'fee-for-service' payment model for doctors, a 'technology arms race' between hospitals and 'direct-to-consumer' advertising of medicines and medical technologies. Some of the consequences of these trends found are: unnecessary testing leading to increased overall health care costs, 'physician deskilling' due to decreased clinical knowledge and psychological and health implications for patients due to less physician-patient interactions and more 'end-of-pipe' solutions. From a brief review, it is also found that the health care system in Canada is less technology-/material-intensive than the health care system in the U.S. with (roughly) the same quality of service which shows that different kinds of health care systems can coexist with one another.

A second activity of the non-physical economy, education, is one that enhances the intellectual and spiritual development of students, guided by a curriculum. According to various studies, teachers are indispensable in this activity in terms of their personal knowledge, their pedagogical capacities and their ability to instill curiosity, enthusiasm, sympathy, and morality in students through complex and dynamic interactions. Yet, similar to health care, even the creative work of teachers are being displaced with Information and Communication Technologies (ICT) such as: talent management software, digital learning technologies, MOOCs, allegedly to improve quality of education. In the United States, some of the trends commonly found to promote such technologies are: a pay-for-performance model for teachers to improve productivity of student grades, a common core standard curriculum and standardized tests for students to get them ready for college and careers. Some of the consequences of the growing technology intensity in education are found to be: teacher deskilling, lack of evidence of improved student performances and psychological implications for students such as diminished social skills, lack of creative and original thinking etc.

These findings suggest that the growing technology-intensity in health care and education may have not significantly improved the quality of service provided, especially since the nature of work in these activities are different. Besides this, they could also lead to a higher environmental burden. In this thesis, I investigate whether the latter is the case, which is done in two steps. First, I investigate whether the non-physical economy is less polluting than the physical economy. Next, I examine the environmental consequences of the rising technology-intensity of the non-physical economy. The empirical research method applied is the Environmentally Extended Input-Output (EE-IO) analysis, which is used to compute the direct and indirect environmental effects of the physical and the non-physical economy. Direct effects refer to the pollution recorded at the place where it arises (for example, emissions due to health care). Indirect effects refer to the pollution caused by industries that supply inputs to health care, and for which the health care sector (as sector of use) is (indirectly) responsible. Through an EE-IO analysis, environmental effects (such as emissions) are ascribed to the sector of use, by reallocating emissions from the sector where they originate (sector of origin) to the sector that uses the goods or services supplied by this sector. The EE-IO analysis makes use of an Input-Output (I-O) table which records intermediate deliveries of goods and services between sectors in an economy, as well as each sector's deliveries to final demand. In addition, it uses the environmental accounts of each sector to compute the total emissions for which a sector can be held responsible, which consist of its own (direct) emissions plus the emissions that are related to the inputs it purchases from other industries. The two equations that guide this computation are $B = b * (1 - A)^{-1}$ and $E = B * f$, where B= a vector of total (direct+indirect) emission intensities (per sector); b=direct emission intensity vector; $(1\text{-A})^{-1}$=the 'Leontief Inverse matrix' (derived from an I-O table) that represents the technical coefficients or the total (direct+indirect) inputs required per unit of a sector's output; f=final demand and E=a vector of total (direct + indirect) emissions per sector for a given level of final demand f. The results found were that the non-physical economy in the United States is less polluting in terms of global warming and acidification potential, energy use and tropospheric ozone gas emissions, even if emissions are re-allocated from sector of origin to sector of use. This result suggests that the impact on the environment will be lower if human beings become increasingly interested in non-material rather than material growth. However, this result may not come about if the non-physical economy gets more technology-intensive.

To empirically investigate the increase in technology-intensity in health care and its corresponding environmental burden, two comparative studies based on the EE-IO analysis were carried out. The first one compared the health care system in the United States between 1995 and 2015. After adjusting both I-O tables for inflation (using Miller & Blair's (2009) "double deflation" method) and regrouping them for comparable sector classifications, it is shown that the health care sector's technical (Leontief inverse) coefficients increased for 'computer, electronic & optical equipment', 'post & telecommunications', 'electricity & water supply', and 'renting & other business services' − indicating that the technology- or material-intensity (in terms of medical technology, ICT, administrative technology) as well as the electricity-intensity of health care increased from 1995 to 2015. Although the use of 'chemicals & pharmaceutical products' in the health care sector itself decreased, final demand for chemicals & pharmaceuticals per capita almost doubled between 1995 and 2015. In sum, the results found showed that technology/material-intensity in terms of ICT, medical technologies, energy use per unit of output and medicines per capita increased from 1995 to 2015. These data support, or at least do not falsify, the hypothesis of a trend towards higher technology-intensity of health care.

However, the result for the environmental burden of the increased technology-intensity was found to be mixed. Firstly, total CO_2 emission intensity of health care and the indirect contribution from 'post & telecommunications', 'computer, electronic & optical equipment' and 'renting & other business services' decreased from 1995 to 2015, largely due to an economy-wide switch to less carbon-intensive sources of energy. Although the shift from coal to natural gas reduced CO_2 emissions, it also led to other types of environmental problems, such as those associated with increased production of shale gas. Secondly, the indirect emission contribution from 'electricity & water supply' industry to health care's carbon intensity increased due to the increase in energy use per unit of output (possibly due to increased *use* of medical equipment and other technologies in hospitals). This also led to higher total (direct+indirect) emissions from the health care sector in 2015 than in 1995 for the respective levels of final demand. Therefore, as long as the technology-intensity of health care keeps rising, this is likely to involve rising pressure on the environment (not only in terms of emissions but also in terms of increased use of earth's finite resources).

The second study compared the health care system in the United States with the health care system in Canada for the year 2014. The results showed that the U.S. health care sector's technical coefficients were higher than those of Canada's health care for the relevant sectors examined in the previous study. This shows that U.S. health care is more technology-/ material-intensive in terms of medicines, medical technology, ICT and administrative technology than Canada's health care while reliance on human work is lower. Next, the total (direct+indirect) carbon-intensity of U.S. health care was also found to be higher than that of Canada's health care. This is mainly because the indirect emission contribution from sectors, namely, 'chemical & pharmaceuticals', 'renting & other business services', 'electricity & water supply' 'computer programming & information services' to health care are higher in the U.S.. However, the indirect emission contribution from sectors 'telecommunications' and 'computer, electronic & optical products' are found to be lower in the U.S. (in spite of a higher use of their goods per unit of output), possibly due to a lower carbon-intensity of these two sectors in the U.S. than in Canada. All in all, the important insight from these two studies is that even though increased purchase of medicines, ICT and related medical & administrative technologies by health care activities in the U.S. between 1995 and 2015 has not led to higher total CO_2 emission intensity of health care, we know that as of 2014, high-tech health care in the U.S. is still more polluting than Canada's health care. This supports the argument that replacement of human work with technological solutions in the non-physical economy may lead to a higher environmental burden.

In conclusion, since there is lack of conclusive evidence that the promotion of general, country-wide transition to high-tech health care (or education and arts) reduces costs while improving quality and reducing environmental burden, it may be desirable that *free choice of technology* in the non-physical economy is encouraged. The resulting diversity, or mix of low-tech and high-tech approaches in health care, education, arts, etc. would be less polluting than a linear high-tech approach in the non-physical economy, while leaving providers as well as recipients of services in the non-physical economy free to explore different technological paths.

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1 Introduction

1.1 Background

The global climate has been rapidly changing over the last few decades in most parts of the world and is evident from reports of frequent extreme weather conditions, rising of sea levels, acidification of oceans, melting of ice-caps, and extinction of species (NASA, 2020). Since the second industrial revolution (1900s), the planet's temperature has risen by 1,8°F out of which there was a 1,2°F increase in the last five decades alone (USGCRP, 2017). Such high rate of increase has been unprecedented over millenia (IPCC, 2013) which makes global warming an alarming issue.

According to many studies, the warming of the planet is mainly driven by rising emissions of greenhouse gases (GHG) caused by human activities (IPCC, 2013; NASA, 2020). Emission of GHG from the burning of fossil fuels, deforestation and changes in the use of land are some of the activities that have pushed the global temperature up (USGCRP, 2017). It is even determined that human activities may be responsible for 93% to 123% of the observed rise in global temperature in the last five decades (USGCRP, 2017). Figure 1 shows the significance of human influence on the rise in global temperature when compared to other natural factors (e.g. carbon dioxide emissions from volcanic eruptions etc.) for the period 1880-2010. Apart from emitting harmful gases into the environment, these human activities also release toxic discharges into the land and water resources which causes threats to biodiversity (EEA, 2019) and use up non-renewable resources that may affect the well-being of future generations. Such human activities have been found mostly to belong to industries like agriculture, transportation, manufacturing and energy (Ge & Friedrich, 2020) that have been set up for the production of goods.

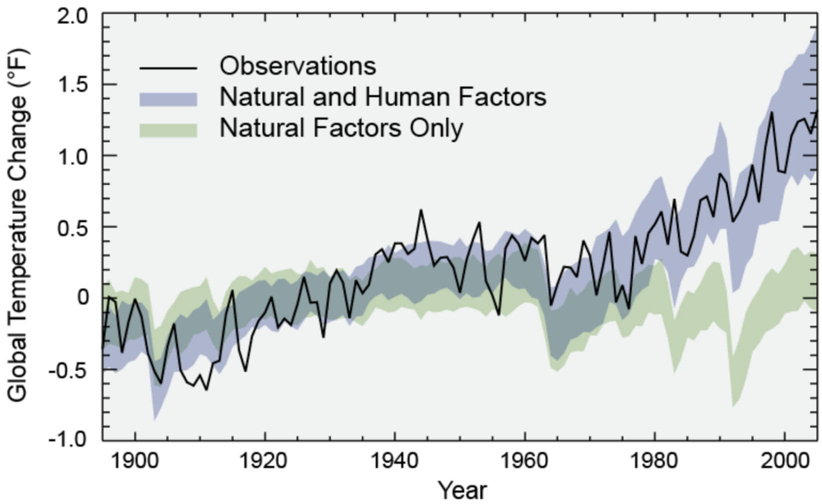

Figure 1: Human influence on temperature change. **Source:** Environmental Protection Agency (EPA, 2016)

The Industrial revolution of the 18th century was a crucial period in history that changed the way human beings survived. It set up factories for the large scale production of goods that allowed more and more people to have access to basic necessitates like food, clothing and shelter. Today, almost 260 years after the revolution, most people around the world enjoy the benefits of industrialization. This is evident from a fall in the percentage of world population living in extreme poverty from 84% in 1820 to just 24% in 2015 (Roser & Ortiz-Ospina, 2020). Therefore, the activities belonging to the polluting industries are crucial for human beings to enjoy certain extent of good living standards. This is why, despite the recognition of the stress exerted by these industries on the planet due to their nature, it is not possible to simply stop these activities.

Yet, recent studies have found that we are in the middle of the planet's sixth mass extinction with at least 50% of animal species already gone extinct due to over-exploitation and pollution (Ceballos, Ehrlich, & Dirzo, 2017). According to a recent report by the Intergovernmental Panel on Climate Change (IPCC) led by top climate scientists, we need to keep global temperature change below 2,7°F (from pre-industrial levels to end of 21st century) to slow down further extreme heatwaves, increases in sea levels and loss of habitats for species. To achieve this target and to keep the consequences of climate change from becoming irreversible, we require urgent global efforts to bring down emissions to 'net zero' by 2050 (Davidson et al., 2018; IPCC, 2018). This means that environmental degradation is no more a problem we can afford to put off to the future.

To deal with this dilemma, there is a lot of research and development on going to make these industries more green through the use of renewable sources of energy to compensate for their negative impact on the environment (IPCC, 2011). Greener technologies are definitely a critical first step but will this be enough to solve the looming issue of climate change? Personal consumption expenditures per capita have grown by 163% in the United States and 123% in the Euro Area from 1970 to 2018 [1] (The World bank, 2019d). Figure 2 shows the rise in consumer spending per capita (inflation adjusted 2012 prices) per year on some durable and non-durable goods in the United States.

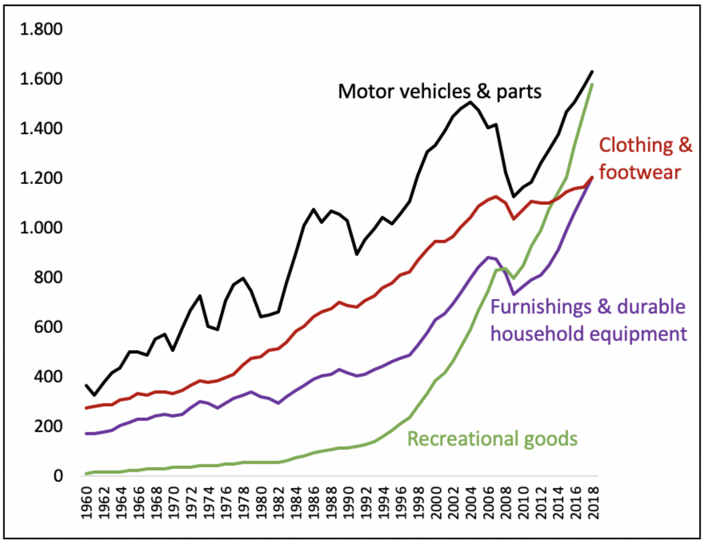

Figure 2: Consumer spending per capita. **Country:** United States. **Source:** BEA (2020b); The World bank (2019e)

From Figure 2, it can be seen that a person in 2018 is spending almost 4 times more on motor vehicles and its parts, 7 times more on furniture and household items, 118 times more on recreational goods (sporting equipment, audio and video equipment etc.) and 4 times more on apparel on an average than

[1] The personal expenditures per capita include all goods and services such as cars, washing machines, computers etc. in US dollars in 2010 prices.

one in 1960. This means that there is increasingly more demand for goods, and this, too, by what is considered the well-developed economies who already have good standards of living. As consumption of goods increases, its impact on the environment will also increase (Schor, 2010).

A dominant force that has driven such consumer spending on goods is the use of massive marketing and advertising strategies by businesses who offer the very same goods in different styles, prices, designs and quality (Schor, 2010). In the United States, an estimated $200 billion was spent by businesses on digital and TV advertising in 2019 (eMarketer, 2019) and on an average, each dollar spent on ads led to about $9 in sales (Hsu, 2020). 'Fast fashion' brands like Zara, H&M etc. have completely changed the playing field of the apparel industry by shortening product life cycles and selling trendy clothing for very cheap prices [2]. Such a business model has allowed for an average American consumer to own twice as many clothes in 2007 than what (s)he did in 1990 (Schor, 2010). In the electronics industry, marketing strategies such as 'planned obsolescence' is common to compel consumers to buy the latest products which again shortens product life cycles and increases consumption (Sarhan, 2017). Such strategies have, in a way, led consumers into believing that they need more and more of goods, most of which have a burden on the environment, even after they have secured sufficient amounts of it for a decent living (Schor, 1993). If this continues, just transforming to greener technologies cannot be the only solution in the long run. We may require more drastic measures by adopting a different way of living if we want to reduce the stress on the planet (Schor, 2010).

1.2 Philosophical foundations

To adopt a different way of living, it is essential to become aware of the true motivation of human beings in life. Keynes in an essay written in 1930, *Economic possibilities for our grandchildren*, explained that within approximately 100 years, living standards would be high enough to meet all material needs, and he hoped that human beings would then begin to look for the 'real values of life' (Keynes, 1930). In his view, the production and consumption of material goods or the accumulation of material wealth is not the *goal* but just a *means* towards achieving the 'real values of life'. Keynes' view on the human being had Aristotelian roots, particularly the idea that material goods are needed for human beings only to enable them to perform 'fine actions' (Naastepad & Mulder, 2018). If the human being is perceived in terms of a trichotomy of the 'body', 'soul' and 'spirit', then the material conditions provided by economic activities are only required to satisfy the needs of the 'body'. For example, all human beings have the need to be clothed, fed and housed which are considered as needs of the body or material needs. These needs can be met by the goods-producing industries or the physical economy. Beyond this, the needs of the 'soul' and 'spirit', which are considered as higher parts of our being, are increasingly 'non-material' in nature (Naastepad & Houghton Budd, 2015). By non-material, it can refer to needs such as enjoying a classical dance performance, studying philosophy or engaging in therapy. These needs are generally met in non-material ways, for example, a musician's concert, a teacher's lesson or a psychologist's advice, outside the physical economy i.e. by the non-physical economy (Naastepad & Houghton Budd, 2015). This idea of the human being again suggests that we have needs other than our material livelihood and the purpose of the economy is only to provide material conditions for our non-material development (Naastepad & Houghton Budd, 2019). Empirical evidence for this

[2] The low prices come from using cheaper materials and labour. The average price at Zara is between $20-$40 (Marci, 2019)

perspective on the motivation of human beings can be observed in the long-term structural change in the economy. The share of the goods-producing industries in GDP has declined over time, while human endeavours directed at non-material needs, such as health, education, research and arts have increased as a share of GDP. A detailed explanation of this evidence is given in section 2.3.2.

The conception of non-material needs or the 'real values of life' can be understood based on Aristotle's idea of the 'good life'. For Aristotle, *eudaimonia*, translated as happiness, or 'the good life' is the end or the goal towards which all actions of human beings are directed (Page, 2010). This is the only end that is intrinsically good in itself and is not pursued for the sake of some other end. In order to achieve the 'good life' or eudaimonia, the development and excellent use of our capacities and faculties (Page, 2010) through contemplation and reflection are suggested to be the one and only way (Kern, 1983). Therefore, the 'good life' is a life of excellence or the full development of the potentialities of a human being (Skidelsky & Skidelsky, 2012). The satisfaction of bodily needs are then required only insofar that they support the ability of human beings to flourish. For example, a poor man who has very little wealth has to toil for an earning which will leave him with not enough time for contemplation and reflection (Kern, 1983). So, wealth and material needs are necessary but should be limited as they are only a means towards the ultimate end. But how do we identify this limit for human beings? Keynes (1930) predicted living standards to rise by 4 to 8 times in the rich parts of the world within 100 years and when this happens, people would have *enough* to take care of their material needs, leaving them free to pursue the 'real values of life'. Today, ninety years after Keynes' estimation, living standards in terms of income per capita (inflation adjusted) in the United States have risen by almost 6 times from 1930-2019 (BEA, 2020a). The living standards in the rich parts of the world can be said to be high enough to meet their material necessities, on average at least (the distribution of income still is a huge problem). Therefore, in principle, human beings in the rich parts of the world have the opportunity to pursue the 'real values of life' (Keynes, 1930) or to realise the 'good life' (Skidelsky & Skidelsky, 2012).

However, in reality, it is difficult to find evidence for how much is *enough* for people to lead the 'good life' because if we look at how people generally behave (for example, the pattern of consumer spending given in Figure 2), they come close to how the currently dominant Neoclassical-utilitarian Economic theory describes the (insatiable) consumer. In the Neoclassical view, human beings are considered as rational 'utility maximisers' who strive to maximise pleasure and minimise pain based on their own self-interest (Skidelsky & Skidelsky, 2012). From this perspective, since what matters is quantity of pleasures or desires, there would be no limits to the consumption of goods and wealth by human beings. This is because human *wants*, as opposed to human needs, are infinite and when we are driven by them, new wants will arise continuously and faster than old wants are satisfied. (Skidelsky & Skidelsky, 2012). This way people become insatiable and consume more and more than what they already have. Even if this is how human beings currently behave, we have seen that this is not environmentally sustainable (besides its other adverse consequences on economic and financial systems); the earth may collapse under the weight of our consumption. Therefore, the question is, is this self-interested and insatiable nature of human beings, as perceived by Neoclassical economists and reflected in the real life behaviour of most people, innate and unchangeable? If yes, then it will become difficult to solve our environmental problems. But on the basis of the Aristotelian perspective, it need not be so.

The consumption of material goods or the pursuit of material wealth based on one's own self-interest, as depicted in reality, need not be the goal or end for people. Instead, according to Aristotle, this should be treated as a mere means towards the ultimate goal of the 'good life' (Skidelsky & Skidelsky, 2012). From the idea of the 'good life' which is a life of excellence, we can see that there is a difference between the human being as (s)he is and the human being as (s)he could be. The 'good life' is not just about pursuing our endless desires based on our self-interested nature as not all desires or pleasures can be assumed to be good (evident from the destruction of the environment by human activities). Rather, to realise 'eudaimonia' or the 'good life', desires need to be transformed into virtues. Aristotle believes that human beings have the natural potentiality to be virtuous but this needs to be activated by our intellect which in turn needs to be guided by morals (Kern, 1983). Therefore people need to *educate their desires* to the point that they become desirable or virtuous (Skidelsky & Skidelsky, 2012) through the development of character or capacities, including intelligence, consciousness, creativity and especially morality that are essentially non-material in nature (Naastepad & Houghton Budd, 2015). Through the disciplined education of our desires, human beings can "*choose* not to want more than they need" (Skidelsky & Skidelsky, 2012, p. 46). We can move from being insatiable consumers to realising that what we are looking for, beyond a certain level of material needs, is growth in the non-material sense. This way, we can also develop ourselves to become less egotistical and more concerned with the needs of others, including the environment. When human beings exercise this educated choice, then the desires that create a burden on the environment will not get chosen.

Health care, research and education are some cultural activities in the non-physical economy that could be a source of consciousness, creativity, intelligence and morality for human beings (Naastepad & Mulder, 2018). These activities could support people in educating their desires to become more interested in the 'real values of life' or 'the good life' and more concerned with the well-being of others and the environment. If human beings do intend to develop beyond material necessities and look to educate their desires, then this itself could also be a solution to the environmental problems. This is because when human beings start thinking about their true needs, that is the fulfilment of their higher goals or development of their capacities which are likely to be found in the sphere of developing the intellectual and moral virtues that are supported by the cultural activities, it would require exercise and not more environmentally harmful consumption (Skidelsky & Skidelsky, 2012). The important point from an environmental point of view is that, unlike the goods-producing industries, cultural activities tend to produce non-material 'outputs' which, moreover, may require fewer material inputs than goods production. This means that a shift in human endeavours from goods production to cultural activities may reduce the burden of total human activity on the environment as compared to the current situation where consumption continues to grow.

It is to be noted that my thesis merely observes that the two positions on human motivation, namely the Aristotelian view (as represented by Skidelsky & Skidelsky (2012), Kern (1983) and others) and the Neoclassical-utilitarian view, exist, and that chances of solving the environmental problem may be low when we are stuck with the second position only; therefore, it looks at what the first position could mean for the environment.

1.2.1 Aristotle's 'good life' from a psychological perspective

The idea that the needs of human beings are hierarchical in the sense that there is an ultimate end towards which all other actions are directed (Kern, 1983) has become familiar in management circles through Maslow's *Theory of human motivation.* Maslow (1943) argues that human motivation is driven by needs and identifies five levels of human needs (shown in Figure 3). One starts at the bottom level, where one is motivated primarily by physiological needs and as and when the corresponding needs are gratified, one moves up the pyramid, until the top most level where one aims to fully develop one's capacities.

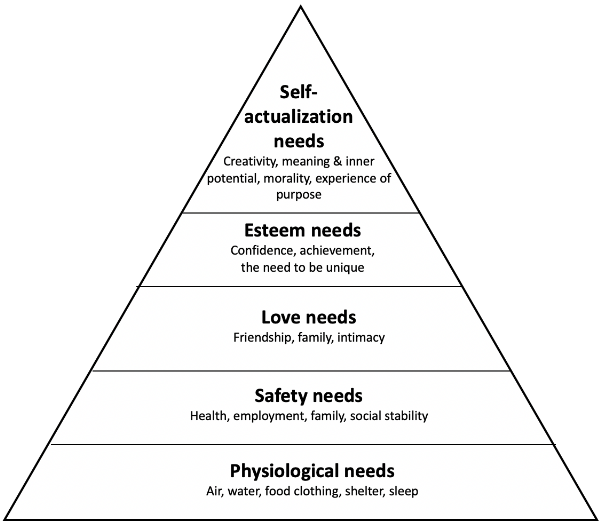

Figure 3: Maslow's hierarchy of needs

Maslow, who is suggested to be inspired by Aristotle's philosophy (Ivie, 1986), recognises the concept of self-actualisation on the highest level of needs as about becoming everything that one is capable of becoming (Daniels, 1982). This may be likened to Aristotle's idea of fulfilling the *lower needs* of the 'body', in order to be able to fulfil the *higher needs* of his 'soul' and 'spirit' which is to realise the 'good life'. However, Maslow's model has been criticised by a few authors for suggesting a selfish process of personal development and for being elitist and unscientific as its empirical evidence was largely developed from a selected group of self-actualising people (Compton, 2018; Neher, 1991; Whitson & Olczak, 1991). Taking the first criticism about the model being focused "on the self", Compton (2018) argues that this is untrue as Maslow's version of self-actualisation having attitudes and behaviours that went beyond the self to include concerns for others. For example, Compton (2018) mentions characteristics such as "profound interpersonal relationships", "tolerance for self and others" and "a dedication to a vocation that they saw as being a service to others". Based on this, 'self-actualisation' for human beings will include responsibility for the well-being of others and for the environment which again reflects Aristotle's idea of developing a virtuous character in order to lead the 'good life'. The critique of the model being elitist comes from the assumption that it neglects socio-cultural factors such as racism, sexism, poverty and discriminates people struggling with lower needs as 'inferior'. Compton (2018) denies both these assumptions by arguing that Maslow did find evidence of self-actualisation in people of colour, women and people of different income levels and he only referred to self-actualising people as superior in the sense that they are more skilled at fulfilling their capacities. Regarding the last critique of the model, that it lacks empirical evidence of people moving from lower needs to higher needs, perhaps the empirical observation mentioned above, of the declining share of the goods-producing industries (mainly set up to provide basic material needs) in GDP and the growing share of activities in non-material or cultural spheres such as education, research, health care, arts etc. (see section 2.3.2 for a detailed explanation), could serve as empirical support. This empirical observation may point to the possibility that once lower-level or basic needs are satisfied, human beings begin to look for non-material development.

Once again, the thesis does not propose that the idea behind Maslow's pyramid and the goal of self-actualisation are right. Additionally, the thesis also does not delve into each level of human needs given in Maslow's pyramid. Rather the question studied in this thesis is what would be the impact on the environment if the needs of human beings developed from lower, largely material needs to higher, largely non-material needs. If activities intended to meet higher, non-material needs do not produce material goods as 'output' (or much less so) and are also *less* polluting than the physical economy, meeting people's non-material needs would not be as harmful to the environment as compared to when human beings continue to be focused on material consumption. If this is the case, could a shift in human development from lower needs to higher needs of Maslow's pyramid, or from material needs to non-material needs help solve the world's environmental problems?

Despite this promising outlook, it is important to study more in-depth the way non-material needs are met. On the one hand, on the side of demand, there exist forces that mislead people into believing that the needs of the 'soul' and 'spirit' or the higher, non-material needs can also be met with the consumption of goods or the physical economy (Naastepad & Houghton Budd, 2015). On the other hand, from the supply side, non-material needs such as health care, education, research, even the arts, are increasingly created using technology rather than human work.

Regarding demand, consider, for example, plastic surgery, which may be done for various reasons. If it is done, for example, to replace a finger of hand lost in working with machines, this surgery certainly meets a material need. But plastic surgeries are also done for cosmetic reasons, in which case a material 'solution' is provided to meet a non-material or higher need, for example feelings of self-worth (Pruzinsky, 1993). However, if the real problem is that this person does not see his or her own value, and tries to find it by adjusting the body to a socially accepted norm in a particular place and time, one might ask whether this is going to help. Studies have found that the risk of suicide is slightly higher among women who have undergone breast augmentation procedures and the presence of Body Dysmorphic Disorder (BDD) is higher among cosmetic surgery patients (Sansone & Sansone, 2007). If this is the case, would they not be better helped if they realised what the true problem is, for example, a low self-esteem, and tried to deal with that directly (rather than trying to change something physical which is not the real problem)? This will be seen only if we become more conscious of what our true needs are with potential support from cultural activities.

As another example, in the U.S. health care services, the use of 'direct-to-consumer' advertising (which is now permitted by law) has resulted in an increased demand for drugs and treatment by patients (Koshy, 2015). This is because most of these drug advertisements promise a 'quick fix' to complex human problems related to their health. But do they necessarily improve people's health and well-being? There is sufficient evidence to suggest that they may not (see Chapter 3). At the same time, there are trends on the supply side to replace human medical work with 'technical solutions', especially ICT. For example, the diagnostic tasks of physicians that come from years of acquiring knowledge and skills are increasingly replaced by software technologies such as computer-aided diagnostic systems (Carr, 2015). The creative and cognitive tasks of teachers in traditional face-to-face environments are being displaced by computer-assisted instructions and digital education. There are studies to suggest that these technologies do not necessarily improve the quality of non-material value creation and can even degrade important human relationships (e.g. teacher-student relationships) that are important to the outcome. A detailed literature review of these trends and their implications for human being's non-material development are presented in Chapter 3. The crucial point for this thesis is that if non-material needs of human beings are increasingly being met in material ways and if these trends in the cultural activities continue, this may not only psychologically harm people but also reduce the difference with the physical economy in terms of environmental burden. Therefore, the way of meeting non-material needs also has to be taken under consideration to determine the impact of pursuing higher needs on the environment.

1.3 Societal Relevance

The societal relevance of this thesis lies in rethinking the idea of growth. Till now, the focus of economies has been on growth in material terms to improve living standards. However, such growth has major consequences for the natural environment (further explanation in section 2.2). This thesis proposes growth in non-material terms for economies that have reached sufficient material prosperity. This may not only be beneficial to the environment but can also support human beings to develop their capacities.

This idea can have profound consequences for businesses. The current understanding of the role of businesses in society would have to be transformed which will include two main changes. Firstly, we would need to make a distinction between organisational models that are adequate for the production or the creation of material goods, and organisational models that would be adequate for the non-physical economy or the creation of non-material value (knowledge, ideas). Secondly, the non-physical economy that aims to meet the non-material needs of human beings will have to be funded just like the production of material goods. To this end, ideas about the goal of the business would need to be reviewed. Businesses or industries would then need to serve two goals rather than one: the production of goods that are needed by people, and the generation of surpluses to fund the creation of non-material value (Naastepad & Houghton Budd, 2019).

1.4 Scientific relevance

There is a wide range of research in economics to solve the world's environmental problems. Some popular approaches found are 'green growth' which is to make technologies more resource efficient without stopping economic growth (Jacobs, 2012) and 'de-growth' which refers to the concept of achieving economic well-being without the need to actually grow (opposite to involuntary degrowth) (Jackson, 2009; Victor, 2019). This study differs from the other approaches in literature by distinguishing (in Aristotelian tradition) between material and non-material needs, and investigating what the impact on the environment would be if, as human beings, we could gradually leave our fascination with material growth behind us and became more conscious of our non-material needs.

1.5 Research Objective

The objective of this research is to study the impact of human development from lower to higher needs on the environment or more specifically, to investigate whether meeting higher needs is less polluting than meeting lower needs. Although the question of whether the will to develop from lower to higher needs, or free will, exists, has been a subject of debate for ages, even millennia, it is not the subject of my thesis. Rather, my thesis will focus on what it could mean for the environment when, *once material needs have been met*, we as human beings tend to look for growth in non-material terms rather than further growth in material terms. This will be done, taking into consideration the means used to meet the higher needs.

1.6 Research framework

A conceptual model is developed to translate the lower and higher needs of Maslow's pyramid into material and non-material needs, which are subsequently matched to the physical and non-physical economies. Based on this conceptual framework, the thesis aims to study the impact of a possible transition from a predominantly physical to a largely non-physical economy on the environment.

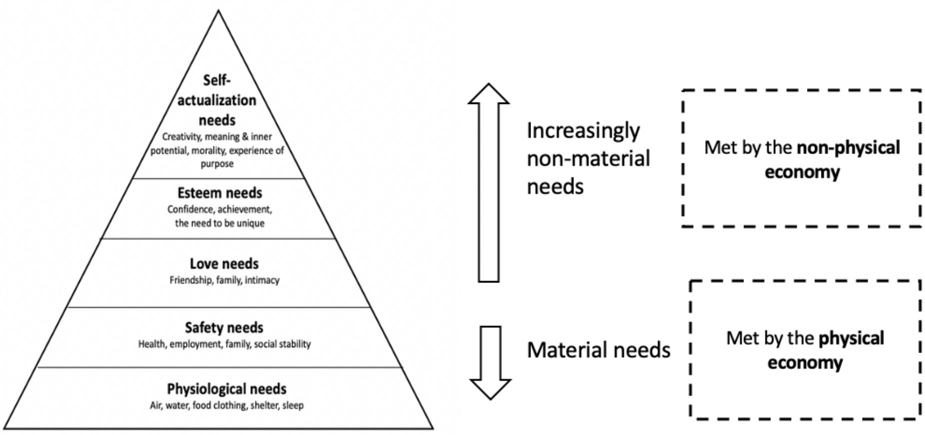

Figure 4: Conceptual model

1.7 Research question

The objective of the research is to study the impact of (a possible) human development from lower (material needs) to higher (non-material needs) on the environment. As already explained, this is based on a strong assumption, namely that, with rising living standards, the needs of human beings grow increasingly non-material. Although I have briefly discussed (Aristotelian) literature that suggests that this may be the case, and pointed to a long-term structural change that is taking place in the economy (the declining share in GDP of the physical economy) that suggests the same, it is not an aim of this thesis to prove or disprove this assumption. Therefore, the main research question to be investigated is (conditionally) framed as follows:

If, with rising living standards, the needs of human beings grow increasingly non-material, could the further development of the human being (from material to increasingly non-material needs) help solve the world's environmental problem?

The answer to this question will depend on whether non-material needs are best met in non-material rather than material ways. Therefore, answering this question will require further investigation into whether the creation of non-material value in the non-physical economy to meet the higher needs of human beings is less intensive in material inputs than the production of goods in the physical economy. However, a complication is likely to come up. As already explained, even if the higher needs of human beings are best met in non-material ways, people may believe that their higher needs can also be met in material ways (through higher consumption of goods). Indeed, there appears to be a growing trend to meet non-material needs in material ways. For example, in health care, there is a trend to replace care given by doctors, nurses, therapists etc. by medicine, medical technology and the use of software and robots. Similarly in education, there is a trend to replace teachers and hours spent in the class with robots and digital teaching programmes. Even the fine arts are becoming increasingly technology- intensive. This may reduce the difference between the environmental burden of meeting higher as compared to lower needs. This leads to the following sub-questions:

1.7.1 Sub questions

1. What is the impact on the environment of the non-physical economy (meeting non-material needs) as compared to that of the physical economy (meeting material needs)?

   I will investigate the direct and indirect environmental effects of the activities belonging to the physical and non-physical economy.

2. What is the environmental impact of the non-physical economy when this consists mainly of human work as compared to when this human work is replaced with technical solutions?

   I will investigate the direct and indirect environmental effects of activities belonging to the non-physical economy when these are met mainly through human work, as compared to the direct and indirect environmental effects of the same when they are increasingly met through material (technical) solutions.

1.8 Structure of the thesis

Based on the research objective and research (sub-)questions, the thesis is structured as follows.

In **Chapter 1** (the present chapter), an introduction to the environmental problem and a potential solution based on an (Aristotelian) perspective on the (evolving) needs of human beings (as compared to the Neoclassical-Utilitarian perspective) is identified and the research objective and research questions are presented.

In **Chapter 2**, an explanation of the wider context of the research objective through a literature study and analysis is presented. I investigate the impact of economic growth on the environment based on empirical and theoretical findings. I further analyse the structural shift from a predominantly physical economy (in the past) to a largely non-physical economy in advanced economies.

In **Chapter 3**, recent trends in the way non-material needs are met in technology-intensive ways are investigated through a literature review. The study aims to explain the main drivers behind these trends, namely, free-market objectives such as profit-maximisation, competition and cost reduction without regard to its impact on the quality of the non-material value created in cultural activities, namely, health care and education. Chapter 3 prepares for the analysis of the environmental impact (in Chapter 5) of the increasingly dominant role of technology in meeting the non-material needs of human beings.

In **Chapter 4**, the Environmentally Extended Input-Output (EE-IO) analysis, which forms the basis for the empirical work carried out to answer the first and second sub-question is illustrated with a simple example. This is followed by its application to the economy of the United States to compare the direct and indirect environmental burden of the physical and the non-physical economy (first sub-question). The results show that the physical economy has at least twice more environmental burden than the non-physical economy even when both direct and indirect impacts are taken into account.

In **Chapter 5**, a brief review of the environmental impact of the rising technology-intensity in the non-physical economy found in Chapter 3, especially ICT, is presented. This is followed by two empirical studies on the environmental effects of the high-tech non-physical economy by comparing the health care sector of the United States in the year 2015 (taken to be more technology intensive) with that in the year 1995 (taken to be relatively less technology intensive) and by comparing the health care system in the United States (high-tech) with that in Canada (relatively low-tech) using the EE-IO analysis.

In **Chapter 6**, a concluding discussion and reflection on the various trends found in the non-physical economy and their implications for human beings, economic factors and the environment are presented.

2 Context Analysis

2.1 The pursuit of economic growth

Economic growth is defined as the increase in the production of goods and services on a national level (Hueting, 1980). This is measured by setting up a System of National Accounts (SNA) to record economic activities. An important component of the SNA is the Gross Domestic Product (GDP). Today, economic growth in terms of GDP is seen as an indicator of a nation's progress (Costanza et al., 2009; Stiglitz et al., 2018) or a nation's material prosperity (Hirsch, 1977) and higher growth in GDP is taken as a reflection of higher welfare. But is it?

In the past, economic growth was generally seen as a *means* towards other things that were considered desirable, such as higher standards of living or, especially after the Great Depression of 1930s, higher levels of employment, rather than an end itself. Only in the early 1960s, the use of economic growth as an end was introduced by the then newly established Organisation for Economic Co-operation and Development (OECD) (Tily, 2015). However, to what extent does GDP still measure welfare, especially when the environmental effects of further growth are taken into account?

2.2 Implications of economic growth for the environment

Some of the most developed countries in the world are found to be responsible for the highest carbon dioxide (CO_2) emissions globally. A study found that out of the total emissions from 1975 to 2017, the share of the United States and the European Union were 25% and 22% respectively (Ritchie & Roser, 2020). Figure 5 shows a plot of GDP per capita (taken in constant 2010 $), a measure of living standards, and CO_2 emissions (taken in kilo tonnes), an indicator of environmental impact, for economies, namely, United States, European Union (E.U.), high income countries [3] and the world, for the period 1960-2014.

From Figure 5 it can be seen that except for the E.U., all other economies have a rising trend in CO_2 emissions with growing living standards. In fact, the emissions on a global level are growing faster than living standards. Although, in recent times, the rate of increase in emissions has slowed down in most high income economies, there is still an overall continued increase (except for the E.U.). Most of the increases are driven by oil & gas (energy) and transportation sectors apart from other exogenous factors (for example, events like Fukushima nuclear disaster in Japan in 2011, changing weather conditions in Canada etc.) (Dion, 2018; Kiko Network, 2008).

In the United States, CO_2 emissions have been increasing till the year 2007 mainly due to increasing consumption of goods along with growth in population (Feng et al., 2015). However, there was a decline in CO_2 emissions from 2007. Studies show that this decline in emissions can be attributed to two main factors, namely, the switch from coal powered plants to natural gas (a fossil fuel less carbon-intensive than coal) and the Financial crisis of 2008 (Feng et al., 2015). Unfortunately, this decline did not last as emissions were estimated to have spiked in 2018 due to increased demand from the transportation and energy sectors (Rhodium Group, 2019).

[3] High income countries include 80 countries whose Gross National Income is at least $12.376

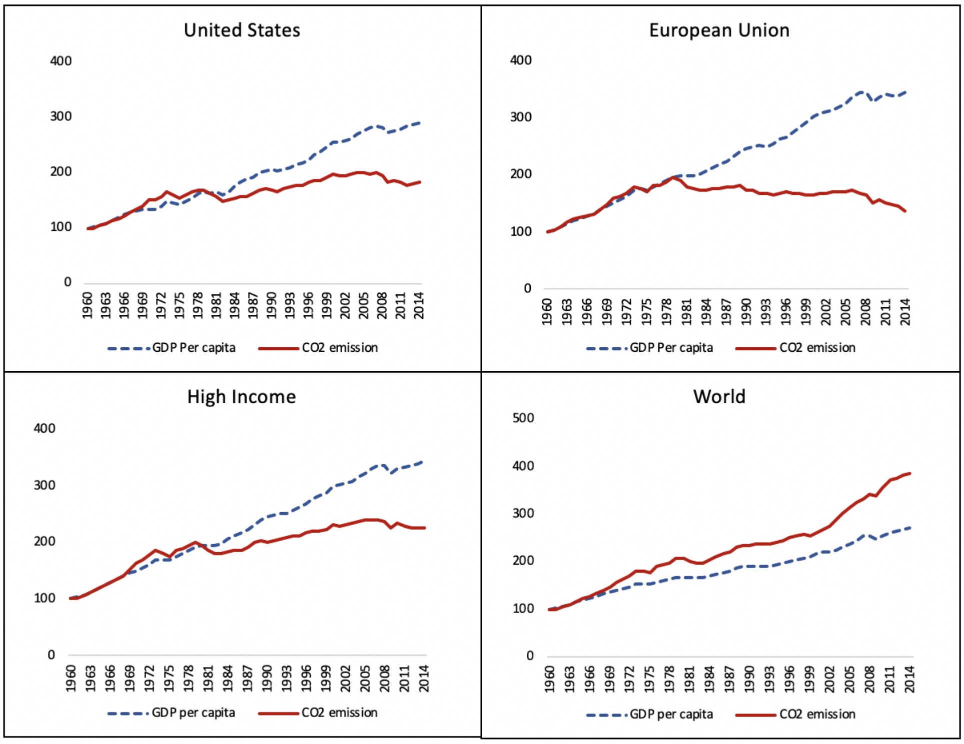

Figure 5: CO_2 emissions and GDP per capita by country. **Source:** The World bank (2019a,c)

The United States which was committed to the Paris agreement of 2016[4] to reduce their emissions by a large share before 2030 has even requested to withdraw from it in order to meet economic growth targets (Farand, 2019). The E.U., on the other hand, has been relatively successful in cutting down CO_2 emissions over the years. In the United Kingdom (taken to be part of the E.U. in Figure 5), the decline is attributed to the use of cleaner technologies and reduced demand for energy from commercial and industrial sectors (Hausfather, 2019). However, the same downward sloping trend does not apply to all the countries in the E.U.. For example, Germany has a declining trend of emissions with growing living standards whereas Italy and Netherlands have a rising trend (The World bank, 2019a,c). Irrespective of the trend of CO_2 emissions, most of the advanced economies are failing to meet the climate goals [5] set by them for the Paris Agreement (Gibson, 2019).

The International Resource Panel report revealed that we need to "decouple" GDP growth from environmental burden urgently if we expect our economies to grow continuously in material terms (through the production and consumption of goods) with the earth's finite resources. This means that we need to bring down emissions or resource use faster than GDP growth (UNEP, 2011). Figure 5 suggests that the growth in GDP has only been relatively decoupled (emissions declining at a rate slower than GDP per capita) from CO_2 emissions for most high income economies. Even hints of absolute decoupling (emissions declining at the same rate as that of GDP per capita) does not seem to be visible anywhere

[4]The Paris Agreement is a convention that brings all the members of the United Nations Framework Convention on Climate Change (UNFCCC) together to respond to the climate change crisis. This means that all the members must report their emissions and policies to further bring them down periodically (UNFCCC, 2020)

[5]Climate goals are set as a percentage of emissions that the respective country commits to cut down before a target year. Examples: The United Kingdom has committed to reduce emissions by 80% and the EU has committed to become carbon neutral by 2050.

except in the E.U.. These findings are based on just one type of environmental pollutant, namely, CO_2 emissions. There are several other toxic pollutants such as methane, SOx, NOx etc. and energy & resource use which also have a burden on the environment and the ecosystem. Studies have found that even other environmental impacts such as material consumption and resource use have only been relatively decoupled from economic growth (Jackson, 2009; Ward et al., 2016).

These conclusions support the argument that greener and cleaner technologies can be solutions in the short run but for the long run, we may have to adopt a different way of living if we want a radical decline in emissions and other impacts to the ecosystem. Can a radical decline in emissions or absolute decoupling of GDP growth from environmental impact be possible if the economy continues to grow?

2.2.1 Theoretical foundations

A theory that supports the idea that economic growth and care for the environment can go hand in hand is the **environmental Kuznets' curve**, proposed in the early 1990s, that establishes an inverted U-shaped relationship between GDP growth and environmental degradation in an economy (Grossman & Krueger, 1991). This means that an increase in GDP has a negative impact on the environment up to a certain point after which the quality of the environment increases with increase in GDP. The idea is that people give priority to the environment once their incomes have reached a certain level. This also implies that economic growth is essential to reduce the pressure on the planet (Dasgupta et al., 2002; Dinda, 2004). Empirical analysis has found that economies with an average income of \$3.000-\$10.000 per capita should have reached the threshold point for some pollutants (Dinda, 2004). However, Arrow et al. (1995) among many others have criticised the environmental curve to have not included all possible pollutants which means any evidence of this curve in an economy does not fully reflect the actual impact of its economic growth on the environment. They also found the curve to have not addressed the consequences of indefinite growth on the earth's finite resources on the present and future generations.

On the other hand, the **'threshold hypothesis'** proposed by Max-Neef (1995) tells the opposite story. It states that an increase in economic growth has a positive impact on the quality of life up to a certain point after which any further increase in economic growth negatively impacts the quality of life. Here, the quality of life includes environmental quality as well as personal well-being of people in societies. This is based on the argument that the carrying capacity of the earth is limited and continued economic growth in material terms may allow us to reach those limits quickly (Arrow et al., 1995). Alternate indicators to GDP like the Index of Sustainable Economic Welfare (ISEW) and the Genuine Progress Indicator (GPI) were developed in order to capture measures such as income inequality, social components and environmental quality in an economy. Studies using these indicators show that the threshold point was reached mostly around 1970s and 1980s in rich economies like the United States, the United Kingdom, Germany, Australia and Japan (Alexander, 2012; Lawn & Clarke, 2010; Max-Neef, 1995). This suggests that further 'material' growth after the 1970s did not contribute positively to quality of life. Table 1 gives the threshold points and the corresponding GDP per capita in 2010 prices observed for the countries mentioned above. It can be seen from Table 1 that the threshold range lies between \$20.000 to \$40.000 GDP per capita and the economies have continued to grow beyond the threshold. If the threshold hypothesis can be accepted, it is essential to not grow further at least in 'material' terms if we want to protect our quality of life and the environment. Based on this, the next logical question would be to ask how else can we improve the quality of life?

Table 1: Threshold range. **Source:** Lawn & Clarke (2010); Max-Neef (1995); The World bank (2019c)

Country	**Threshold Year**	**GDP per capita in threshold year**	**GDP per capita in 2018**
United States	1970	$23.207	$54.579
United Kingdom	1975	$19.401	$43.324
Germany	1980	$26.137	$47.477
Netherlands	1980	$30.361	$55.022
Japan	1998	$41.277	$48.919

2.2.2 Modified threshold hypothesis

Combining the Threshold Hypothesis with the insights given by an Aristotelian perspective on the developing human being may lead to a new insight, namely, that after a certain level of income the quality of life no longer increases with further growth in the production and consumption of goods, but increases with efforts to meet the non-material needs of human beings. The point beyond which the quality of life does not increase with further material growth, but increases with growth in the non-material sense may be called the ‘material threshold’. This leads to the following hypothesis:

If, after having reached their material threshold, human beings aspire to grow mainly in the non-material sense, and if non-material needs are mainly met through non-material (mental, intellectual, spiritual) activities, further growth may not harm the environment.

This I call the **‘Modified Threshold Hypothesis’** or **‘Material Threshold Hypothesis’**. This follows Aristotle’s idea explained in section 1.2 that human beings need material wealth only insofar that they support their development of capacities in order to realise the ’good life’. This hypothesis allows us to rethink growth from material to non-material terms (Naastepad & Houghton Budd, 2015). However, it should be noted that the promise of this hypothesis will depend on the input-intensity of the non-physical economy. If the activities that create non-material value are met in more material ways (for example, when some of the human work of doctors and therapists are replaced with medicines and medical technologies, when creative tasks of teachers are replaced with digital learning technologies etc.) rather than in more non-material ways, then further growth in these activities may begin to pose a similar environmental burden like the production and consumption of goods. A review of the literature on how the non-material needs of human beings are currently met is presented in Chapter 3.

2.3 Support for the material threshold hypothesis

In this section I present some empirical observations to support the material threshold hypothesis as well as the philosophical assumption on which it is based. In order to empirically investigate the hypothesis that humanity as a whole may be developing from lower needs to higher needs or from material to non-material needs, I will try to classify economic activities based on the type of needs they meet and their nature of work.

2.3.1 Classification of the physical and the non-physical economy

The commonly found classification of economic activities in the literature are primary, secondary, tertiary sectors or in terms of their production of 'goods' or 'services' (Henriques & Kander, 2010; Suh, 2006). However, for my study, I choose to use the classification of the 'physical economy' and the 'non-physical economy' taken from existing literature, for example Naastepad & Houghton Budd (2015, 2019) who distinguish between the physical economy (goods-producing economy) and the non-physical economy (related to ideas, creativity, capacities), Baumol (1967) who distinguishes between production of goods and "personal services" and Keynes (1930) who distinguishes between the need for goods and the need for the "real values of life". There are two main reasons as to why I choose this classification and they will be elaborated in the subsequent paragraphs.

Using the United Nation's International Standard Industrial Classification of all economic activities (ISIC) Revision 3, I have tried to classify activities as either 'physical' or 'non-physical'. Activities that do not fall into either of the categories will not be included for my study. The ISIC, given in Table 2, is chosen because it is a widely used by researchers to report and analyse data on national accounts statistics, employment statistics, business demography etc. (United Nations, 1990). This system classifies economic activities into 17 sections in the first level and divides each of those into three more levels of sub-processes. However, for my study, the first level and to some extent, the second level of classification will be used in order to collect compatible data across countries and environmental indicators for the empirical analysis in Chapters 4 and 5.

Using Table 2, I classify economic activities as 'physical' or 'non-physical' based on two points of differentiation. The first is their **purpose** or the type of human needs they meet. Economic activities that meet people's material needs such as food, shelter, clothing etc. are considered to be the physical economy, or the goods-producing economy, and those that intend to meet people's higher, non-material needs, or the "real values of life" (Keynes, 1930) such as studying philosophy, enjoying a cultural dance performance etc. are considered to be the non-physical economy (Naastepad & Houghton Budd, 2015, 2019).

'Agriculture', 'fishing', 'mining', 'manufacturing', 'electricity & water supply' and 'construction' are categorised as belonging to the physical economy as they produce goods such as food products, industrial products, energy products etc. that help to meet human material needs or the lower needs of Maslow's pyramid (Naastepad & Houghton Budd, 2015). Here, it should be noted that not all of the goods produced by these economic activities need to be consumed in their final form by human beings. For example, mining includes the extraction of non-renewable resources such as petroleum and natural gas, which cannot be consumed by people directly. However, these goods are essential for the generation of electricity which serves human physical needs such as warmth, light etc. in buildings that act as shelter. Other activities like 'trade', 'accommodation & food services', 'transportation & communication', and other services that are directly related to the production of goods are also included in the physical economy. For example, if a yoga ashram uses a building, the building, including inputs such as 'electricity & water' for operation and maintenance (this in turn may require inputs from 'mining') and 'accommodation & food services' for the stay and food (this may again require input from 'agriculture') serves a physical need (shelter, warmth, light and food for yogis). Even if the yogis are in the pursuit of enlightenment (a non-material goal), their bodies still need certain amounts

Table 2: ISIC Rev.3 classification of economic activities. **Reference:** United Nations (1990)

Section	Economic activity	Description	Type of needs met
A	Agriculture, hunting and forestry	Growing of crops, farming of animals and related activities	Meets material needs
B	Fishing	Operations of fish hatcheries, fish farms	Meets material needs
C	Mining and quarrying	Mining of coal and metal ores, extraction of crude petroleum	Meets material needs
D	Manufacturing	Manufacture of food products, textiles, wood and paper products, chemical and pharmaceutical products, plastics, machinery and equipment, transport equipment	Meets material needs
E	Electricity, gas, & water supply	Production, collection and distribution of electricity, gas, steam and water supply	Meets material needs
F	Construction	Site preparation, building of constructions	Meets material needs
G	Wholesale and retail trade	Wholesale and retail of agricultural goods, household goods	Meets material needs
H	Hotels and restaurants	Short stay accommodation, bars, canteens	Meets material needs
I	Transportation, storage and communications	Land, water, air transport and supporting services, courier activities and telecommunications	Meets material needs
J	Financial intermediation	Banking, insurance	Not-included
K	Real estate activities, renting and business activities	Real estate activities, renting of transport and machinery equipment, computer consultancy activities and advertising	Not-included
L	Public administration and defence; compulsory social security	Administration of the State, defence activities, public order	Not included
M	Education	Primary, secondary, higher and adult education	Meets non-material needs
N	Health and social work activities	Hospital activities, medical and dental practice activities and social work activities	Meets non-material needs
O	Other community, social and personal service activities	Recreational, cultural, sporting activities and some sanitation activities	Meets non-material needs
P	Private households with employed persons		Not included
Q	Extraterritorial organisations and bodies		Not included

of food and shelter. This is how the physical economy serves the non-physical economy. The physical economy meets our material needs, thus enabling us to pursue non-material goals in the non-physical economy.

Further, there are three main activities that are classified as non-physical, namely, ‘education’, ‘health care’ and ‘other community, social & personal service activities’ (consists of fine arts and recreation) in the sense that, for example, a doctor’s advice or a teacher’s lesson or an artist’s performance meets a non-material need or the higher needs of Maslow’s pyramid. These activities can be a source of knowledge, consciousness and creativity to help human beings develop their capacities to realise their ’good life’ (Naastepad & Mulder, 2018) or to pursue the "real values of life" (Keynes, 1930). Here, it becomes important to justify why health care activities are included in the non-physical economy. If one views the human being as mainly a body which needs ’repair’ when it is ’broken’, one may think of health care as meeting a material or a physical need. But if we see the human being as a being who is longing to grow in knowledge, understanding, morality and so on, (based on Aristotle’s perspective of a human being) the body is the vehicle of the soul and spirit and the goal of health care is to enable the soul to carry out its tasks in life (Skidelsky & Skidelsky, 2012). It is only based on the latter view that health care is categorised as meeting a non-material need.

Activities such as finance and insurance activities, real estate activities, professional and technical activities will not be included because they cannot be clearly classified as either material or non-material. They may be non-physical in the sense that they do not produce material goods as output but they may not meet human psychological and spiritual needs that correspond to the higher levels of Maslow’s pyramid. Activities of households and extraterritorial organisations will also be left out since they are undifferentiated.

A second important differentiation between the two types of economy are in terms of their **potential for productivity growth**. In the production of goods (manufacturing, agriculture) and services that support the production of goods (trade, transportation), there is a much higher potential for productivity growth than in the non-physical economy (Baumol, 1967). This will be illustrated in section 2.3.2. This difference is mainly because of the nature of work in the two kinds of economic activities. In the physical economy, human labour is mainly instrumental, an input into the production process that may be reduced by labour saving innovations, without loss of quality (Baumol, 1967). On the contrary, in the non-physical economy or "personal services", human work is itself generally the final output of activities which means that the quality of output depends directly on human work (Baumol, 1967). For example, if a consumer purchases a mobile phone (an output of the manufacturing sector), (s)he will be indifferent as to how much labour went into it as long as the quality and price are fine. But when it comes to doctors, teachers, scientists, artists, this may not be the case, because the quality of the service will depend greatly on the quality of the person providing it (Baumol, 1967).

This criterion for classification has two important remarks. Firstly, the use of the word ‘service’. It has become common to classify all activities other than the production of goods as ’services’. However, in the classification proposed in this thesis, I distinguish between services related to the physical economy (for example, telecommunications), where it does not matter too much who is providing them as long as the output is of the desired quality, and the creation of non-material value, or "personal services" as Baumol (1967), including education, research, health care and the performing arts, where it matters a great deal who is providing them. A description of the significance of human work in these activities to meet people's non-material needs is presented in Chapter 3. Secondly, my definition of the non-physical economy applies in particular to 'personal services', for example, doctor's advice, treatment by a physiotherapist or psychologist, or nursing in health care activities. Industries producing goods that are used in health care, such as medical technology or pharmaceutical products, can be classified as belonging to the physical economy. This is because in the production of medical products, labour is an input into the production process which to a relatively high degree could be replaced by machines, whereas in medical services, human work is itself the output.

2.3.2 The rising importance of the non-physical economy relative to the physical economy

If it is in the nature of human beings that they want to develop from material to non-material needs (refer section 1.2), one would expect this to become visible in a change of the structural composition of the economy. Vice versa, if the structure of the economy changes over time, this may reflect an evolution in the needs of the human being. As a first step towards understanding this relationship, I have investigated the relative significance of the physical and non-physical economy by comparing the demand for them, and labour productivity. Figure 6 shows two plots, namely, the physical and the non-physical economy as a share of GDP and the real GDP per capita (in 2013 prices) from 1948 till 2015 in the United Kingdom. From Figure 6, it is evident that with growing living standards in the last 70 years, the share of the physical economy has declined by almost half whereas the share of the non-physical economy has grown by almost 4 times. And this regards only a relatively short period of 70 years.

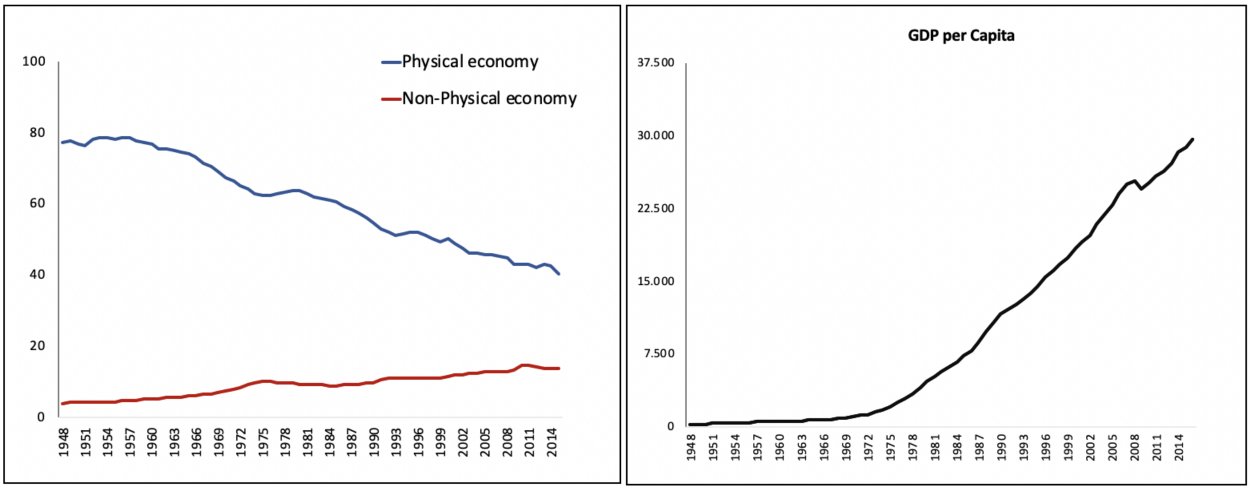

Figure 6: Share of the physical and non-physical economy in GDP and the real GDP per capita (in 2013 prices) from 1948 to 2015. **Country:** United Kingdom. **Source:** Bank of England (2020)

An economic explanation for the rising significance of the non-physical economy is the low income elasticity of demand for the goods produced in the physical economy and a relatively higher income elasticity for the activities in the non-physical economy. This means that with rising incomes, demand for higher quality health care services and higher education increases in order to improve quality of life (OECD, 2005; Schettkat & Yocarini, 2006). Although the income elasticity of the wider known 'services' (includes financial, real estate and social services) have been contested by studies (Gundlach, 1993), when health care, education, research and recreation (includes arts) are considered separately, the income elasticity is found to be elastic for health care and recreation and unity for education (Falvey & Gemmell, 1996). Therefore, it can be interpreted that with rising living standards, human beings tend to move from material to non-material needs.

Another explanation is the structural shift of employment from the physical to the non-physical economy. Due to the nature of the physical economy, technological progress over the years has improved the efficiency and productivity of its production processes. These developments can be measured using labour productivity which is defined as output to hours of labour. If we take 'λ' to be the labour productivity, 'y' to be the value added in real terms and 'h' to be the number of hours worked, we have,

$$\lambda = \frac{y}{h} \tag{1}$$

Figure 7 shows the rise in real value added and the total hours worked by persons employed in the Eurozone over the period 1970-2007 in the goods-producing economy.

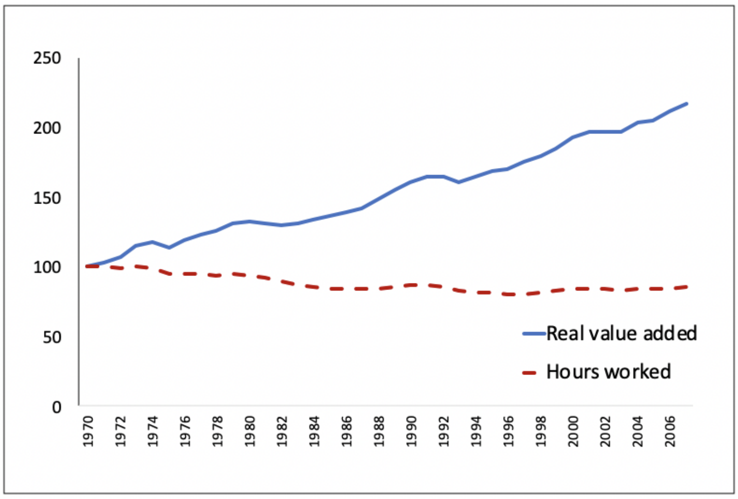

Figure 7: Total real value added and total hours worked in the physical economy in the Eurozone between 1970-2007. **Source:** EU KLEMS database. **Reference:** Naastepad & Mulder (2018).

It can be seen from Figure 7 that a person in 1 hour can produce 2,5 times more value in 2007 than what (s)he could in 1970 in the physical economy. Therefore, the number of hours of work required to produce a certain level of output has decreased and labour productivity (λ) has increased. Technological advancements that increase λ provide us with two options. One is to produce more goods at the same hours of labour and the other is to produce same level of goods with fewer hours of labour. This is called the productivity dividend (Schor, 1993). It can be inferred from Figure 7 that the productivity dividend has been used to produce increasingly more goods and at the same time reduce hours of work in the physical economy. This is not necessarily a bad consequence as workers are now being liberated from the need to perform highly demanding 'physical and routine mental labour' in order to meet people's material needs (Naastepad & Mulder, 2018). This freed up time for the workers can then be used by them to explore other opportunities and meet needs in the form of scientific or artistic developments (or what Marx called the "free development of their individualities") (Marx, 1858 [1993]) that are generally non-material in nature and lie outside the physical economy.

Since human work in the non-physical economy in itself creates non-material value, replacement of human work with labour-saving innovations is not as straightforward as in the physical economy. This is evident from Figure 8 which shows a similar plot as Figure 7 for such activities. The number of hours as well as the real value added have risen significantly for these cultural activities which suggests that labour productivity growth λ in the non-physical economy is low. Comparing the two plots (Figure 7 and Figure 8), it is evident that the freed up time for the workers in the physical economy are being used to support the growth of the non-physical economy (Naastepad & Mulder, 2018).

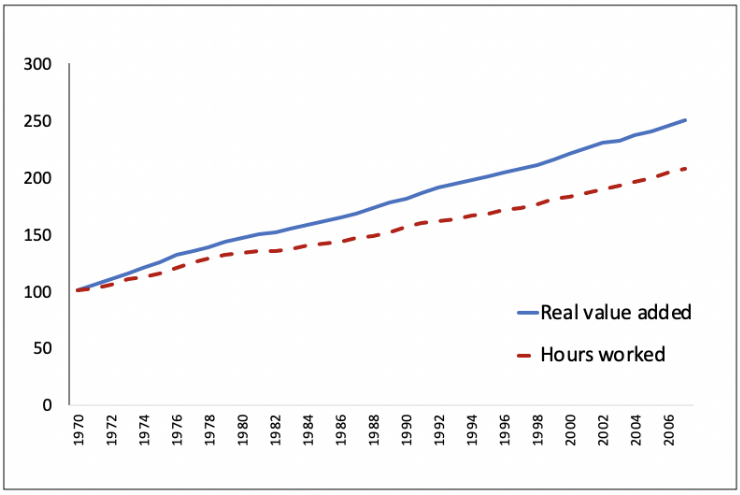

Figure 8: Total real value added and total hours worked in the non-physical economy in the Eurozone between 1970-2007. **Source:** EU KLEMS database. **Reference:** Naastepad & Mulder (2018).

As mentioned in section 2.3.1, the higher needs of Maslow's pyramid or the non-material needs of human beings are generally met by the non-physical economy. Therefore, these structural changes may reflect that human beings are, in fact, climbing up Maslow's pyramid by pursuing higher needs that are generally non-material in nature. Although the plots shown above can be taken as evidence to a certain extent, it is not in my thesis to prove this development of human beings further. In the following chapters, I will only be investigating the effects of such a development from an environment point of view, that is, if the creation of non-material value is less intensive in material inputs, this structural change could help reduce pressure on the environment.

2.4 Chapter conclusions

Economic growth, which was earlier seen simply as a means to an end is now increasingly identified as an end in itself. But the resulting growth in GDP in all countries, and particularly well-developed countries in the world has not necessarily translated into better environmental welfare. In fact, other than the European Union, no other country is close enough to absolutely decouple GDP growth from carbon emissions and energy consumption. Based on the report by the IPCC, the earth may not be able to sustain the environmental burden with these current trends. Theoretical support to this with the 'threshold hypothesis' that argues that increasing economic growth may not enhance quality of life and the environment beyond a threshold was found. Using this hypothesis, I proposed the 'material threshold hypothesis' which refers to this threshold as a 'material' threshold and further growth beyond the material threshold in 'non-material' terms may not harm the environment.

In this context, the physical and the non-physical economy are distinguished based on their purpose and their potential for productivity growth (or nature of work). The purpose of the physical economy is to produce goods to meet material needs of human beings and its nature is such that human labour in its activities can easily be reduced with progress in technologies without affecting the quality of its output. On the other hand, the purpose of the non-physical economy is to meet the non-material needs of human beings and the nature of its work is such that the quality of non-material value created depends highly on human work. Based on this classification, some evidence of the development of human beings from the physical (material needs) to the non-physical (non-material needs) economy was shown using the rising significance of the share in GDP of the non-physical economy to that of the physical economy and a structural shift of employment from physical to non-physical economy.

3 Trends in the non-physical economy

This chapter explains that there are different ways to meet non-material needs, and that nowadays there exists a tendency to meet non-material needs in increasingly high-tech, material input-intensive ways, because this is believed to be an effective way of fighting the 'cost-disease', that is, the rising cost of services provided in the non-physical economy. However, concerns have been raised in the literature regarding possible negative effects of increasingly high-tech provision of 'personal services' (such as health care, education, artistic performance) on the quality of these services as well as on the environment. This chapter reviews the literature for what it has to say about possible effects of higher technology-intensity on the quality of services of health care and education— because one wouldn't want to hold back technological progress in the non-physical economy if technology significantly improves the quality of services (even, perhaps, when this implies bad news for the environment). This chapter is a prelude to Chapter 5, where the environmental effects of more and less material input-intensive ways of meeting non-material needs are discussed, measured, and compared.

3.1 Fighting the 'cost disease': Concerns regarding quality and environmental effects

A consequence of the nature of the activities in the non-physical economy is that they can be expensive. Figure 9 shows the rise in health care expenditures per capita in constant prices in the United states for the period 1970-2018. It is seen that health care expenditures have risen by 5 times in a span of almost 50 years. These rising costs can also be visible in education and performing arts (Baumol, 2012; Felton, 1994).

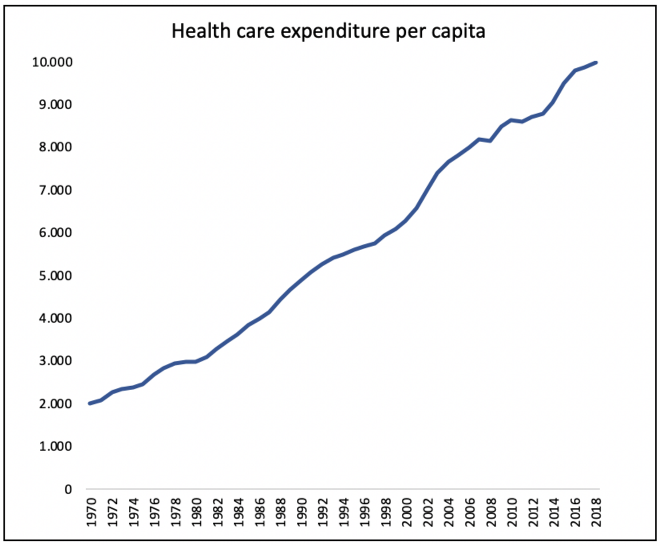

Figure 9: Health care expenditures per capita in 2015 prices. **Country:** United States. **Source:** OECD (2020a,b)

Baumol (2012) calls these rising costs in health care, education and performing arts the **'cost disease'**. He explains that the high growth of labour productivity (λ) in the physical economy allows for their corresponding labour wages to rise. This reflects in the market and as a result, the wages for human work in the non-physical economy will also have to rise. Since λ growth in the non-physical economy is low (as observed in section 2.3.2), their rise in wages cannot be compensated by driving more output and so the costs of these activities end up increasing. Evidence for the validity of this theory is found in various studies (Bates & Santerre, 2013; Felton, 1994). However, despite the rising costs in the non-physical economy, Baumol (1993, 2012) argues that the people in the rich parts of the world should be able to afford these activities. This is because the average rise in λ in an economy (high in the physical economy and low yet positive in the non-physical economy) increases the overall living standards of a society which means that people will get richer and will be able to afford more of everything (Baumol, 1993, 2012). These high costs can be supported if funds from the productivity gains in the physical economy (due to labour-saving innovations) are directed towards the non-physical economy (Baumol, 1993, 2012; Naastepad & Houghton Budd, 2015, 2019). This way, the creation of non-material value through human work in the non-physical economy to meet the non-material needs of the people could remain affordable and as mentioned in Chapter 1 and Chapter 2, could be less of a burden on the environment.

However, in reality, following the Neoclassical 'utility maximisation' view, funds from the productivity gains in the physical economy usually end up in financial markets seeking short term financial returns rather than using them to support the development of human capacities (Naastepad & Mulder, 2018). Since investment opportunities are limited in a shrinking physical economy as a share of GDP (as observed in section 2.3.2), these funds are also being *invested* in activities such as health care, research and education in search for greater returns (Naastepad & Mulder, 2018). When the habit of maximising utility or maximising profits travels beyond the boundaries of the physical economy, the human work in the non-physical economy, which according to Aristotle are sources of consciousness, creativity, intelligence and morality, gets treated merely as a cost to be minimised.

Human tasks in the non-physical economy are replaced with technological solutions in order to bring down the rising costs of its activities (Bain and Company, 2012; Naastepad & Mulder, 2018). Standardisation, computerisation and robotisation of hitherto human tasks are found to be some solutions to improve the productivity and efficiency of these activities (Naastepad & Mulder, 2018). Evidence of these trends will be presented in detail in the following sections. When doctors, teachers and artists are driven by monetary incentives, there may be conflict of interests which may affect the quality of their work (Lux, 1990). When profit maximisation becomes the goal in activities that support non-material value creation, Lux (1990) asks "should the doctor's purpose be to cure a patient or make money?". This brings to mind Baumol's (1967) warning that, when the non-material needs of human beings are met with technical solutions intended to keep costs low and improve productivity, then the quality of the non-material value created by them may not remain the same.

Apart from the impact of these technical solutions on the quality of the services that are provided to meet non-material needs, they may also end up increasing the pressure on the environment. Some of these trends lead to the production of more (material) goods and/ or (over-)consumption of goods as a way to meet non-material needs, in which case meeting the higher, non-material needs may also have a similar negative impact on the environment as meeting material needs. The bottom line is that the cultural activities that support one to fulfill one's higher goals are being treated in the same way as the physical economy even though they are very different by nature and if this persists, even these activities may become a burden on the environment.

3.2 Health care: Technical fix or "an art and a science"?

According to the World Health Organisation (WHO), the health of a human being "is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 2020). This means that there are different aspects to human health and is not just about 'fixing' what is 'broken'. What constitutes as perfect well-being for each human being depends on the understanding of what is needed for them to flourish (Skidelsky & Skidelsky, 2012, pp. 154–156). At the same time, the distinction between *curing* people who are sick and *enhancing* the ones who are already healthy needs to be made (Skidelsky & Skidelsky, 2012, pp. 154–156). According to Skidelsky & Skidelsky (2012, pp. 154–156), these judgments on human health need to be both objective as well as ethical; for "[i]f every state of the body can be seen as defective relative to some other, preferred state, then we are all in a sense perpetually ill". Unless we can arrive at some objective judgement, the "assimilation of medicine into the economic rat race ... where the demand for health is insatiable" will turn the world into "a vast hospital" (Skidelsky & Skidelsky, 2012, pp. 154–156), leading to an explosion of medical costs. Therefore, in order to make these judgements about the health of a human being, we have to become conscious of our objective needs. Based on these aspects, health care is understood as an activity of the non-physical economy that takes care of the health of a human being in order to enable him to develop intellectually and psychologically (meeting the needs of his soul and spirit).

Over the past century, there has been substantial progress around the world in helping human beings survive. Life expectancy of human beings has risen from an average of 28,5 years in 1800 to an average of 71 years in 2014, child mortality rates have fallen from an average of 36% of world population in the 1900s to just an average of 4% now (Roser, Ortiz-Ospina, & Ritchie, 2020; Roser, Ritchie, & Dadonaite, 2020) and diseases such as small pox, polio and measles which are associated with potential fatal complications have been mostly eradicated (Praderio, 2019). Today, health care is a highly significant activity as it takes up 10% of world GDP (The World bank, 2019b) with about 43 million health care professionals around the world working to enhance people's lives (Buchan, Dhillon, & Campbell, 2017). All these milestones have been achieved due to advancements in medicine and medical technologies, improved living standards, increased availability of food and increased access to education (Riley, 2001). It is safe to say that the world has achieved unprecedented progress in human survival.

Despite accomplishing major milestones in human survival, the general health of human beings in current times cannot be said to be very impressive, especially in the case of the United States which is one of the most developed countries. The United States spends almost 17,9% of its GDP on health care (the highest among all advanced countries) up from 12,1% in 1990 and just 5% in 1960 (NCHS, 2019). Health care spending per person, again the highest among all countries, was $10.739 in 2017 (NCHS, 2019). Despite such significant spending, more and more Americans are suffering from health issues. The prevalence of chronic illnesses [6] such as obesity has risen from 23% in 1990 to almost 40% in 2016 and diabetes has risen from 9% in 1990 to almost 14% in 2016 among the American adult

[6] Chronic diseases are conditions that last for a prolonged period of time, requires regular monitoring and affects quality of life. In many cases, it can also lead to death. Some of the most common are: Alzheimer's, addiction (alcohol and drug abuse), diabetes, depression, hypertension, arthritis, heart failure, cancer, Schizophrenia and other psychotic disorders, HIV/AIDS etc. (CMS, 2019)

population (NCHS, 2019). In 2017, it was found that almost 26% of American adults suffered from some form of mental illness (Johns Hopkins Medicine, 2020). A study also found that an American born after 1945 has a ten times higher chance of experiencing depression than one born fifty years prior to that (Lux, 1990). These are some disturbing evidence of the health of the American people. Why is it that, despite being the most technologically advanced country with one of the highest living standards (on average at least), their health is not excellent?

In current times, there is not much evidence of health care systems trying to reverse the rising trend of these chronic illnesses. In the case of obesity, health education to change the unhealthy lifestyles of Americans have not been very successful and physicians generally resort to bariatric *surgery* (to reduce the fat) when obesity begins to threaten a person's life (Hannah, 2014). Mental health issues are not usually an isolated problem and are found to be related to other illnesses (e.g. depression is associated with illnesses like heart disease, alcohol addiction etc.) (Hannah, 2014) and socio-economic problems such as unstable income, unemployment, the loss of meaningful work, or even the loss of meaning in a world where there is so much invention and innovation, but where "these novelties have failed to translate into broadly shared progress and the betterment of our overall civilization" (Giridharadas, 2018, p. 3). Yet, the most common response of health care systems on mental health issues is to treat its symptoms with drugs and a limited set of talking therapies rather than to deal with their root causes (Giridharadas, 2018; Hannah, 2014). Chronic illnesses, which impact almost 50% of the American population, are not ailments that can be simply 'fixed' in one go (Hoff, 2010). They require a holistic approach to care which involves serious changes in lifestyle, counseling and extended psychological and/or pharmacological consultations by physicians who know the patient well (Hoff, 2010). If considerable time and effort are not spent by the physician in understanding the patient's lived and experienced concerns, the condition could even become fatal. In the view of Saunders (2000), medicine or the practice of clinical judgements is both an art and a science where a physician performs many activities other than just applying his clinical or book knowledge such as enhancing the physician-patient relationship and reflecting on his knowledge of the patient and himself. Kaplan et al. (1989) conducted a study on the influence of physician-patient communication on the outcomes of chronic illnesses such as diabetes, hypertension, ulcers and breast cancer and found that more patient and less physician control in terms of questions and interruptions, more sharing of personal opinions by physicians and patients, and more communication of information to patients who seek it are all related to better health conditions reported during the follow-up. Another study by Stewart et al. (2000) found that the more a patient perceived a physician visit as 'patient-centered', the better was their health outcomes such as lower level of discomfort, improved mental health and fewer diagnostic tests and referrals to other physicians in the two months subsequent to the study. It is also found that physicians who express emotions in their non-verbal behaviour, for example, by spending less time reading a patient's chart and having more eye-contact and by showing more gestures such as head nods were perceived as favourable by patients (Roter et al., 2006). Therefore, interpersonal skills such as understanding, empathy and relational versatility developed over time by physicians and other health professionals are essential as these could be instrumental in detecting any kind of hidden symptoms (Dyche, 2007). This shows the significance of the role of physicians and the need for complex human interactions with patients in health care settings to provide care for human beings (Roter et al., 2006).

3.2.1 The ICT revolution in health care: do standardisation and automation lower costs and improve the quality of health care?

In recent times, advances in health information technologies have transformed the way physicians and patients interact with each other. The intensity of Information and Communication Technology (ICT) use in health care activities, which is the share of ICT capital to total capital, has increased from 0,03% in 1970 to 12% in 2005 (Pramudita, 2015). This rise in technology-intensity can be attributed to a few drivers. The first one is the privatisation of health care and the commercialization of the pharmaceutical industry. In section 3.1, I briefly explained that the funds from the productivity gains in the physical economy are being *invested* in health care as a way of maximizing financial returns. Bain and Company (2012) even makes this obvious with their headline "To win in a *shifting profit pool*, companies need to improve how healthcare is delivered". When ‘free market’ values like competition and profit-maximization were initially introduced, they were justified as a way to bring down the rising health care costs in America (Bain and Company, 2012). However, the statistics on health care spending over time show that their costs have not come down. In fact, as mentioned above, health care spending per capita in the United States is the highest among all developed countries. Two of the many contributing ’free market’ factors to increasing health care costs have been identified as a "technology arms race" between hospitals and direct-to-consumer advertising of medicines and medical technologies (Koshy, 2015). These two factors are chosen for my study because they are also identified as the trends that increase technology-/ material-intensity in health care activities. Further explanations on the impact of these two factors on the quality and costs of health care will be presented in the forthcoming paragraphs.

A second driver of rising technology-intensity in health care is today’s systems of ’Managed care’ that initially aimed to reduce its rising costs. In such systems, the services provided by hospitals and the compensation for physicians are generally controlled by insurance companies through government regulations to prevent wasteful health care services (Bhattacharya et al., 2013; Feldstein, 2007). But over time, hospitals and physicians got together to form larger groups to demand higher payment from the insurance companies which led to loosening of cost control (Feldstein, 2007). This made Managed Care insurance companies to focus on innovative ways to control costs through the adoption of *computer information systems* in hospitals for doctors to back up all possible tests and treatments (Feldstein, 2007). This has led to an enormous administrative burden and their associated costs (Feldstein, 2007). Today, spending per capita on health care administrative costs in the United States is $2500 which is considered the highest among all developed nations (Abrams, 2020). ICTs are generally used to *standardize* reporting of patient data to facilitate billing, monitoring of quality and for other managerial purposes (Hunt et al., 2017). Now, all of these administrative activities require computers and the latest software technologies. It may be argued that administration would be even more expensive if it had to be done without computers. But it is also possible that ICT itself induces huge administrative systems, simply by making them possible.

Finally, policies such as the American Recovery and Reinvestment Act (ARRA) of 2009, signed by former President Barack Obama that allocated $19,2 billion towards the incorporation of health information technologies in health care facilities (Howell, 2009) could also be considered a driver for their widespread adoption in recent times. In sum, all these drivers promote the nation-wide transition to high-tech health care. But does the adoption of such technologies actually reduce health care costs and improve the quality of care provided?

Today, software technologies such as Electronic Health Records (EHR), Electronic Medical Records (EMR) and Clinical Decision Support Systems (CDSS) have become common in health care centres (Y. Chen et al., 2013; Frey & Osborne, 2017). EMR or EHR systems are typically used to digitise traditional paper charts of patients which can in turn aid physicians in tasks such as communication, administration, coordination and even decision support (Hillestad et al., 2005). In the United States, 86% of all office based physicians had adopted an EMR or EHR system in 2017, almost twice as much as in 2006 (NCHS, 2019). The CDSS are computer systems that aid physicians in decision making tasks for each individual patient at the point of care, allegedly as a way to improve patient safety and reduce medical errors. In electronic prescribing (e-prescribing) systems, which is a computer system that allows physicians to create and send prescriptions electronically to pharmacies (Zadeh & Tremblay, 2016), the software has in-built decision support to alert physicians about potential prescribing errors (Lyell et al., 2017). In 2018, almost 73% of health care professionals and 99% of pharmacies adopted e-prescribing technology (Surescripts, 2019). The common idea among these healthcare information technologies is to replace some of the tasks performed by physicians or doctors. The creative and analytical work (or the art of medicine as viewed by Saunders (2000)), to make value judgments and diagnose based on each patient's unique conditions, comes from years of development and expertise of clinical knowledge. Yet, these new information technologies readily displace these tasks (Carr, 2015). During patient visits, physicians are increasingly found to be working on computers by "closing pages, clicking check boxes, and typing notes—stopping only for the briefest of physical examinations before returning to the computer" (Hunt et al., 2017). Hoff (2011) suggests that the automation and standardisation of tasks using these information technologies could result in 'physician deskilling' which includes 'decreased clinical knowledge' due to their reliance on the decision making ability of these software. He also found that physicians are not entirely comfortable with these technologies. The inflexibility of the EMR systems due its fixed templates for the entry of patient data consumes a lot of the physician's time during a patient's visit (Hoff, 2011; Hunt et al., 2017). Additionally, the 'cut and paste' option provided by these systems compels physicians to enter generic comments owing to time restrictions which makes it difficult for one to make an informed decision (Hoff, 2010, 2011). The use of this feature can also lead to redundant and inaccurate documentation of patient data (Hoff, 2010). In e-prescribing software, physicians have reported concerns about prescribing the wrong drug or wrong dosage because of the software's poorly designed drop-down menus (Zadeh & Tremblay, 2016). From a patient's perspective, the use of these health information technologies by physicians reduced their time spent for intimate interactions such as listening and questioning (Hoff, 2011; Rouf et al., 2007) which can be disruptive to the physician-patient relationship (Y. Chen et al., 2011). A study found that physicians spend 54% of the time on EHR systems during a patient's visit (this included time spent on the particular patient's EHR prior to the patient's visit, during and after hours) (R. A. Young et al., 2018). There is also no strong evidence till date that the use of these technologies improves the well-being of patients (Carr, 2015; Overton, 2020). For example, Yanamadala et al. (2016) found that the patient outcomes after surgical procedures, in terms of complications, was the same between hospitals that use EHR systems and ones that do not.

Not only has the quality of care not significantly improved, conclusive evidence of reduced health care costs due to technology adoption is also not widely found. In fact, some studies have found that these technologies have increased overall health care costs for patients (Callahan, 2017; Koshy, 2015). This is because, in many cases, most of these software end up ordering more tests (most of which are expensive) due to its standardised approach to health care delivery. A study found that the likelihood of a physician to order a diagnostic imaging test is 40%-70% more when he has access to EMR systems (Mccormick et al., 2012). Another study found that physicians who used an EHR system ordered more blood count tests, Computerized Tomography (CT) tests and X-rays than physicians who did not use an EHR system (Hakim et al., 2017). Overton (2020) found that the use of EMR systems also doubled the administration of medication besides increasing the number of Electrocardiograms (ECG) and laboratory tests performed and lowering patient satisfaction. All these extra drugs and unnecessary testing leading to higher overall spending with relatively poor patient satisfaction are all one aspect of the unintended consequences of healthcare information technologies. Another important aspect, which is not commonly focused on is the additional environmental burden from the direct use of these information technologies and indirect impacts from its unintended consequences. A more detailed analysis of this will be presented in Chapter 5.

Besides standardisation, adoption of automation and robotisation in health care practices is another trend that is observed more and more nowadays. McKinsey Digital (2013) finds that artificial intelligence, machine-learning and advanced robotic technologies will be applied in diagnostics, drug discovery and robotic surgery in the coming years. It even discusses next generation genomics that can 'extend and enhance lives' with newer drugs. 'Tele-health' technologies, now quite common, makes use of ICT to provide long-distance health care services such as consultation, therapy, diagnosis, review and education to patients. This has shifted the traditional face-to-face relationships between doctors and patients to the internet in order to make services more accessible and instantly available to people (J. D. Young et al., 2018). It is reported that 52% of consultations by one of America's largest health care providers, Kaiser Permanente, were conducted virtually in 2016 (Owens, 2018). 'Tele-presence' workstations have been developed to allow operating surgeons to perform surgeries on physically remote patients (whether in geographically distant areas or within the same operating room) by recreating and amplifying the motor, visual and sensory movements of the surgeon like performing an actual open surgery (Lenoir et al., 2002). It is expected to increase the speed, reduce errors and reduce the number of health care professionals inside an operating room (Lenoir et al., 2002). In 2017, 2.862 robotic platforms were installed in the United States which constitutes 65% of the total number of robotic platforms installed globally. The number of robot-assisted surgical procedures in the United States and few other countries have risen by more than 10 times in the period from 2006 to 2018[7] as shown in Figure 10. It is also found that the adoption of such robotic systems encourage surgical rather than non-surgical ways of treatment due to direct-to-consumer advertising of these technologies (further explanation in the next section) (Koshy, 2015). Advances in Natural Language Processing (NLP) capabilities combined with the objective of cost reduction have resulted in the development of intelligent text based synchronous counselling chat boxes for a range of mental health issues such as depression, anxiety, addiction and eating disorders (Hoermann et al., 2017; Peters et al., 2019). The development of an artificial intelligence based diagnostic supercomputer by IBM named 'Dr. Watson' will supposedly help physicians with complex decision-making tasks, treatment plans and one day even

[7] This is specific to the family of Da Vinci surgical systems that consists of a Surgeon's console, patient-side cart etc. manufactured by Intuit Surgical Inc. Some examples of surgical procedures that use this system are Hysterectomy, Sacrocolpopexy, Prostatectomy, Hernia Repair, Mitral Valve Repair, Transoral Surgery etc. (Intuit Surgical Inc., 2019)

could even replace them (Brynjolfsson & McAfee, 2016; Cohn, 2014).

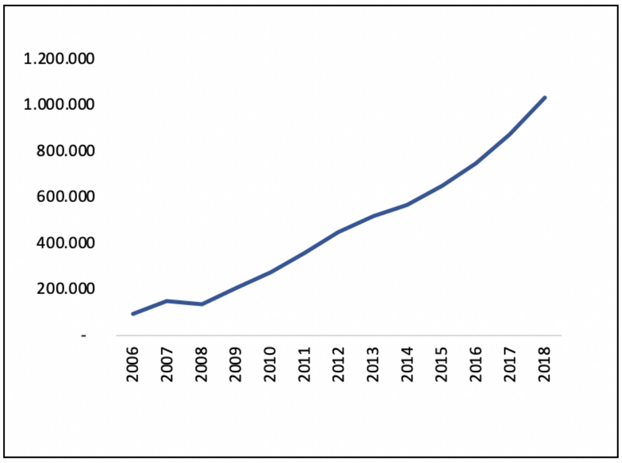

Figure 10: Number of surgical procedures performed using Da Vinci surgical systems. **Source:** Intuit Surgical Inc. (2019)

Such extent of technological advancements, some of which look like they are out of a science-fiction movie, are certainly not without some benefits. Decreased blood loss during surgery, shorter hospital stays and cosmetic benefits due to its minimally invasive procedures are found to be some of them (Hussain et al., 2014). However, a study conducted by Reza et al. (2010) found that the benefits of robotic surgery were mostly short-term with no big impact in its long term benefits when compared to regular surgical procedures. They conclude that for the cost of acquiring, using and maintaining, the clinical benefits of robotic surgery on patient outcomes (such as complications or long term benefits) are not very different to that of regular surgical procedures. Another study finds that if robotic procedures completely replace traditional surgeries, it would create an added cost of about $2.5 billion every year (Barbash & Glied, 2010). Koshy (2015) also determines that investment in costly medical technologies by hospitals and physicians leads to overconsumption of medical services. Due to the introduction of free-market objectives like competition, hospitals tend to compete on the latest medical technologies in a "technology-arms race" in order to attract more patients (Koshy, 2015). Since the latest technologies are expensive, hospitals need to use them a lot to cover the high costs which lead to unnecessary treatments and high costs for patients. It was found that the higher the investment of hospitals on medical technologies, the higher was the expenditure per patient (Koshy, 2015). The overuse not only leads to unnecessary expenditure but also exposes patients to potentially harmful health outcomes such as cancer. A study predicts that if CT scans are continued to be overused (for example, as a result of the use of EHR systems or other factors such as physician's remuneration methods or marketing strategies (discussed in section 3.2.2)) without any intervention, it will lead to at least 2% of all imminent cancers (Consumer Reports, 2015). Besides this, an important consequence of these technologies is on the skills of physicians and surgeons. Carr (2015) discusses how radiologists could be prone to overlook any other abnormality, when software technologies like computer-aided detection and diagnosis systems 'prompt' areas of potential tumors or cancers. This could even turn fatal for the patient. On the other hand, such 'prompts' have also been found to give considerable false positives, compelling the radiologist to recall patients for a biopsy (a test that may lead to unnecessary complications for the patient)(Carr, 2015). A study found that if the system's outcomes on mammograms are accepted without any overlook, almost 80-90% of breast cancer patients would have to be recalled (Philpotts, 2009). Another study conducted by Lyell et al. (2017) with final year Australian students in a controlled setting found that the use of e-prescribing systems with in-built decision support lead to the risk of an automation bias with acceptance of false positive alerts and failure to detect prescribing errors. According to Carr (2015), if surgeons and physicians continue to depend on the recommendations from a computer code, they may lose their tacit knowledge (knowledge that has been acquired over time but difficult to be codified) and reflexes which may indirectly affect their diagnostic and problem detection skills. Earlier, surgeons had autonomy to a great extent in operating rooms and could improvise and adjust procedures to suit each unique patient through the complex process of "internalization, reasoning and imagining" (Lenoir et al., 2002). But today, the surgeons are merely 'operators' of these technologies. They no longer have the *necessity* to be experts at medicine (Carr, 2015) because surgeries that were considered complex before (e.g. cardiac bypass surgery) have become 'routine' today (Lenoir et al., 2002).

In conclusion, the ICT revolution, in terms of standardisation, automation and robotisation has transformed how health care is delivered today. The technologies, as explained above, threaten the creative and cognitive skills of doctors without any significant evidence to prove that they improve the quality of care provided. The lack of robust evidence that the higher technology-intensity in health care has reduced costs and improved quality is in line with observations of a more general, system-wide "productivity paradox" which is the slow-down in productivity growth despite the rapid increase in the use of ICTs, especially in the non-physical economy (Brynjolfsson, 1993; Nordhaus, 2006). Above all, these technologies, besides their environmental impact in terms of energy use and material use, can result in redundant testing and higher dispensation of drugs which could further create an unintended environmental burden.

3.2.2 Other trends in health care: growth without benefit?

'Too much medicine' or 'overtreatment' are other recent issues related to the provision of unnecessary health care services with potential harm to people and no significant benefits (Hensher et al., 2017). 'Too much medicine' leads to increased GDP growth without improving the value provided to people. For example, a study by Welch & Passow (2014) finds that when women undergo a mammogram annually from the age of 50 for a decade, among 1000 women only 0,3 to 3,2 women will avoid death from breast cancer, 3 to 14 women will be over-diagnosed and over-treated and 490 to 670 women will have 1 false alarm at least (out of which 70-100 will get a biopsy). From the health care provider's side, some of the factors that lead to 'too much medicine' are the role of payment systems, supplier-induced demand and over-use of medical technologies ("the technology-arms race" discussed in section 3.2.1) (Hensher et al., 2017). In the United States and in a few other developed countries, for a long time, a 'fee-for-service' payment model has been the most dominant financing method for doctors. As the name suggests, doctors are paid per patient visit with a separate fee for each service provided to the patient. Doctors have a 'financial' incentive to see more patients and provide more services as a way to increase their income (Barnum et al., 1995). Although the Affordable Care Act of 2010 advocates physicians to give more attention to quality of care (fee-for-value) rather than quantity, it was reported that 86% of physicians were still being paid under the fee-for-service payment model in the Unites States in 2016 (Pearl, 2017). Gosden et al. (1999) found that doctors working under a fee-for-service model were more likely to have higher volumes of consultation and tests ordered along with lower patient satisfaction than doctors working under a 'salaried' payment model (Gosden et al., 1999). Rich et al. (2013) discuss the case of CT scan overuse in the case of acute lower back pain. When the physician's rewards are attached to the order of these tests, he will make himself accessible to patients with lower back pain and may even invest in marketing to encourage patients with these symptoms to seek help. In the case where there is no reward attached to the order of these tests, physicians tend to recommend treatments that would satisfy the patient's expectations in order for them to return to him in the future (Rich et al., 2013). Other examples include electroencephalograms (EEG) for patients with a headache or inserting cardiac stents for patients who have a fairly stable cardiac health conditions (Koshy, 2015). As mentioned earlier, when hospitals compete with one another in terms of expensive medical technologies, unnecessary treatments get pushed on patients through doctors which, combined with the fee-for-service systems, leads to higher rewards for both hospitals and doctors (Koshy, 2015). These incentives allow hospitals and health care professionals to create a 'supplier-induced demand' for medical technologies and drugs among patients (Barnum et al., 1995; Hensher et al., 2017). These recent developments of 'too much medicine' may become visible in the changing technical coefficients in I-O tables for health care activity over the years, especially coefficients associated with the industries that manufacture medicines and medical technologies for health care. These developments along with the rise in ICT in health care are empirically investigated using the EE-IO analysis in Chapter 5.

Another issue closely related to 'too much medicine' that also tends to meet non-material needs such as health and well-being in a material input-intensive way is 'pharmaceuticalisation' (Hensher et al., 2017). Pharmaceuticalisation is described as the process that transforms every human condition into opportunities for pharmaceutical mediation or treatment with medical drugs (Gabe et al., 2015). This clearly suggests that there is a rise in solving complex human problems with simplistic technical fixes (Moncrieff, 2003). This is done by pharmaceutical companies with commercial interests along with physicians in some direct and indirect ways to maximise returns. A prominent example of pharmaceuticalisation is the Direct-to-Consumer Advertising (DCA) that is permitted by law since the early 1990s in the United States (also in New Zealand) (Gabe, 2014). Prescription drugs and the latest medical technologies that were earlier advertised to health care professionals alone, are now being directly marketed via television and press to 'consumers' (individuals who may or may not have health issues). The initial intention to permit DCA was to make people more aware about the available disease treatments so that they can take a well-informed decision along with their physician (Parekh & Shrank, 2018). However, most of these advertisements for drugs are found to overstate their benefits, understate their risks and fail to promote healthier lifestyles as an alternative to drugs (Parekh & Shrank, 2018). In 2015, it was found that drug companies spent $5 billion on prescription drug advertising (Robins, 2016), a nine-fold increase from just $55 million in 1990 (Wilkes et al., 2000). Connors (2009) found from a survey that 75% of physicians believed that DCA causes a patient to think that the advertised drug is more effective than what it is and this misunderstanding among patients pressurises physicians to prescribe the advertised drug. But what is shocking is that the advertised medical products do not necessarily have to be completely safe, approved by the government or lead to the reported health outcomes (Connors, 2009). For example, an advertisement by Pfizer's antidepressant 'Zoloft' (a Selective serotonin reuptake inhibitor (SSRI)) tells that chemical imbalance may be the cause for depression and a few other psychiatric diagnosis such as anxiety, Premenstrual dysphoric disorder (PMDD) etc.

and that Zoloft can correct it (Stange, 2007). However, there is still no clear evidence till date for an ideal 'chemical balance' in a brain. So what are these drugs selling? Connors (2009) even calls out pharmaceutical companies for "manufacturing disease". He refers to a marketing line of an over-active bladder medication named 'Detrol' that stated "to people annoyed by . . . frequent urges to use the bathroom" which attempts to mislead people with mild bladder issues to believe that they have a serious problem that needs to be treated with a drug (Connors, 2009). Aldous Huxley, a philosopher, is quoted to have said, "Medical science is making such remarkable progress that soon none of us will be well" (Frances, 2013). If every mild discomfort in human beings is called an illness or a condition, then almost everyone on this planet must be sick. This means that these marketing strategies that are used purely to maximise financial returns and increase the market share of companies can drive human beings into behaving like Neoclassical 'utility maximisers' even in the non-physical economy as they will demand more treatments for every mild discomfort like a consumer unsatisfied with his/her health (Koshy, 2015). However, this does not have to continue to be this way. Based on the Aristotle's perspective, we can end this blind pursuit of self-interested desires, at times influenced by forces such as advertising, by becoming aware of our true needs and 'educating our desires' (Skidelsky & Skidelsky, 2012).

3.2.3 Does ICT-intensive care lead to better health?

Health Information and Artificial Intelligence technologies such as EMR, EHR, e-prescribing, telehealth and robot-assisted surgeries have transformed health care systems not just in the United States but in almost all countries in the world. A 2019 survey by Philips (2019) finds that although the United States leads in the adoption of electronic health care records by physicians, countries like the United Kingdom and Australia are also catching up in this area. On the other hand, when it comes to the use of artificial intelligence technologies among health care professionals, the United States actually lags behind Germany and the United Kingdom (Philips, 2019). Among the developed and industrialised countries, various Government initiatives and policies to increase the adoption of these ICT technologies have been implemented. For example, in Germany, the 'E-health' Act of 2016 and the more recent "Digitale-Versorgung-Gesetz" (Digital Care Act) of 2019 were implemented to promote the development of EHR, tele-health services and health apps (Herberger, 2019). In the United Kingdom, a highly ambitious initiative called the National Programme for IT (NPfIT) was introduced as early as 2002 to centralise health care records of patients and provide complete e-prescribing technologies on a national level. This initiative, however, got dismantled in 2010 due to the technologies' failure to deliver expected clinical benefits along with a few technical and administrative issues (Justinia, 2016). Irrespective of the impact of these technologies on the quality of outcome, health care activities are getting increasingly more technology-intensive in almost all the industrialised countries[8].

From a brief overview of the status of digital health and artificial intelligence technologies in the largest advanced economies in the world, I found that Canada is one country where the adoption of these technologies has been relatively slow. Canada, which shares a border with the United States and has approximately $1/10^{\text{th}}$ of the latter's population, spends only 10,7% of its GDP on health care activities

[8]It is to be noted that health care in the developing countries are also getting technology-intensive. For example, 85% of health care professionals adopt AI in their practices in China, the highest among all countries (Philips, 2019). However, I have chosen to focus only on the highly advanced countries for this investigation.

(OECD, 2020b) (compared to 17,6% in the United States). The per capita health expenditures of the Canadian people are also half of that of the United States. One of the main reasons for the lower expenditures in Canada is because most hospitals are not-for-profit and most health care services are publicly funded by the Government (Koshy, 2015; Ridic et al., 2012). This is unlike the system in the United States where health insurance for medical services have to be purchased by the people from private insurance companies (a mix of for-profit and not-for-profit companies) except for a few groups who are insured by the Government (Ridic et al., 2012). Although there are various implications of these two types of health care systems for access, quality and patient satisfaction, two crucially different characteristics of the Canadian system is the restriction on competition between hospitals for a 'technology-arms race' to attract patients (Koshy, 2015) and the absence of direct-to-consumer advertising. Hospital spending on expensive medical technologies are limited through budget controls by the government (Ridic et al., 2012). This has resulted in a relatively lower availability of medical equipment than the United States. Some evidence of this is given in Table 3.

Table 3: Medical technologies. **Source:** OECD (2020b)

Measure	**Year**	**United States**	**Canada**
No. of CT scanners per 1 million population	2014	41	15
No. of MRI scanners per 1 million population	2014	38	9,5
No. of CT exams per 1 thousand population	2018	270	159
No. of MRI exams per 1 thousand population	2018	119	52

Table 3 shows that the United States leads Canada in all the measures by an average of 2,6 times. Budget controls on hospital spending, besides other technical, legal and regulatory barriers, have also impacted the adoption of digital health and robotic technologies in Canada (Christodoulakis et al., 2017). For example, in the case of robot-assisted procedures, since hospital purchases are controlled by the Canadian government, all the Da Vinci surgical systems in place in hospitals have been procured only through donor funded programs (Zorn et al., 2016). This is in contrast to the United States where most of the robot-assisted surgical systems are purchased by hospitals themselves (Zorn et al., 2016). When it comes to tele-health technologies, Canada again lags behind most countries. One of the reasons is that some of the companies that provide this facility are private and charge an annual subscription fee to patients which has been a point of concern for physicians as the idea of charging Canadians for medical services, albeit virtual, goes against their health care system's *universality* principle which states that health care must be provided to all Canadians irrespective of their ability to afford it (CBC, 2017). Another reason for the slow adoption of tele-health practices by physicians is that compensation for their digital consultations is reported to be limited as the government pays physicians on a fee-for-service basis that is primarily based on face-to-face physician-patient interactions (although this is slowly changing in recent times) (Canadian Medical Association, 2019). Table 4 presents a comparison between Canada and the United States on the state of adoption of some e-health technologies. It can be observed that technology-intensity in Canadian health care activities is lower than in the United States.

Is the lower adoption of ICT in Canadian health care negatively affecting their quality of care? The

Table 4: Trends in ICT adoption

Measure	Year	United States	Canada	Source
Percentage of primary care physicians using EMR/EHR	2015	84%	73%	(Mossialos et al., 2016)
Percentage of physician-patient interactions conducted through virtual means	2016	52%	0,15%	(Canadian Medical Association, 2018)
No. of Da Vinci robot surgical systems per 1 million population	2017	8,31	0,85	(Grant, 2017)

answer to this question is not very straightforward as there are various cultural, social and political factors apart from the health care system and rate of adoption of technologies that will affect quality of patient care. Besides, each country's health care system has its own set of advantages and disadvantages on patient outcomes, a review of which is beyond the scope of this study. Therefore, I will focus only on some relative health care indicators between Canada and the United States to assess their quality of care.

Although both Canada and the United States do not have the healthiest population when compared to Nordic and a few other European countries like Spain and Italy, The Commonwealth Fund (2017) ranked Canada two positions higher than the United States in terms of overall health care performance. Canada ranked better in terms of cost-related access to services and health outcomes such as infant mortality rates and adults over 18 years with at least two out of the five common chronic conditions[9] (The Commonwealth Fund, 2017). The United States had 2-6 times more number of avoidable hospital admissions per 100,000 population than Canada for chronic conditions like diabetes, asthma and heart disease (The Commonwealth Fund, 2017). An older 2007 survey found that a higher percentage of Canadians reported patient-centered care (e.g. in terms of time spent with the physician) and that Canadians with chronic conditions take fewer drugs when compared to Americans (Starfield, 2010). Koshy (2015) also found that having fewer medical equipment did not affect the availability of medical treatments and services to Canadians although some cases of delayed treatments and higher waiting times have been reported (Ridic et al., 2012; The Commonwealth Fund, 2017). Thus, there is not much evidence to suggest that the quality of health care in Canada has been compromised due to lower rate of adoption of ICT (this is solely based on the comparison with the United States). Based on these findings, it can be concluded that technology-intensive health care delivery is not an absolute necessity to improve quality of health care for patients.

3.2.4 Conclusion

From the review of literature on the technology-intensity of health care in the United States, it is found that health care is getting increasingly more technology-intensive. They are identified to be driven by free-market forces (or privatisation), the systems of Manged Care and governments to reduce the rising costs of health care in ways similar to reducing costs in the physical economy, namely by substituting human work with technology. However, since the nature of work in health care and their

[9]The five common chronic conditions are arthritis, asthma,; diabetes, heart disease and hypertension.

potential for productivity growth are very different from work in the physical economy (see section 2.3.1), concerns have been raised regarding to what extent it is possible to replace human work with technology without affecting the quality of the services provided, the knowledge and expertise of doctors, nurses, therapists and other providers of care, and the general level of health. It is also argued that, although these technologies intend to reduce health care costs, there is no conclusive evidence for it, which could explain the system-wide "productivity paradox" which holds especially for health care and other activities of the non-physical economy.

3.3 Trends in education and research: changing perspectives on the goals of education and the role of the teacher

In Aristotle's view, education is an activity that supports students (or human beings in general) to realize his or her potentialities (Collins, 1990). Teachers play a very significant role in this activity by being aware of the capabilities of each of their students in order to support the fulfilment of their capacities (Collins, 1990). This essentially means that the goal of teaching is to encourage students "to learn how to think in order to know" guided by a curriculum that enhances their intellectual and spiritual development (Collins, 1990). Bertrand Russell, a British philosopher, defines education as an activity that encourages students "to experience a sense of intellectual adventure in an atmosphere of open inquiry" (Hare, 2002). He specifies three elements essential to his idea of an ideal teacher. The first of it is 'kindliness' which is the quality of a teacher that creates a friendly relationship with the student and encourages him to appreciate learning and develop the art of questioning ideas. According to him, this is crucial for teachers to not perceive students as a means to some purpose (Hare, 2002). The second element is 'knowledge' which refers to the ability of the teacher to help develop in students the "pure delight" that comes from learning and acquiring knowledge without trying to *always* look for some benefit (Hare, 2002). The final element is 'courage' because teachers, apart from teaching lessons, can also have an impact on the character of their students (Hare, 2002). Hence, teachers are not mere machines who are just efficient, competent and proficient in their subjects but are also 'emotional' and 'passionate' human beings who bring joy, creativity and challenge to their students (Hargreaves, 1998). If human beings are thought of as comprising of a body, mind and soul, as mentioned in section 1.2, teacher-student relationships cannot be based on some blueprint (or on technology) as it will involve complex and dynamic interactions between two human beings (Collins, 1990) to instill curiosity, enthusiasm, sympathy, and morality in the student.

In this perspective, education is considered an activity of the non-physical economy that supports a human being to meet his higher, non-material needs to lead the 'good life'. However, since the 1960s, education is also considered to have an important role in economic growth through its contribution to the 'knowledge economy' (Gilead, 2015). In 1963, American economist Theodore Schultz stated that "the economic value of education rests on the proposition that people enhance their capabilities as *producers* and as *consumers* by investing in themselves and that schooling is the largest investment in human capital" (Carnoy, 2009). Gilead (2015) argues that this view of education has led to educational economists driven by economic goals to direct the curriculum of education which was hitherto performed by educational philosophers. Economic values of productivity, efficiency and financial returns in the realm of education has even led to the development of an 'education production function' which looks at a school as a production unit with inputs and a single measure of output, much like in the case of a manufacturing plant (Hanushek, 2020). The input measures include student characteristics, peer characteristics, community characteristics and school resources and the output measure is generally student performance or grade retention or some long term output like employment (Gilead, 2015; Hanushek, 2020). Rice & Schwartz (2014) discusses an overview of some trends implemented by policy makers to improve the 'productivity' of schools. They include increasing the pressure on schools and teachers by linking students' grades of some standardised tests to monetary incentives or school sanctions to improve efficiency, increasing pressure on schools to improve their performance in order to compete for the best students who can also bring in good funds and applying best practice approaches inspired from productive schools (Rice & Schwartz, 2014).

Among these trends, the most common in the United States is the 'pay-for-performance' model to motivate teachers to increase their efforts in order to improve student achievements. But are all teachers in it for the money? Lortie (1975) does not think so. He believes that the teacher's rewards are more personal or "psychic". Studies have also found that teachers generally do not enter the profession for monetary reasons and having a pay-for-performance model increases competition between teachers which could discourage good work (Moore Johnson, 1984). Not only is this model problematic with respect to teacher motivation, there is also not much evidence to prove that it has improved student outcomes. A case study conducted by Eberts et al. (2002) compared a school with a performance-based pay and a school with a traditional pay system (i.e. only based on years of experience and completion of post-graduation degrees) and found that although the pay-for-performance system had a higher course completion rate, student achievements in terms of grades and passing rates were lower when compared to the traditional system. A more recent study of New York city's public schools by Fryer (2013) found that these incentives, in fact, had a negative impact on student achievements (in terms of grades from mathematics and reading courses) in both elementary and middle schools and no impact on student attendance and graduation rates. Another recent trend is the adoption of 'common core standards' across schools (all levels) in the United states since 2009 which assess students based on standardised tests in order to get them ready for college and careers. A student who gets a benchmark score in these tests, most of which are multiple choice questions, is ideally 'ready' for college (Barnwell, 2016). On the one hand, this means that the students are viewed as mere customers who spend on education to get a "ticket" to better standards of living (Gupta, 2015). On the other hand, teachers find its curriculum to be narrow with inappropriate modes of instruction that could be detrimental to student learning (Barnwell, 2016). For example, before the standardised testing, a teacher in an English class would take days to teach works of classic literature ensued by a period of reflection and discussion on the subject. But with standardised testing, students are merely given portions of literature and made to answer questions based on them immediately with no opportunity for discussion or reflection (Greene, 2018). Most teachers also feel that the scores from these standardised tests are not useful to them to understand how a student thinks or learns (Barnwell, 2016; Greene, 2018). Although standardised testing is common in many countries, according to Sahlberg (2011) the Finnish education system has been one to not support standardisation of teaching and/or testing. In fact, teachers in Finland enjoy professional autonomy in deciding the school's curriculum and the form of student assessment and they are compensated based on their teaching experience and not on student performance (Sahlberg, 2011). This is why the teaching profession in Finland is valued even more than doctors and lawyers by their people. Despite not following the education systems of other countries, Finland still consistently ranks one of the highest among all the OECD countries in international student assessments since 2001 while United States ranks below the OECD average (Sahlberg, 2011). The example of Finland shows that the standardised testing and teaching adopted in the United States does not necessarily translate to better student performance. A crucial aspect of these standardisation trends in education is that they go hand-in-hand with the use of Information and Communication technologies. For example, Huseman (2015) reports how an American fourth-grader uses technologies such as Google docs on an iPad to summarise lessons in a common-core standardised class. Further discussion on the role of technologies will be presented in the next section.

Besides school education, higher education and academic science, which according to Aristotle is about knowing better or 'to know in a truer sense' (Himanka, 2014), are also getting commercialised (Berman, 2012; Bok, 2009). Since the 1970s, when scientific knowledge began to be considered as an important contributor to the 'knowledge economy' which in turn leads to economic growth through innovations, private industries established new forms of associations with universities (Irzik, 2013). Companies began to fund researchers to carry out research such as clinical tests for them, in which case the company has a huge stake in the research outcomes. This is particularly problematic because there exists a conflict of interest which could cloud the researcher's judgement in conducting and reporting the investigation (Berman, 2012; Bok, 2009). For example, British petroleum, an oil and gas company, granted $500 million to a group of researchers at the University of Berkeley to research alternative sources of energy to solve the climate crisis. But it is highly likely that the researchers will focus on solutions that are commercially viable and lucrative for the company and not necessarily on one that is the best alternative for the environment (Berman, 2012). When the academic community is driven by commercial and corporate interests, the notion of researchers engaging in curious science or knowledge that is socially or culturally highly relevant but not necessarily commercially interesting may get diminished (Feldman & Desrochers, 2004).

Therefore, the introduction of productivity, competition and monetary incentives for teachers and schools, the standardisation of education and the commercialisation of research activities are changing the views of what constitutes as good education and good pedagogy. If these trends continue, the goals of education according to Aristotle's view, which is to support human beings in realising their highest potentialities, may not get fulfilled. The next section explains how some of these trends are reinforced with the help of ICT.

3.3.1 The ICT revolution in education: Does technology adoption still support education to be a source of creativity and reflection?

Head (2014) explains how the principles of 'scientific management' or 'business process engineering', commonly found in the corporate world to improve labour productivity and efficiency through monitoring and control over workers, have entered the sphere of education and research. An example of this is the profit and loss statement generated for each professor at the Texas A & M university which evaluates the performance or quality of the professor by inspecting the difference between their annual salaries and the number of students along with the tuition fee and the amount of funds for research they have attracted (Head, 2014; Simon & Banchero, 2010). These principles of management and efficiency are embodied in intelligent ICT systems that are commonplace today in just about every activity (Budin, 1991) and the intensity of their use in education in the United States has increased from 0.4% to about 12% from 1970 to 2005 (Pramudita, 2015). Head (2014) refers to these systems as Computer Business Systems (CBS) that control, based on the goals of a number of stakeholders with vested interests, what teachers should teach and researchers should research (Naastepad & Mulder, 2018). For example, the Enterprise Resource Planning (ERP) software, SAP, develops software for higher education and research that embeds machine-learning algorithms to monitor and manage research ideas, their execution and outcomes, to plan and control salaries of 'employees' to drive better results, and to receive insights on student engagement and performance (SAP, 2020). This way, ICT converts teachers, researchers and students into mere numbers and codes that can be analysed for better outputs (Head, 2014), takes away their autonomy and decision-making capabilities and discourages their creative and original thinking (Naastepad & Mulder, 2018).

Besides taking control over the activities of teachers, ICT is also displacing some of their cognitive and creative tasks with the development of digital learning, computer-assisted teaching, computer-assisted grading software and online learning applications. In 2008, it was found that all public schools in the United States provided at least one computer with access to the internet per three students (NCES, 2018). One-to-one computing is a growing trend of providing a computing device such as laptops or tablets to each student from elementary to high school. The idea is to enable students to use these digital technologies in classrooms and at home to read, write, communicate and carry out research. The Maine Technology Initiative has been providing the State's middle school students with one-to-one access to wireless devices such as iBook laptops from its $37 million agreement with Apple in 2002 (Lei & Zhao, 2008). The Michigan's Freedom to Learn Initiative has issued laptops and other wireless devices to about 30.0000 students in its state (Lei & Zhao, 2008). It has become common among students in elementary schools to use iPads and middle and high schools to use all-in-one devices such as Google Chromebook and Microsoft Surface for learning in schools. The education Technology market, popularly known as EdTech, was worth about $8 billion in 2013 with online courses and testing and assessment software constituting the major share (A. Chen, 2015). Digital applications such as CodeMonkey and Flocabulary that creates games and educational songs respectively to enhance learning are common among American K-12 schools (Shulman, 2017). Molnar (2015) finds that the technology requirements associated with the common core standardised learning and testing has driven this increase in ICT use by students. Despite claims by policy-makers and EdTech companies that these technologies enhance student learning, a report by OECD (2015) finds that there has been no noticeable improvement in student performances from their exposure to education technologies. In fact, they find that students who use computers frequently in schools do much worse than ones who use computers rarely. Stoll (2000) argues that the most important thing in a classroom is a teacher and a set of motivated students and anything that separates them like educational movies, computers or instructional multimedia devices, although may appear fun to students, will diminish the learning environment. The educational technologies might look like they are teaching history or literature on the surface but underneath, Stoll (2000) believes that these technologies only teach students to look at the web for answers instead of asking their teacher or peers. This can make students lazy, emotionally detached and destroy social skills (Stoll, 2000). Employees of high-tech companies like Google, Apple etc. in the Silicon valley send their children to schools (for example Waldorf schools) where there are no computers or iPads in classrooms. This is because the parents know better than anyone else what digital education does with children. These low-tech schools instead teach students using the traditional blackboard with colourful chalk, provide books and encyclopedias and do not use standardised testing. These schools believe that teaching is a "human experience" and technologies cannot be a substitute for that (Richtel, 2011).

Computer-assisted instructions are some of the latest technological innovations which can adapt the lessons to the needs of each individual student based on real-time data capture of their actions (DreamBox, 2020). This way, DreamBox, which has developed an Intelligent Adaptive learning system, claims that their system can even act as a 'personal tutor' to its students sometimes even without the need for a human teacher (DreamBox, 2020). This is seen as a cost-effective alternative to traditional face-to-face teaching and learning. But will education, with the adoption of these technologies, continue to be a source of creativity and consciousness for human beings? Laura & Hannam (1991) argue how these technologies disrupt the deep and trusting relationships between teachers and students and make communication between them increasingly impersonal and mechanized. When students spend more time on computers and less time interacting face-to-face with teachers and peers, it could also inhibit their ability to cultivate trusting and loyal bonds in schools and in the wider society (Laura & Hannam, 1991). A study by Uhls et al. (2014) showed the importance of social face-to-face interactions by comparing two groups of preteens' ability to recognize non-verbal emotional cues in which one group spent five days without any access to computers or other forms of media at an outdoor education camp and another spent those days in a regular school. Based on pretests and posttests, it was found that the former group had a better understanding of those emotional cues than the latter (Uhls et al., 2014). This literature casts doubt on the increased use of ICT in classrooms as a substitute for traditional teaching tasks. Does it support the important values that educational activities are meant to support?

There has also been rapid progress in the transformation from face-to-face learning in universities to online environments where there is no more need for the teacher and the student to be physically present together. Massive Online Open Courses (MOOCs) are online courses that have been developed as a way to provide free access to higher education for students around the world who have a computer and access to the internet while cutting down on costs (Chukwuedo et al., 2019). Shah (2019) finds that in 2019, at least 13.500 online courses and about 30 online degrees were being offered as MOOC by more than 900 universities around the world. In 2019, the net worth of MOOC provider platforms like Coursera and Udacity went up to $ 1 billion through their partnerships with enterprises and universities (Adams, 2019; Businesswire, 2019). Machine-learning algorithms and Artificial Intelligence are primarily used in these environments to customise courses to the needs of each student (Frey & Osborne, 2017) and to provide interaction tools for students and teachers to enhance 'social learning'. Carr (2012) explains that one of the main motives of these features is to build an extensive behavioural database by tracking student's actions on the platform in order to gain insights on teaching and learning. Yet, there is no evidence of any regulatory oversight on the type and extent of data that is being mined from students (Carr, 2012). Apart from privacy concerns, there are also psychological implications on students from adopting these technologies. Russell (2005) discusses that the lack of physical proximity leads to a phenomenon called "distancing effect" where teachers will not be able to identify the emotional states of the students (e.g. boredom, misunderstanding etc.) or understand their well-being and questions, and to adapt teaching accordingly (Russell, 2005). This could cause psychological and emotional harm to students which could inhibit them from realizing his or her capacities (Chukwuedo et al., 2019). Studies have found that, on an average, only less than 10% of students enrolled in an online course complete it and some of the reasons to drop out were lack of motivation, feeling of isolation and presence of hidden costs (purchase of an expensive book recommended by professors in order to understand the course better) (Khalil & Ebner, 2014). Studies have also found that students had higher failure rates and lower grades on an average in online courses when compared to their performance in traditional classroom settings (Konnikova, 2014). Similar to health care, automation and robotisation are also other trends in development in the activities of education. For example, a 'Bot-teacher' named Botty which was developed by the University of Edinburgh could be considered one of the first attempts at automating teaching for MOOCs (Bayne, 2015). In an experiment, the bot was made to search for tweets with the hashtag #edcmooc on twitter and reply to those tweets with automated responses during an online course. The bot responded to 1.500 tweets from answers to simple questions on deadlines to slightly more complex tasks such as discussion of course content to some extent to even making social conversations like "That sounds wonderful, wish I was there" (Bayne, 2015; Havergal, 2015).

In conclusion, ICT technologies have penetrated another activity (i.e. besides health care) that is considered as a source of knowledge, consciousness and creativity and is supposed to support the intellectual and spiritual development of human beings. They have been found to displace the role of teachers in the educational activities by replacing creative and complicated human relationships with standardised 'routine' tasks, at the risk of inflicting psychological harm on students, teachers and researchers.

3.3.2 Conclusions

Education, according to Aristotle, is seen as an activity that supports the ability of human beings to flourish through the development of character in which the teacher plays a vital role by instilling curiosity, enthusiasm, courage, creativity and morality in the student. However, as seen from the recent trends of standardisation and ICT revolution in education and research, the modern teacher does not teach, nor educate, but merely guides the students towards information (found on internet and other sources external to the teacher). The role of the teacher is no longer to inspire, nor to make lessons and to determine the contents of teaching, but merely to tell the student where (s)he can find the necessary information, and how to process this information, in order to meet the requirements of (standardised) exams controlled by state educational bodies and commercial interests. Concerns are that this reduces the knowledge and experience of teachers, restricts the contents and societal relevance of education, and limits students' independent, critical thinking and commitment to solving pressing social and cultural problems.

3.4 Chapter conclusions

In this chapter, I reviewed the literature on the increasing technology-intensity of the non-physical economy. The activities of the non-physical economy such as health care, education, research and the fine arts have been found to experience Baumol's 'cost disease' due to their low labour productivity growth λ. Yet, it is argued that the high costs of these activities can be afforded by the people in the rich parts of the world if they can be funded out of the productivity gains that are continually generated in the technologically progressive physical economy. Despite no compelling economic necessity to lower costs in the non-physical economy, in reality, people seek to cut costs in these activities without paying much attention to the quality of their outcomes. This was found to be one of the main economic drivers for the introduction of standardisation, computerisation and robotisation to replace hitherto human tasks in the non-physical economy.

The activities of the non-physical economy, namely, health care and education were explored on two accounts, firstly- the goals of these activities from a philosophical perspective and secondly- recent trends of increasing technology-intensity or trends that support such growth of high technology-intensity in these activities. Health care is seen as "an art and a science" that takes care of the overall well-being of human beings and education is seen as an activity that supports one to develop intellectually and spiritually. A common similarity between the two activities, from a philosophical perspective, is the significance of the role of human work in meeting people's non-material needs; doctors in the case of health care and teachers in the case of education. Doctors are considered to be indispensable for their knowledge and expertise they possess to provide care for their patients and teachers for their knowledge and passion to bring creativity, enthusiasm and curiosity in students. However, recent trends show that doctors and teachers no more have high autonomy in deciding what is best for their patients and students respectively. Some of their creative tasks are slowly getting replaced with software technologies like digital health, digital learning etc. as a way to minimise costs among other economic reasons such as increasing productivity and competition. Several examples of these technologies in health care such as EMR, CDSS, e-prescribing, tele-health, robot-assisted surgeries and in education like one-to-one computing, computer-assisted instructions and MOOCs were presented. Despite the use of all these technologies in health care, there is no conclusive evidence to suggest that its costs have been minimised. In fact, a 'technology arms race' in health care activities in the United States was found to be one of the reasons to drive higher costs. Even if the economic goals (cost reduction, productivity) for which these technologies were introduced are not fulfilled, I looked into whether they at least offered substantial benefits to patients and students in health care and education respectively? Some of the studies reviewed in this chapter suggest that there has been not much improvement in the quality of outcomes of these activities in terms of patient satisfaction, long-term clinical benefits or performance of students. Other studies suggest that these technologies can threaten the goals of these activities as seen from the philosophical perspective because they can negatively affect the deep and trusting human relationships between doctor-patient and teacher-student which are considered vital in meeting the non-material needs of human beings.

4 Environmental impact of physical vs. non-physical economy

In Chapter 2, we saw that the non-physical economy has grown relative to the physical economy in terms of their shares in GDP over the last 75 years. As explained in Chapter 1, meeting the higher, non-material needs of human beings may be less polluting than meeting material needs. If this is so, the observed structural shift could help solve the environmental problems we are faced with today. The purpose of this chapter (and the next) is to investigate the direct and indirect environmental effects of the non-physical economy as compared to the physical economy.

This may require some explanation. If we compute only the direct environmental effects of the non-physical economy, this may lead to an underestimation of its total effects on the environment. For example, if a manufacturing industry produces a CT scanner for health care activities, and we look only at direct environmental effects, the environmental impact of this production process is attributed to the manufacturing sector. Only the environmental impact from the use of the CT scanner in hospitals will be assigned to health care activities. This is generally regarded as 'direct impacts' of each economic activity. Based on this example, it may be obvious that the manufacturing process may contribute more to global warming than the use of CT scanners (Williams, 2011). Evidence of these direct impacts is discussed in section 4.2.3. However, when seen from the sector of destination or sector of use, it may not be appropriate to blame the full responsibility of environmental burden on the activities of the physical economy. For example, if the health care activity did not demand for a CT scanner, the manufacturing industry would have no need to make the product, thereby generating a lower environmental impact. Therefore, it is also important to reallocate the responsibilities of environmental burden from sector of origin to sector of destination or sector of use (Kitzes, 2013) when computing the comparative environmental burden between the physical and non-physical economy. The result after this reallocation will reflect the direct and indirect environmental impacts of economic activities taking into consideration their respective input-intensities. To carry out this reallocation, an 'environmentally extended input-output analysis' is applied. Details of this method is explained in section 4.1 followed by its application to the economy of the United States in section 4.2.4.

4.1 Environmentally extended Input-Output (EE-IO) Analysis

Consider the purchase of a cotton t-shirt by a consumer. The t-shirt is manufactured from two main components- cotton fabric and packaging. The cotton fabric and packaging in turn have to be produced from cotton fibre and plastic respectively. Each of these again has a production process. A simplified illustration of inputs required to produce a t-shirt is given in Figure 11.

Each layer of input to produce the final product i.e the cotton t-shirt, will have its own environmental burden and the final environmental impact associated with the t-shirt must be computed by adding the impact of each production layer. The environmental impact of the top-most layer is considered the 'direct impact' whereas the impacts from the various other layers are referred to as 'indirect impacts' with regards to the purchase of the final product. In reality, there may be so many different production layers for goods that it may not be possible to track them all (Kitzes, 2013). For this reason, we can make use of an input-output table.

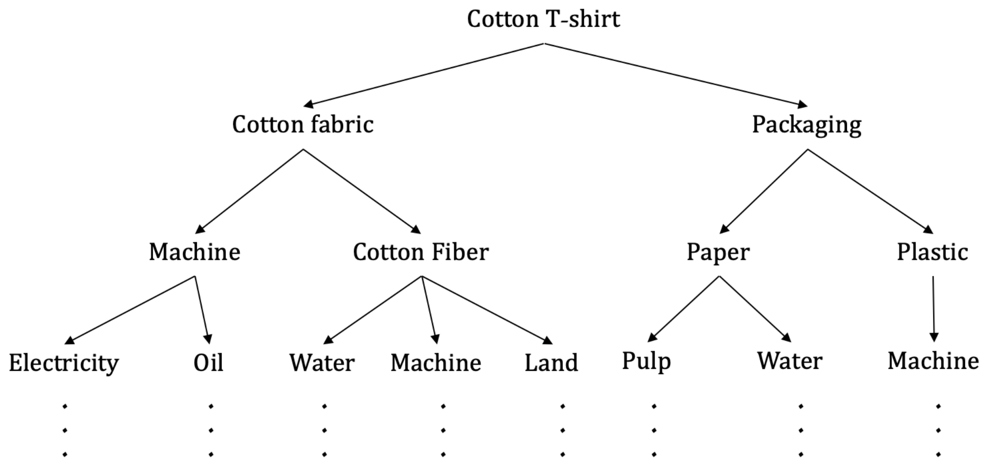

Figure 11: Cotton t-shirt production. **Reference:** Kitzes (2013)

4.1.1 Input-Output Table

An Input-Output (I-O) table represents the inter-dependence of industries or economic activities in an economy. The idea behind the table is that each industry in an economy both produces goods as 'outputs' to other industries and final consumers **and** consumes goods as 'inputs' from other industries (including itself) in order to produce its own output (Miller & Blair, 2009). Here, a distinction is made between consumption, which is the end use of something, and the use of intermediate inputs in production. For example, an output such as electricity is purchased by the manufacturing industry as an input to its production process (inter-industry) to produce a cotton t-shirt and at the same time, electricity is also purchased by households (final consumers) (Miller & Blair, 2009). The first I-O table was developed by Wassily Leontief in 1941 for the United States' economy. Presently, the table is constructed for all developed and some developing countries almost annually. This table can be extended to describe the environmental impacts of producing output from a particular industry taking into consideration the type and amount of inputs the industry requires from others to produce its output. Several studies have applied the EE-IO analysis for countries like Portugal (Cruz & Barata, 2008; Dias et al., 2014), Spain (Alcántara & Padilla, 2009), United Kingdom (Shmelev, 2010), Turkey (Tunc et al., 2007) etc. to find direct and indirect environmental impacts associated with household consumption, the service sector and trade with varying levels of detail in the classification of economic activities. Before going into the explanation of the table and the extended version of it, it is to be noted that the term 'industry' will be interchangeably used with terms 'sector' and 'economic activity' henceforth. Additionally, the table can usually be constructed for an economic area such as a country, region or state but I will assume the economic area to be a *country* as I am only interested in comparing the impacts of activities of the physical economy with that of the non-physical economy on a macroeconomic scale. The foundation for the input-output analysis is referred from Miller & Blair (2009) and its environmental extensions from Kitzes (2013).

Figure 12 shows the template of an Input-Output table with 8 industries. In reality, an economy can be divided into more than 400 industries or even smaller commodities depending on the level of detail in data collection. The dark-shaded portion is the 'main table' that contains the necessary information to describe the inter-industry transactions or intermediate sales. Each row shows how the output of an industry (as producer) is distributed throughout the economy. For example, the row for 'manufacturing' shows how the manufacturing industry provides its output to other industries (including itself) as inputs for further production activities and to end consumers such as households, government etc. as final demand (Miller & Blair, 2009). The sum of each row gives the 'total output' produced by an industry. Each column under 'producers as consumers' represents the inputs needed by an industry from other industries (including itself) and other non-industrial inputs (value-added) such as labour, indirect business taxes etc. to produce its output (Miller & Blair, 2009). The table is said to be balanced when total outputs produced by an industry is equal the total inputs to the industry (row sum = column sum). Although, the transactions in these I-O tables can be reported in physical terms (e.g. kilo joules of electricity sold to manufacturing and households), most databases choose to report them in monetary terms (e.g. the dollar value of electricity sold to manufacturing and households) in order to distinguish between the different types of outputs sold by an industry.

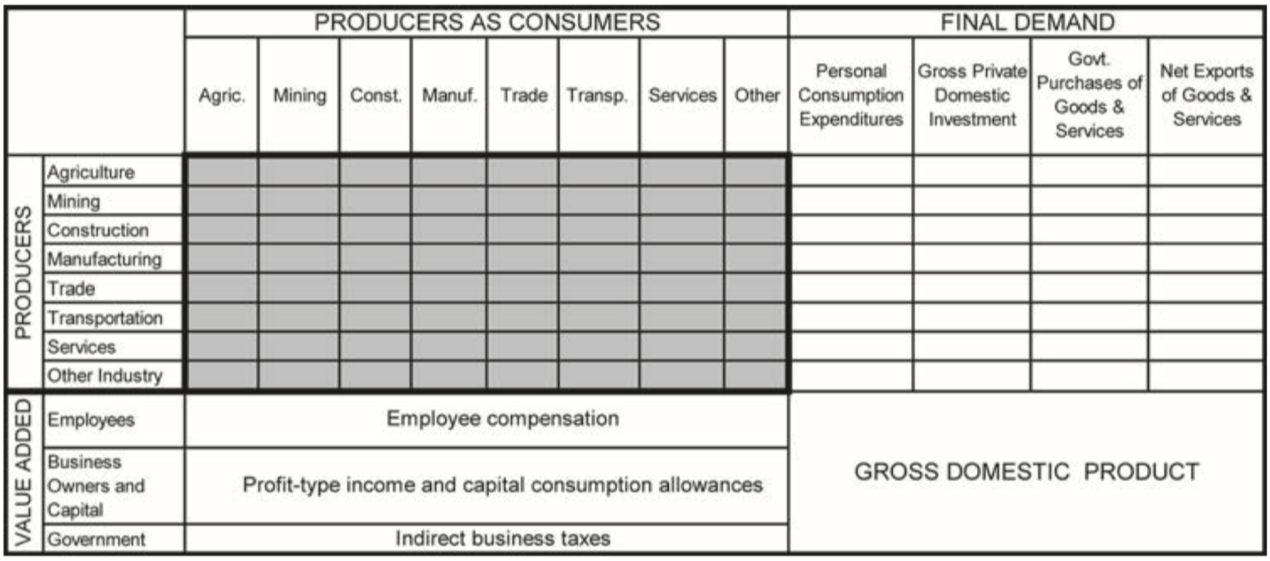

Figure 12: Input-Output Transactions table. **Source:** Miller & Blair (2009)

Consider an economy divided into n industries. The inter-industry transactions (i.e. the dark shaded portion) are labelled as z_{ij} to represent the sale of output by industries i (in the rows) to industries j (including itself; when j=i) (in the columns) (Miller & Blair, 2009). If f_i and x_i represent the 'Final demand' and 'total output' of each industry respectively, the table can represented by the following equations:

$$
\begin{aligned}
x_1 = &\quad z_{11} + z_{12} + ... + z_{1j} + ... + z_{1n} + f_1 \\
. & \\
. & \\
x_i = &\quad z_{i1} + z_{i2} + ... + z_{ij} + ... + z_{in} + f_i \\
. & \\
. & \\
x_n = &\quad z_{n1} + z_{n2} + ... + z_{nj} + ... + z_{nn} + f_n
\end{aligned}
$$

Now the three components, x, $\mathrm{z_{ij}}$ and f can be rewritten as an $n \times 1$, $n \times n$ and $n \times 1$ matrix respectively,

$$x = \begin{bmatrix} x_1 \\ . \\ . \\ x_n \end{bmatrix} \qquad Z = \begin{bmatrix} z_{11} & ... & z_{1n} \\ . & . & . \\ . & . & . \\ z_{n1} & ... & z_{nn} \end{bmatrix} \quad f = \begin{bmatrix} f_1 \\ . \\ . \\ f_n \end{bmatrix}$$

to get the following equation,

$$x = Zt + f \tag{2}$$

where t is nothing but a column vector of 1's ($n \times 1$ matrix) such that when it is multiplied by Z, it gives the row sum of each inter-industry transaction. An underlying assumption in equation 2 is that, in a specific time period (usually a year), the inter-industry transactions between industries do not change. It is assumed in the analysis that each industry purchases inputs from other industries (including itself) only corresponding to the final demand or total output (Miller & Blair, 2009). For example, say it is given that in the month January of year 1, agriculture purchases $ 4 million of output from other businesses in agriculture itself and $ 4 million of output from manufacturing to produce its own output of $ 10 million. In July, if the total output gets doubled (for example, due to doubling of final demand), then it is assumed that each of the inputs to agriculture also get linearly doubled to meet the increase in final demand. Therefore, each industry is assumed to have a fixed recipe of inputs to produce its outputs throughout a given time period (Miller & Blair, 2009).

In the next step, each of the inter-industry transactions (given in monetary terms) z_{ij}, is divided by the total output of the purchasing industry in order to get the 'technical coefficients' a_{ij}. The ratio a_{ij} represents the relationship between each industry's output and its inputs, ignoring the size of the industry.

$$a_{ij} = z_{ij}/x_j \tag{3}$$

The technical coefficients are represented by an $n \times n$ technical coefficient matrix 'A'. This matrix basically describes that in order for industry j to produce $ 1 of its output, it needs inputs worth $ a_{1j} from industry 1, $ a_{2j} from industry 2 ... and $ a_{nj} from industry n. With matrix A it is possible to rewrite equation 2, as follows:

$$x = Ax + f \tag{4}$$

which allows us to write output (x) as a function of final demand (f):

$$x = (1 - A)^{-1} f \tag{5}$$

where $(1\text{-}A)^{-1}$ is called the *Leontief inverse matrix.* The Leontief inverse matrix helps us to compute the total (direct and indirect) environmental effects of an economic activity, as will be explained below.

4.1.2 Environmental Extensions to Input-Output analysis

In order to explain the working principle of the EE-IO method, consider a simple economy with just 2 industries, namely, agriculture (industry 1) and manufacturing (industry 2). The input-output table with the inter-industry interactions, final demand in terms of household and government purchases and value-added in terms of employees and profits are shown in Table 5. All the numbers are taken to be in $ million.

Table 5: Two-industry example. **Reference:** Kitzes (2013); Miller & Blair (2009)

	Agriculture	**Manufacturing**	**Final demand (f)**	**Total output (x)**
Agriculture	4	3	3	10
Manufacturing	4	6	5	15
Value added	2	6		
Total input	10	15		

Table 5 shows that businesses in agriculture industry require $ 4 million of output from other businesses in the same industry and $ 4 million of output from manufacturing industry to produce $10 million of its own total output. Similarly, manufacturing industry requires $ 3 million from agriculture and $ 6 million from other businesses in manufacturing to produce $15 million of its own total output. These values are used to construct a 2×2 Z matrix (inter-industry transactions), and a 2×1 f matrix (final demand) for the given economy.

$$\text{Z}= \begin{bmatrix} 4 & 3 \\ 4 & 6 \end{bmatrix} \qquad \text{f}= \begin{bmatrix} 3 \\ 5 \end{bmatrix}$$

From the Z matrix, the technical coefficient matrix A can be constructed by dividing z_{ij} by x_j; where x_j is the total output of industry j:

$$\text{A}= \begin{bmatrix} 4/10 & 3/15 \\ 4/10 & 6/15 \end{bmatrix} \quad -> \text{A}= \begin{bmatrix} 0,4 & 0,2 \\ 0,4 & 0,4 \end{bmatrix}$$

The next step is to include the environmental impact into the analysis. Let us assume that agriculture emits 5 mega tonnes (MT) of CO_2 in order to produce $10 million of total output and manufacturing emits 7 MT of CO_2 in order to produce $15 million of total output. This represents the 'direct emissions' of each industry. In total, the economy produces 12 MT (=5+7) of CO_2. The amount of CO_2 emitted to produce $1 of output by agriculture and manufacturing can be represented by a 1×2 **direct intensity vector *b*** (tonnes/$).

$$\text{b}= \begin{bmatrix} 5/10 & 7/15 \end{bmatrix} \quad - - > \text{b}= \begin{bmatrix} 0,5 & 0,47 \end{bmatrix} \tag{6}$$

To put this into perspective, we can use the example of the cotton t-shirt from Figure 11 which is an output of the manufacturing industry. With the values in the direct intensity vector b, the purchase of $ 1 worth of t-shirt is found to emit 0,47 tonnes of CO_2 emissions at the first layer. This captures the direct effects. With the use of the Leontief inverse, $(1\text{-A})^{-1}$, a 1×2 **total intensity vector *B*** (tonnes/$) representing the total emissions (direct + indirect) from the different layers associated with an increase in final demand for / total output of an industry by 1 unit is computed. To understand what this means, let's first see how we would compute the environmental effects of the second layer (in Figure 11). The first layer emission intensity or the direct impact of each industry is b =[0,5 0,47] = B_1. To incorporate the second layer of emissions in the economy, we multiply the direct intensity vector *b* vector with technical coefficient matrix A. The idea is that, for example, to produce $ 1 of cotton t-shirt in manufacturing, the industry requires, respectively, $ 0,2 and $ 0,4 worth of inputs from agriculture (e.g. cotton) and manufacturing (e.g packaging) respectively. The input from agriculture will have an emission intensity of 0,1(=0,2*0,5) tonnes/ $ and the input from manufacturing will have an emission intensity of 0,188(=0,4*0,47) tonnes/ $. The sum of the second layer emissions to produce $ 1 of output from manufacturing alone is 0,1+0,188=0,288 tonnes. If we consider outputs from both the industries, we find the total intensity vector *B* for the second layer alone to be,

$$B_2 = b^*A = \begin{bmatrix} 0,388 & 0,288 \end{bmatrix}$$

The above result shows that if we take into account the second layer of inputs along with the first layer in the manufacture of $ 1 of cotton t-shirt, emission increases to 0,47+0,288=0,758 tonnes. To incorporate the third layer of inputs, we multiply the direct intensity vector *b* with the square of technical coefficient matrix (A^2). The idea here is that the production of each second layer input requires inputs from the two industries, i.e to produce $0,2 of output from agriculture (e.g. cotton), it requires $0,08 (=0,2*0,4) from agriculture itself (e.g cotton fiber) and another $ 0,08 (=0,2*0,4) from manufacturing (e.g. a machine). This side of inputs 0,16 (=0,08+0,08) emits 0,08(=0,16*0,5) tonnes/$ of emissions. The other input from manufacturing (e.g. packaging) is similarly made up of $0,08 (=0,4*0,2) from agriculture (e.g. paper[10]) and $ 0,16 (=0,4*0,4) from manufacturing (e.g plastic) which in total emits 0.1128(=0,24*0,47)tonnes/$ of emissions. The third layer indirect emission intensity from manufacturing alone becomes 0,19(=0,1128+0,08) tonnes/$. If we take the entire economy, we find the total intensity vector *B* for the third layer to be,

$$B_3 = b^*A^2 = \begin{bmatrix} 0,27 & 0,19 \end{bmatrix}$$

Now, the total emissions in the purchase of $1 of t-shirt has become 0,47+0,288+0,19=0,948 tonnes. This aggregate value, which includes the indirect emission intensities from the second and third layers has already become twice the direct emissions intensities we started with. Since, in reality, there are multiple layers in the production of a good, this multiplication process must be continued. In the end the total emissions in producing $ 1 of output from the two industries becomes, $B = B_1 + B_2 + B_3 + B_4....$ which can be rewritten as,

$$B = b^*I + b^*A + b^*A^2 + b^*A^3 + ...$$

$$B = b[I + A + A^2 + A^3 + ...]$$

$$B = b * [I - A]^{-1} \tag{7}$$

where I is an Identity matrix and the term $[I-A]^{-1}$ is the *Leontief-inverse matrix* (Kitzes, 2013; Miller & Blair, 2009). The Leontief-inverse matrix allows us to compute the total (direct + indirect) emissions of each industry, that is, the sum of CO_2 emitted by a particular industry itself, plus the emissions related to all the inputs used by that industry. For the given example, $[I-A]^{-1}$ is,

[10] Although this is not exactly an output of the agriculture industry, it is assumed to be so to fit with the example.

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad A = \begin{bmatrix} 0,4 & 0,2 \\ 0,4 & 0,4 \end{bmatrix} \quad I\text{-}A = \begin{bmatrix} 0,6 & -0,2 \\ -0,4 & 0,6 \end{bmatrix} \quad [I\text{-}A]^{-1} = \begin{bmatrix} 2,14 & 0,71 \\ 1,43 & 2,14 \end{bmatrix}$$

Total intensity vector B is computed as,

$$B = b*[I\text{-}A]^{-1} = \begin{bmatrix} 1,74 & 1,36 \end{bmatrix}$$

The total (direct + indirect) CO_2 emissions associated with an increase in final demand for / total output of agriculture and manufacturing by 1 unit equals 1,74 tonnes and 1,36 tonnes respectively. Remember from equation 6 that the direct CO_2 emissions intensity was b=[0,50 0,47]. Accordingly, the 'indirect' carbon emissions associated with an increase in final demand by 1 unit for agriculture equal 1.24 tonnes (=1,74 - 0,50) and manufacturing equal 0,89 tonnes (=1,36 - 0,47).

This computation can also be extended to include the the total emissions associated with a given level of final demand for / total output of an industry by simply multiplying the result of equation 7 with the final demand vector. This reflects the direct + indirect emissions of industries according to their size. It is represented by a 2 × 1 **total upstream emissions vector *E***.

$$E = B * f = b * [I - A]^{-1} * f \tag{8}$$

Total upstream emissions vector E for the given economy is computed as follows;

$$b*[I\text{-}A]^{-1} = \begin{bmatrix} 1,74 & 0 \\ 0 & 1,36 \end{bmatrix} \quad f = \begin{bmatrix} 3 \\ 5 \end{bmatrix} \quad E = \begin{bmatrix} 5,2 \\ 6,8 \end{bmatrix}$$

The total upstream emissions vector shows that production of \$ 10 million of output by agriculture actually emits 5.2 MT of CO_2 and production of \$ 15 million of output by manufacturing actually emits 6.8 MT of CO_2 bringing it to the same total of 12 MT. Comparing the total upstream emission vector E with the direct emissions of the economy, it can be seen that the emissions have been reallocated between the two industries. The difference between the (measured) 7 MT and the (computed or ascribed) 6,8 MT is explained by intermediate deliveries from manufacturing to agriculture. Instead of 7 (out of 12) MT, only 6,8 MT are now ascribed to manufacturing because the emissions associated with the demand from agriculture for inputs from manufacturing are now ascribed to agriculture. This is the working principle behind the EE-IO analysis. This approach supports the use of publicly available databases and avoids the issue of double counting as the classification of consumption of an industry's output as intermediate (by other industries) or final (by consumers like households) is taken to be mutually exclusive (Kitzes, 2013; Miller & Blair, 2009).

4.1.3 Limitations of EE-IO analysis

- As mentioned in section 4.1.1, a strong assumption with the EE-IO analysis is that the 'production recipe' to produce goods by an industry during the period (usually a year) for which the I-O table has been constructed is fixed. Although an industry can reflect increase or decrease in final demand, it always uses a *fixed proportion* of inputs to produce the output to meet that change in demand (Miller & Blair, 2009). It will not be able to accommodate changes in technology, for example, if the cotton t-shirt manufacturing company switches to a more eco-friendly packaging material in the same year, this change may only get reflected in the I-O table constructed the next time. This issue makes the EE-IO model not fit to forecast environmental impacts of economic activities (Bicknell et al., 1998).

- Another limitation is related to the (relatively) highly aggregated nature of the analysis. The transactions recorded in the table may include many different goods that are sold to other industries and to final consumers (Bicknell et al., 1998; Kitzes, 2013). For example, the environmental impact of other industries purchasing $1 from agriculture and a household purchasing $1 from agriculture is assumed to be the same. This issue may be resolved if the economy can be divided into highly detailed level of products/ commodities rather than aggregate industries (Kitzes, 2013). But I will still use aggregate industries for my investigation as I am concerned only with the scale of environmental impact of economic activities on a macro level which need not be affected by this issue.

- A third issue is that the inter-industry transactions are taken to be in monetary terms which may not reflect inter-industry price differences (Bicknell et al., 1998). For example, if manufacturing sells $3 million of its output to the agriculture industry and $ 1 million to the construction industry, then it is assumed that agriculture is more manufacturing-input intensive than construction. But it need not be so if manufacturing actually charges agricultural businesses more than it charges construction businesses for the sale of the same output (Bicknell et al., 1998). Again, this may be resolved to some extent with increasing resolution of the I-O tables.

4.2 Empirical Analysis

4.2.1 Impact on environment

The impact on the environment by an economic activity can be assessed based on various indicators proposed by the OECD (2008). The impacts are divided into two types, namely pollution indicators and natural resource use. Pollution indicators include GHG emissions, SO_x and NO_x emissions and hazardous waste generation. Natural resource use indicators include intensity of energy use, intensity of use of water, forest and fish resources and threatened species. Although all of these indicators are equally important, taking into account the availability of environmental indicators classified based on ISIC Rev.3 economic activities (see Chapter 2) and the availability of comparable indicators in combination with I-O tables for the same year, only some of the pollution indicators like GHG emissions, SO_x and NO_x emissions and one natural resource use indicator, namely, intensity of energy use are chosen. Some of these are combined and/or adapted to get the following four more prominent indicators:

- Global warming potential. This is driven by pollutants such as CO_2, CH_4, N_2O (Eurostat, 2020).
- Acidifying gases. This consist of gases namely SO_x, NO_x and NH_3 (Eurostat, 2020).
- Tropospheric ozone precursors. This consists of non-methane volatile organic compounds (NMVOC), CO, NO_x and CH_4 (Eurostat, 2020).
- Emission relevant energy consumption.

4.2.2 Data collection

The World Input-Output Database (WIOD), 2013 release, provides an annual time series of national Input-Output tables for 40 countries along with the above mentioned environmental indicators for the period from 1995 to 2009 (Timmer et al., 2015). This database reports data from OECD, United Nation's National accounts and other published national statistical institutes (Timmer et al., 2015) and is freely available at *www.wiod.org*. Every national economy in the I-O table is divided into 35 economic activities based on the first level and to some extent, second level of the ISIC Rev. 3 classification (refer Chapter 2) and all inter-industry and inter-country transactions (exports and imports) are reported in million US dollars. Final demand components include final consumption expenditure by households, final consumption expenditure by non-profit organisations serving households (NPISH), final consumption expenditure by government, gross fixed capital formation (net investment on capital), changes in inventories and valuables and exports (Timmer et al., 2015). Value added components mainly include imports, indirect business taxes and compensation for labour and capital services (Timmer et al., 2015). Environmental accounts, namely, emissions to air such as CO_2, CH_4, N_2O, NO_x, SO_x, CO, NMVOC, NH_3 and emission relevant energy use are collected for each of the 35 economic activities. The former indicators are reported in tonnes whereas emission relevant energy use is reported in Terajoules.

4.2.3 Direct impacts

The direct impacts refer to the environmental impacts caused by economic activities based on sector of origin. The indicators mentioned in section 4.2.1 are computed from the environmental accounts given in the WIOD for the United States for the year 2009 (WIOD, 2013). This is done by converting certain individual pollutants to CO_2 equivalents to represent global warming potential, SO_2 equivalents to represent acidifying gases and NMVOC equivalents to represent tropospheric ozone precursors based on the formula given by Eurostat (2020). Details of the formula applied is given in appendix A.1. The WIOD covers '35' economic activities and each industry is labelled by numbers from 1 to 35 as given in appendix A.2. Remember from section 2.3.1 that the economy was split into 'physical' and 'non-physical' and that some activities like finance, real estate etc. were not included. Since the I-O table needs the accounts of all activities in order to reallocate the responsibilities, I will refer to the ignored activities as 'rest of the economy'. The direct global warming potential of the various economic activities are presented in appendix A.3. From the direct emission and energy use values and the total output of each industry, it is possible to compute the emission and energy use intensity for \$1 million of output of the physical and non-physical economy (and rest of the economy) as a whole. Figure 13 shows the relative global warming potential of the physical, non-physical and rest of the economy in producing \$1 million of output. By considering only the direct emissions, it is seen that the non-physical economy has almost 3,5 times more global warming potential than the non-physical economy. Most of this burden in the physical economy was found to come from the electricity & water supply industry. By applying similar computations for the other environmental indicators, I found that the physical economy emits 11 times more acidifying gases, emits 4 times more tropospheric ozone precursors and consumes 5 times more emission relevant energy.

Therefore, when environmental impacts are allocated based on the sector of origin, the physical economy has 3,5 to 11 times (depending on the environmental indicator) more environmental burden than the non-physical economy. However, this result is not enough to draw conclusions regarding the extent

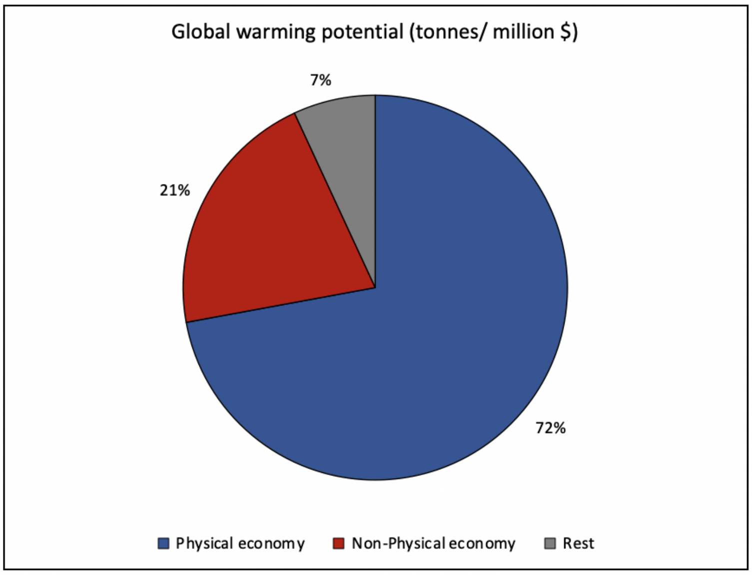

Figure 13: Direct Global warming potential; **Country**-United States; **Year**-2009. Author's calculations.

of environmental impact of the two parts of the economy. An EE-IO analysis is applied to shift the perspective from sector of origin to sector of use to reflect their direct and indirect environmental impacts.

4.2.4 Direct and indirect impacts

Based on the method illustrated in section 4.1, a step-by-step application of the EE-IO analysis to the United States economy for the year 2009 is carried out below.

Step 1: The 35 industry I-O Table from (WIOD, 2013) is taken and split into the required components, namely, the inter-industry transactions table (Z), final demand (f), value added (v) and total output (x). This table is presented in appendix A.4. All the values here are represented in million dollars. It is to be noted that the table is balanced i.e total inputs to an industry = total output of the industry.

Step 2: From the I-O Table, the 35 × 35 **technical coefficient matrix A** is constructed using equation 3. Each column of the main table, which gives the total inputs into an industry (valued in dollars), is divided by the output of that industry. This gives the 'production recipe' of an industry to produce $1 of output to other industries (including itself) and final consumers. The technical coefficient matrix has no unit and is shown in Figure 14 (The industry names corresponding to each number can be referred from appendix A.2).

Step 3: The next step is to calculate the 35 × 35 **Leontief inverse matrix** $(I-A)^{-1}$. The technical coefficient matrix A from the previous step is subtracted from an Identity matrix I first and then the inverse of the resulting matrix is found. The result of this step again has no unit and is shown in Figure 15. This matrix includes all the backward linkages of each economic activity. This matrix is also highly relevant for the investigation of the rising technology-intensity of the non-physical economy in Chapter 5.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	0,164	0,000	0,199	0,013	0,002	0,131	0,006	0,000	0,003	0,007	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,001	0,000	0,000	0,000	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000
2	0,005	0,036	0,001	0,001	0,000	0,000	0,003	0,266	0,013	0,001	0,058	0,019	0,001	0,001	0,003	0,001	0,089	0,009	0,000	0,000	0,000	0,001	0,004	0,005	0,005	0,002	0,001	0,000	0,000	0,001	0,004	0,000	0,000	0,001	0,000
3	0,078	0,000	0,180	0,002	0,195	0,001	0,003	0,000	0,008	0,004	0,001	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,001	0,000	0,080	0,000	0,001	0,000	0,000	0,002	0,000	0,000	0,000	0,009	0,017	0,010	0,003	0,000
4	0,001	0,000	0,000	0,133	0,014	0,004	0,006	0,000	0,001	0,011	0,002	0,000	0,002	0,001	0,004	0,015	0,000	0,001	0,000	0,001	0,002	0,000	0,000	0,002	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,001	0,001	0,000
5	0,000	0,000	0,000	0,004	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
6	0,002	0,000	0,000	0,001	0,000	0,161	0,008	0,000	0,001	0,004	0,004	0,001	0,002	0,001	0,003	0,038	0,000	0,024	0,000	0,001	0,001	0,003	0,002	0,000	0,000	0,000	0,001	0,000	0,001	0,001	0,001	0,000	0,000	0,002	0,000
7	0,002	0,004	0,030	0,010	0,005	0,008	0,131	0,001	0,010	0,020	0,018	0,008	0,008	0,011	0,007	0,015	0,001	0,005	0,004	0,006	0,006	0,012	0,003	0,003	0,003	0,003	0,006	0,007	0,001	0,010	0,015	0,009	0,006	0,011	0,000
8	0,041	0,007	0,002	0,006	0,001	0,006	0,006	0,045	0,035	0,012	0,006	0,004	0,003	0,002	0,001	0,002	0,006	0,031	0,003	0,004	0,002	0,004	0,079	0,139	0,147	0,053	0,005	0,001	0,000	0,008	0,020	0,001	0,002	0,002	0,000
9	0,044	0,010	0,008	0,120	0,029	0,018	0,026	0,006	0,222	0,219	0,023	0,014	0,009	0,012	0,009	0,029	0,000	0,007	0,003	0,001	0,001	0,002	0,002	0,002	0,002	0,002	0,001	0,000	0,001	0,003	0,007	0,002	0,019	0,003	0,000
10	0,003	0,004	0,018	0,004	0,028	0,007	0,009	0,000	0,013	0,054	0,008	0,004	0,022	0,010	0,020	0,036	0,001	0,014	0,013	0,003	0,004	0,007	0,005	0,000	0,000	0,002	0,002	0,000	0,000	0,001	0,003	0,002	0,005	0,001	0,000
11	0,000	0,004	0,003	0,001	0,000	0,010	0,000	0,002	0,002	0,005	0,087	0,005	0,004	0,003	0,005	0,003	0,001	0,035	0,001	0,000	0,001	0,004	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,001	0,001	0,000	0,001	0,001	0,000
12	0,005	0,019	0,018	0,007	0,008	0,022	0,015	0,001	0,011	0,024	0,027	0,251	0,149	0,050	0,108	0,082	0,002	0,054	0,010	0,001	0,003	0,008	0,012	0,039	0,003	0,002	0,006	0,000	0,001	0,002	0,004	0,001	0,001	0,004	0,000
13	0,005	0,007	0,002	0,001	0,000	0,005	0,003	0,000	0,003	0,005	0,002	0,009	0,045	0,005	0,018	0,006	0,001	0,014	0,005	0,000	0,002	0,001	0,002	0,001	0,000	0,002	0,001	0,000	0,000	0,001	0,002	0,003	0,000	0,002	0,000
14	0,001	0,001	0,002	0,004	0,001	0,005	0,006	0,000	0,005	0,008	0,004	0,009	0,029	0,042	0,032	0,013	0,001	0,014	0,005	0,001	0,003	0,002	0,002	0,001	0,000	0,001	0,007	0,001	0,000	0,004	0,008	0,003	0,014	0,003	0,000
15	0,002	0,002	0,001	0,001	0,000	0,003	0,002	0,000	0,001	0,001	0,002	0,004	0,013	0,002	0,183	0,002	0,000	0,004	0,082	0,001	0,002	0,001	0,017	0,039	0,011	0,006	0,002	0,000	0,000	0,001	0,014	0,001	0,001	0,001	0,000
16	0,000	0,001	0,000	0,002	0,001	0,003	0,001	0,000	0,001	0,002	0,001	0,001	0,004	0,003	0,006	0,023	0,000	0,005	0,000	0,000	0,001	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,001	0,002	0,001	0,004	0,001	0,000
17	0,016	0,010	0,019	0,019	0,005	0,025	0,021	0,006	0,025	0,021	0,043	0,023	0,007	0,005	0,007	0,009	0,001	0,003	0,006	0,002	0,007	0,017	0,002	0,003	0,000	0,006	0,006	0,002	0,004	0,003	0,008	0,039	0,006	0,006	0,000
18	0,005	0,020	0,003	0,002	0,001	0,008	0,005	0,003	0,004	0,005	0,008	0,006	0,003	0,002	0,002	0,004	0,020	0,001	0,002	0,001	0,003	0,005	0,014	0,000	0,000	0,004	0,016	0,006	0,014	0,003	0,023	0,002	0,003	0,006	0,000
19	0,001	0,000	0,001	0,001	0,000	0,002	0,001	0,000	0,001	0,001	0,001	0,001	0,001	0,000	0,001	0,001	0,000	0,003	0,004	0,001	0,001	0,002	0,002	0,000	0,000	0,001	0,002	0,002	0,002	0,002	0,002	0,001	0,002	0,003	0,000
20	0,048	0,009	0,059	0,048	0,030	0,067	0,038	0,030	0,042	0,035	0,030	0,037	0,049	0,046	0,041	0,041	0,002	0,027	0,014	0,024	0,012	0,026	0,018	0,017	0,015	0,009	0,007	0,001	0,001	0,008	0,015	0,012	0,009	0,006	0,000
21	0,003	0,001	0,003	0,002	0,003	0,005	0,004	0,001	0,005	0,003	0,005	0,004	0,004	0,002	0,005	0,006	0,001	0,041	0,015	0,003	0,005	0,008	0,009	0,005	0,000	0,004	0,004	0,005	0,003	0,005	0,006	0,005	0,006	0,008	0,000
22	0,001	0,001	0,002	0,002	0,002	0,007	0,008	0,000	0,001	0,005	0,005	0,005	0,004	0,002	0,002	0,005	0,006	0,002	0,005	0,002	0,003	0,012	0,001	0,000	0,018	0,003	0,006	0,013	0,002	0,014	0,008	0,006	0,008	0,009	0,000
23	0,016	0,017	0,025	0,014	0,008	0,028	0,015	0,011	0,015	0,013	0,052	0,022	0,010	0,005	0,010	0,016	0,047	0,011	0,004	0,002	0,006	0,005	0,049	0,009	0,004	0,005	0,003	0,001	0,001	0,003	0,008	0,002	0,003	0,004	0,000
24	0,001	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,000	0,000
25	0,000	0,000	0,001	0,001	0,001	0,001	0,002	0,000	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,000	0,001	0,001	0,001	0,001	0,001	0,002	0,001	0,000	0,001	0,002	0,002	0,000	0,002	0,002	0,001	0,001	0,002	0,000
26	0,003	0,001	0,003	0,003	0,001	0,012	0,014	0,001	0,002	0,004	0,008	0,003	0,003	0,002	0,002	0,006	0,003	0,000	0,011	0,017	0,019	0,009	0,047	0,075	0,088	0,050	0,002	0,004	0,000	0,005	0,003	0,005	0,005	0,008	0,000
27	0,003	0,004	0,005	0,005	0,003	0,011	0,017	0,001	0,007	0,006	0,010	0,006	0,006	0,006	0,005	0,009	0,002	0,009	0,013	0,013	0,014	0,017	0,024	0,035	0,042	0,025	0,098	0,015	0,002	0,017	0,015	0,012	0,011	0,020	0,000
28	0,062	0,040	0,012	0,010	0,012	0,014	0,037	0,001	0,013	0,017	0,020	0,028	0,021	0,016	0,017	0,030	0,013	0,020	0,021	0,023	0,038	0,037	0,056	0,028	0,032	0,017	0,022	0,237	0,128	0,046	0,014	0,018	0,039	0,075	0,000
29	0,018	0,004	0,007	0,005	0,004	0,015	0,017	0,000	0,003	0,008	0,007	0,008	0,006	0,004	0,003	0,015	0,003	0,007	0,035	0,012	0,044	0,042	0,011	0,024	0,007	0,023	0,013	0,024	0,057	0,029	0,018	0,089	0,073	0,042	0,000
30	0,017	0,051	0,059	0,042	0,028	0,075	0,132	0,007	0,103	0,055	0,077	0,070	0,062	0,091	0,080	0,069	0,027	0,085	0,057	0,071	0,071	0,089	0,077	0,080	0,108	0,057	0,092	0,111	0,029	0,128	0,118	0,069	0,095	0,117	0,000
31	0,009	0,003	0,007	0,006	0,002	0,015	0,009	0,002	0,007	0,007	0,014	0,012	0,003	0,002	0,003	0,004	0,002	0,002	0,005	0,002	0,006	0,008	0,006	0,008	0,006	0,007	0,007	0,002	0,003	0,003	0,009	0,014	0,007	0,013	0,000
32	0,003	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,004	0,003	0,000	0,002	0,000
33	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,004	0,000	0,018	0,001	0,000
34	0,003	0,005	0,007	0,005	0,004	0,011	0,013	0,001	0,008	0,008	0,010	0,009	0,006	0,006	0,007	0,009	0,003	0,014	0,014	0,007	0,009	0,021	0,008	0,019	0,008	0,010	0,057	0,013	0,010	0,016	0,018	0,019	0,012	0,084	0,000
35	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Figure 14: **Technical coefficient Matrix A.** Author's calculations.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	1,226	0,001	0,299	0,022	0,062	0,193	0,012	0,000	0,008	0,014	0,003	0,002	0,002	0,001	0,002	0,011	0,001	0,007	0,001	0,001	0,001	0,032	0,001	0,001	0,001	0,001	0,002	0,001	0,001	0,002	0,004	0,007	0,004	0,003	0,000
2	0,028	1,043	0,016	0,013	0,007	0,016	0,013	0,292	0,037	0,019	0,079	0,036	0,011	0,006	0,014	0,011	0,098	0,026	0,005	0,003	0,003	0,008	0,033	0,051	0,052	0,021	0,006	0,003	0,002	0,005	0,015	0,006	0,004	0,005	0,000
3	0,119	0,001	1,250	0,009	0,245	0,022	0,008	0,001	0,014	0,011	0,003	0,002	0,002	0,002	0,002	0,004	0,001	0,002	0,002	0,002	0,001	0,103	0,001	0,002	0,003	0,001	0,004	0,003	0,001	0,003	0,013	0,023	0,015	0,006	0,000
4	0,002	0,000	0,002	1,154	0,017	0,007	0,009	0,000	0,003	0,014	0,003	0,001	0,003	0,002	0,006	0,019	0,000	0,002	0,001	0,001	0,003	0,001	0,001	0,002	0,000	0,000	0,001	0,000	0,000	0,001	0,002	0,001	0,002	0,002	0,000
5	0,000	0,000	0,000	0,005	1,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
6	0,004	0,002	0,003	0,003	0,001	1,194	0,012	0,001	0,002	0,006	0,007	0,003	0,004	0,002	0,006	0,048	0,001	0,030	0,001	0,001	0,002	0,005	0,004	0,001	0,001	0,001	0,002	0,001	0,003	0,001	0,003	0,001	0,001	0,003	0,000
7	0,012	0,008	0,050	0,019	0,019	0,018	1,157	0,004	0,021	0,033	0,029	0,018	0,017	0,018	0,018	0,025	0,004	0,013	0,010	0,009	0,011	0,022	0,009	0,009	0,009	0,006	0,012	0,014	0,004	0,016	0,022	0,015	0,012	0,019	0,000
8	0,062	0,013	0,026	0,020	0,011	0,028	0,017	1,053	0,054	0,032	0,020	0,015	0,011	0,007	0,010	0,013	0,014	0,040	0,008	0,007	0,006	0,012	0,094	0,155	0,164	0,062	0,010	0,005	0,003	0,012	0,027	0,005	0,007	0,008	0,000
9	0,077	0,018	0,042	0,184	0,058	0,047	0,048	0,014	1,296	0,306	0,041	0,030	0,027	0,023	0,031	0,060	0,004	0,021	0,012	0,004	0,005	0,012	0,009	0,009	0,007	0,005	0,005	0,003	0,002	0,006	0,014	0,007	0,030	0,009	0,000
10	0,009	0,006	0,028	0,009	0,037	0,013	0,014	0,003	0,019	1,064	0,013	0,009	0,028	0,013	0,030	0,042	0,002	0,018	0,017	0,004	0,005	0,011	0,008	0,003	0,002	0,003	0,005	0,002	0,001	0,003	0,006	0,003	0,008	0,003	0,000
11	0,002	0,006	0,006	0,002	0,002	0,015	0,002	0,004	0,004	0,008	1,098	0,009	0,007	0,005	0,009	0,005	0,002	0,040	0,003	0,001	0,001	0,006	0,002	0,002	0,001	0,001	0,003	0,001	0,001	0,001	0,003	0,001	0,002	0,002	0,000
12	0,019	0,033	0,041	0,019	0,023	0,047	0,030	0,012	0,026	0,047	0,050	1,347	0,220	0,075	0,191	0,122	0,009	0,085	0,033	0,004	0,008	0,019	0,027	0,065	0,012	0,008	0,015	0,004	0,004	0,007	0,015	0,006	0,007	0,011	0,000
13	0,008	0,009	0,006	0,002	0,002	0,009	0,005	0,003	0,006	0,009	0,005	0,014	1,051	0,007	0,026	0,009	0,003	0,017	0,008	0,001	0,003	0,003	0,004	0,004	0,002	0,003	0,003	0,001	0,001	0,002	0,003	0,004	0,001	0,003	0,000
14	0,004	0,004	0,006	0,007	0,004	0,010	0,010	0,002	0,009	0,014	0,008	0,016	0,036	1,047	0,045	0,018	0,002	0,019	0,010	0,002	0,004	0,005	0,005	0,006	0,003	0,003	0,011	0,003	0,002	0,005	0,012	0,004	0,016	0,006	0,000
15	0,006	0,004	0,006	0,003	0,002	0,008	0,005	0,002	0,004	0,004	0,006	0,009	0,019	0,004	1,227	0,005	0,002	0,008	0,102	0,002	0,004	0,003	0,023	0,050	0,015	0,008	0,004	0,001	0,001	0,002	0,019	0,002	0,002	0,003	0,000
16	0,001	0,001	0,001	0,003	0,001	0,005	0,001	0,000	0,002	0,003	0,002	0,002	0,005	0,004	0,009	1,024	0,000	0,006	0,001	0,001	0,001	0,002	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,002	0,001	0,005	0,002	0,000
17	0,028	0,013	0,035	0,030	0,015	0,040	0,031	0,011	0,037	0,035	0,053	0,036	0,016	0,010	0,018	0,019	1,003	0,012	0,010	0,004	0,009	0,023	0,007	0,010	0,005	0,009	0,010	0,005	0,006	0,006	0,012	0,043	0,009	0,010	0,000
18	0,012	0,023	0,011	0,007	0,005	0,017	0,011	0,010	0,010	0,011	0,016	0,013	0,008	0,005	0,008	0,009	0,024	1,006	0,005	0,003	0,006	0,010	0,019	0,006	0,005	0,007	0,021	0,011	0,017	0,006	0,027	0,007	0,007	0,011	0,000
19	0,002	0,001	0,002	0,001	0,001	0,003	0,003	0,001	0,002	0,002	0,003	0,003	0,002	0,001	0,002	0,002	0,001	0,004	1,005	0,001	0,002	0,003	0,003	0,001	0,001	0,001	0,003	0,003	0,003	0,003	0,003	0,002	0,003	0,005	0,000
20	0,078	0,016	0,102	0,072	0,058	0,106	0,057	0,038	0,066	0,063	0,047	0,061	0,071	0,058	0,070	0,063	0,008	0,043	0,025	1,028	0,017	0,042	0,029	0,032	0,027	0,015	0,014	0,006	0,004	0,014	0,025	0,018	0,017	0,013	0,000
21	0,007	0,004	0,008	0,005	0,007	0,011	0,009	0,003	0,010	0,008	0,010	0,009	0,008	0,005	0,009	0,010	0,003	0,045	0,018	0,004	1,007	0,012	0,013	0,008	0,004	0,006	0,008	0,009	0,006	0,008	0,010	0,008	0,009	0,012	0,000
22	0,005	0,004	0,008	0,006	0,006	0,014	0,015	0,002	0,006	0,010	0,011	0,011	0,009	0,006	0,008	0,011	0,008	0,007	0,008	0,005	0,007	1,017	0,005	0,005	0,023	0,006	0,011	0,021	0,006	0,019	0,012	0,010	0,013	0,016	0,000
23	0,030	0,022	0,045	0,025	0,020	0,047	0,025	0,019	0,028	0,026	0,069	0,038	0,021	0,011	0,023	0,027	0,053	0,021	0,009	0,004	0,009	0,013	1,057	0,017	0,010	0,008	0,007	0,004	0,002	0,006	0,013	0,007	0,007	0,008	0,000
24	0,001	0,000	0,002	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,001	0,001	0,000	0,000	0,000	0,000	0,001	0,001	0,000	0,000	0,000	0,000
25	0,001	0,001	0,002	0,002	0,001	0,003	0,004	0,000	0,002	0,002	0,002	0,002	0,002	0,001	0,002	0,003	0,001	0,002	0,002	0,001	0,001	0,002	0,003	0,002	1,001	0,002	0,003	0,003	0,001	0,003	0,002	0,002	0,001	0,003	0,000
26	0,009	0,004	0,012	0,008	0,006	0,023	0,023	0,004	0,008	0,010	0,017	0,010	0,009	0,006	0,009	0,013	0,006	0,006	0,014	0,020	0,023	0,014	0,055	0,083	0,096	1,055	0,005	0,008	0,002	0,009	0,007	0,008	0,008	0,013	0,000
27	0,013	0,009	0,018	0,014	0,011	0,027	0,033	0,005	0,019	0,018	0,022	0,019	0,016	0,013	0,017	0,020	0,007	0,020	0,021	0,019	0,022	0,028	0,036	0,049	0,056	0,033	1,117	0,028	0,008	0,027	0,025	0,019	0,019	0,033	0,000
28	0,126	0,070	0,076	0,040	0,042	0,073	0,090	0,026	0,052	0,056	0,063	0,077	0,060	0,044	0,061	0,073	0,034	0,058	0,053	0,044	0,072	0,084	0,102	0,070	0,069	0,042	0,059	1,336	0,188	0,086	0,046	0,057	0,085	0,138	0,000
29	0,035	0,012	0,028	0,016	0,014	0,037	0,036	0,006	0,016	0,022	0,021	0,024	0,019	0,014	0,018	0,030	0,008	0,021	0,046	0,019	0,056	0,058	0,024	0,039	0,021	0,033	0,028	0,044	1,069	0,042	0,031	0,104	0,089	0,063	0,000
30	0,085	0,089	0,147	0,108	0,086	0,167	0,224	0,042	0,191	0,146	0,151	0,154	0,133	0,142	0,172	0,143	0,056	0,149	0,106	0,100	0,109	0,151	0,136	0,143	0,166	0,093	0,151	0,189	0,069	1,178	0,173	0,111	0,148	0,188	0,000
31	0,015	0,005	0,015	0,010	0,007	0,024	0,014	0,004	0,013	0,013	0,019	0,019	0,008	0,005	0,009	0,010	0,004	0,006	0,008	0,004	0,007	0,012	0,010	0,013	0,009	0,009	0,011	0,004	0,004	0,005	1,012	0,016	0,009	0,016	0,000
32	0,004	0,000	0,001	0,000	0,000	0,001	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,003	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,004	1,003	0,000	0,003	0,000
33	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,004	0,000	1,019	0,002	0,000
34	0,013	0,011	0,020	0,014	0,012	0,025	0,027	0,005	0,020	0,020	0,021	0,022	0,017	0,013	0,019	0,020	0,007	0,024	0,023	0,012	0,017	0,032	0,019	0,031	0,019	0,018	0,075	0,026	0,017	0,025	0,028	0,028	0,021	1,102	0,000
35	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,000

Figure 15: **Leontief Inverse Matrix.** Author's calculations.

Step 4: The 1×35 **Total intensity vector *B*** which gives the total (direct + indirect) emissions with an increase in final demand for / total output of agriculture and manufacturing by 1 unit as given by equation 7 is computed next. This requires a multiplication of the direct emission intensity vector b measured in tonnes/ million $ (or) joules/ million $ from the environmental accounts of the WIOD database with the Leontief's inverse matrix. Since there are four environmental indicators, only the computation for global warming potential (refer appendix A.5) will be elaborated here. The final results for the other indicators will be presented in Table 6. Figure 16 shows the computed total intensity vector B measured in tonnes/ million dollars (The vector is shown as a column to fit the page).

Economic activities		Total emission intensity vector B (in tonnes/ million $)
Agriculture, Forestry and Fishing	1	2.072,9
Mining & Quarrying	2	1.366,3
Food products manf.	3	850,4
Textile products manf.	4	481,8
Leather products manf.	5	320,8
Wood products manf.	6	863,5
Paper products manf.	7	452,2
Coke, refined petroleum products manf.	8	857,9
Chemicals & pharmaceutical products	9	666,0
Rubber & plastics products	10	427,1
Other non-metallic mineral products	11	1.816,2
Basic & fabricated metals	12	607,5
Machinery and equipment	13	275,0
Electrical & Optical Equipment	14	146,9
Transport Equipment	15	272,0
Manufacturing, Nec; Recycling	16	270,9
Electricity, Gas & Water Supply	17	5.555,5
Construction	18	276,3
Repair of Motor Vehicles	19	140,1
Wholesale Trade	20	87,1
Retail Trade	21	160,1
Hotels & Restaurants	22	330,9
Inland Transport	23	932,7
Water Transport	24	1.956,7
Air Transport	25	1.407,8
Supporting Transport Activities	26	427,8
Post & Telecommunications	27	174,3
Financial Intermediation	28	84,1
Real Estate Activities	29	62,1
Renting & Other Business Activities	30	118,9
Public Admin and Defence	31	241,2
Education	32	353,0
Health and Social Work	33	159,5
Other Community, Social and Personal Service	34	371,4
Private Households with Employed Persons	35	-

Figure 16: **Total intensity vector B:** Direct and Indirect emission intensities to produce $1 million of output; **Unit-** Tonnes/ million $; Author's calculations.

To understand the extent of direct and indirect emissions from the results in the total intensity vector B, Figure 17 is presented. This gives the share of direct and indirect global warming potential in the total intensity vector of each activity after the EE-IO analysis in producing $1 million of output.

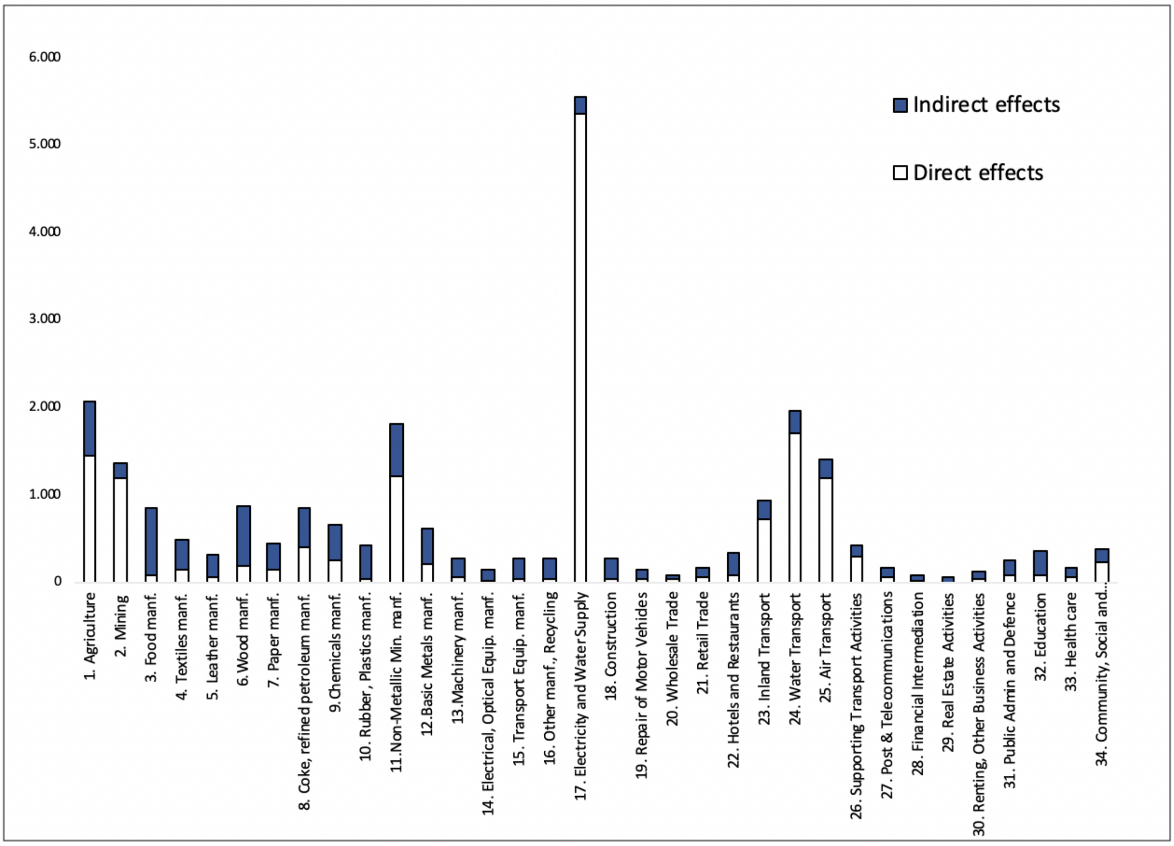

Figure 17: **Total intensity vector 'B' breakdown I:** Share of direct and indirect emissions in total emissions for producing $1 million of output. Author's calculations.

From Figure 17, it can be seen that education, health care and some parts of the physical economy like manufacturing, construction and trade have a higher share of indirect emission intensity. If we refer back to section 4.2.3, electricity and water supply had the maximum direct impacts among all the economic activities but it can be seen now that it has the least amount of indirect effect. The total emission intensities computed hints at the possibility that the ratio of environmental burden of the physical to the non-physical economy as found in section 4.2.3 may not remain the same. However, it is still clear that the physical economy has a higher total global warming intensity than the non-physical economy. Taking the analysis a step further, let us look at how the global warming potential intensity has changed for health care (as an example) based on the Leontief inverse matrix with Figure 18.

Figure 18 consists of a simple element-wise multiplication of the direct intensity vector b with health and social work column (column 33) of the Leontief Inverse matrix given in Figure 15, followed by the addition of the multiplication results to illustrate how the value 160 tonnes/ million $ under health care in Figure 16 is calculated.

It can be seen that the direct global warming potential intensity of health care (52,5 tonnes/ million $ from appendix A.5) is retained with an added indirect impact of 0,9 tonnes/ million $ from health care itself to get to a total contribution of 53,4 tonnes/million $ from health care alone. The second biggest indirect contributor to the health care activity is from electricity, gas and water supply industry. This is surprising because the technical coefficient for electricity and water supply in health care is quite low when compared to sectors like business services, real estate and financial services (from the fourth

Health care

160 (tonnes/ million $)

Economic Activity		Direct intensity vector 'b' (tonnes/ million $)	Health care column from Leontief inverse matrix (No Unit)	Total intensity vector 'B' for health care sector (tonnes/ million $)
Agriculture, Forestry and Fishing	1	1456	0,004	6,22
Mining & Quarrying	2	1188	0,004	5,10
Food products manf.	3	79	0,015	1,19
Textile products manf.	4	151	0,002	0,27
Leather products manf.	5	57	0,000	0,01
Wood products manf.	6	188	0,001	0,27
Paper products manf.	7	146	0,012	1,74
Coke, refined petroleum products manf.	8	397	0,007	2,73
Chemicals & pharmaceutical products	9	254	0,030	7,73
Rubber & plastics products	10	32	0,008	0,25
Other non-metallic mineral products	11	1203	0,002	1,85
Basic & fabricated metals	12	213	0,007	1,53
Machinery and equipment	13	60	0,001	0,08
Electrical & Optical Equipment	14	23	0,016	0,37
Transport Equipment	15	35	0,002	0,07
Manufacturing, Nec; Recycling	16	28	0,005	0,13
Electricity, Gas & Water Supply	17	5361	0,009	50,77
Construction	18	37	0,007	0,24
Repair of Motor Vehicles	19	28	0,003	0,07
Wholesale Trade	20	31	0,017	0,55
Retail Trade	21	67	0,009	0,58
Hotels & Restaurants	22	83	0,013	1,07
Inland Transport	23	726	0,007	5,26
Water Transport	24	1699	0,000	0,24
Air Transport	25	1187	0,001	1,76
Supporting Transport Activities	26	289	0,008	2,33
Post & Telecommunications	27	51	0,019	0,99
Financial Intermediation	28	13	0,085	1,08
Real Estate Activities	29	4	0,089	0,38
Renting & Other Business Activities	30	37	0,148	5,41
Public Admin and Defence	31	87	0,009	0,80
Education	32	70	0,000	0,02
Health and Social Work	33	52	1,019	53,45
Other Community, Social and Personal Services	34	238	0,021	4,98
Private Households with Employed Persons	35	0	0,000	0,00
			Total	160

Figure 18: **Total intensity vector 'B' breakdown II:** Health and Social work. Author's calculations.

column in Figure 18). Yet, due to the very high global warming intensity of the electricity and water supply industry, as seen in the direct intensity vector b (see first column), its indirect contribution to health care's total (direct+indirect) global warming intensity becomes almost as big as health care's contribution itself. This is why the total global warming potential intensity of health care (160 tonnes/ million $) increases by almost 3 times from its direct intensity (52,5 tonnes/ million $). Electricity and water supply industry's high indirect contribution does not apply to health care alone. Even total intensities of some industries in the physical economy, education and other personal services have increased due to indirect effects from electricity and water supply. This level of detailed analysis ends here for this chapter as I am only interested to see if the physical economy has a higher environmental burden than the non-physical economy even when emissions are reallocated. Chapter 5 will delve more into this with the investigation of the technology-intensity of the non-physical economy using technical coefficients.

Step 5: The final step is to compute the 35×1 **total upstream emissions vector *E*** vector per equation 8. This is done by multiplying the total intensity vector B (rearranged as a 35×35 diagonal matrix) with the 35×1 final demand vector 'f'. The total emissions from all activities obtained in this step exactly matches the total emissions obtained with the direct emission accounts we started with (refer appendix A.3). This essentially means that global warming potential accounts collected based on sector of origin has been 'reallocated' based on sector of use. Figure 19 gives the total emissions (direct and indirect), in tonnes, associated with a given level of final demand for an industry.

Economic activities		Total upstreams vector E (in tonnes)
Agriculture, Forestry and Fishing	1	223.511.818
Mining & Quarrying	2	158.388.310
Food products manf.	3	416.118.163
Textile products manf.	4	13.224.983
Leather products manf.	5	399.314
Wood products manf.	6	7.029.230
Paper products manf.	7	75.598.752
Coke, refined petroleum products manf.	8	171.672.558
Chemicals & pharmaceutical products	9	184.798.122
Rubber & plastics products	10	16.972.169
Other non-metallic mineral products	11	24.673.580
Basic & fabricated metals	12	36.477.504
Machinery and equipment	13	55.253.563
Electrical & Optical Equipment	14	47.786.388
Transport Equipment	15	105.198.939
Manufacturing, Nec; Recycling	16	27.017.426
Electricity, Gas & Water Supply	17	1.105.299.837
Construction	18	265.215.159
Repair of Motor Vehicles	19	23.980.621
Wholesale Trade	20	50.942.947
Retail Trade	21	163.699.182
Hotels & Restaurants	22	197.711.680
Inland Transport	23	132.047.640
Water Transport	24	56.033.934
Air Transport	25	146.487.672
Supporting Transport Activities	26	15.320.124
Post & Telecommunications	27	47.800.676
Financial Intermediation	28	80.616.149
Real Estate Activities	29	101.128.456
Renting & Other Business Activities	30	84.239.444
Public Admin and Defence	31	678.713.051
Education	32	71.609.439
Health and Social Work	33	262.131.749
Other Community, Social and Personal Services	34	211.239.424
Private Households with Employed Persons	35	-

Figure 19: **Total upstream emissions vector E:** Direct and indirect emissions from each economic activity reallocated to the sector of destination or sector of use; **Unit**-Tonnes. Author's calculations

If Figures 19 and 30 (in appendix A.3) are compared, the row highlighted in orange denote the change in environmental burden of health and social work (as an example of the non-physical economy) and the row highlighted in blue denotes the change in environmental burden of electricity and water supply industry (chosen as an example of the physical-economy) as a result of the EE-IO analysis. The burden of health and social work due to its demand for inputs from other industries (especially electricity and water supply) has increased by 3 times and the same for electricity and water supply has almost been halved. The reallocated emissions are divided as physical, non-physical and rest of the economy to *compare* the impact in producing $1 million of each economy's output. The ratio of global warming potential after the EE-IO analysis of the physical economy to the non-physical economy in producing $1 million of output has reduced from 3,5 times to 1,75 times. The reallocated relative global warming potential in producing $1 million of output is shown in Figure 20.

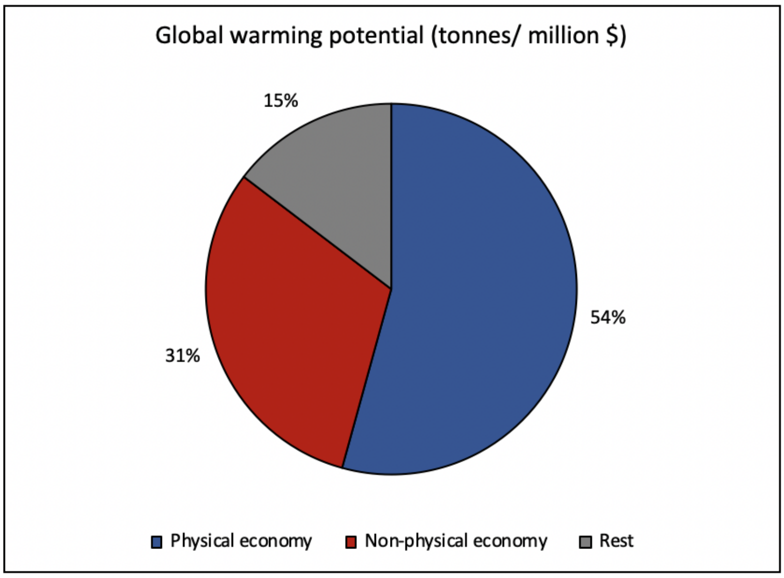

Figure 20: Direct and indirect global warming potential. **Country:** United States. **Year:** 2009. Author's calculations.

When the same procedure was applied to the other environmental indicators, it was found that the physical economy still emits 2,8 times more acidifying gases, emits 2 times more tropospheric ozone precursors and consumes 1,8 times more energy than the non-physical economy. A summary of the results before and after the EE-IO analysis is presented in Table 6.

Table 6: **Summary:** Ratio of environmental impact of physical to non-physical; **Country:** United States. **Year:** 2009.

Indicator	**Direct**	**After EE-IO: Direct + indirect**
Global warming potential	3,5 times	1,75 times
Acidifying gases	11 times	2,8 times
Tropospheric ozone precursors	4 times	2 times
Emission relevant energy use	5 times	1,8 times

4.3 Chapter Conclusions

Therefore, the results before and after the analysis show that the physical economy has a higher environmental burden than the non-physical economy (at least twice). This confirms the proposed 'material threshold hypothesis' or the 'modified threshold hypothesis' proposed in section 2.2.2 that the development of human beings from material to non-material needs beyond the material threshold may imply a lessening of environmental problems. However, this will be the case only in circumstances where the non-physical economy does not grow more and more polluting. In Chapter 3, we saw that the technology-intensity in terms of ICT and other trends are increasing in the non-physical economy in the United States. If this is indeed true, then these trends will be reflected in some of the technical coefficients of the health care column in the Leontief Inverse Matrix between two spaced out time periods and/or between two countries with different technology-intensities in health care. This leads to the investigation of my second sub-question using the same EE-IO method in the next chapter.

5 Environmental impact of the growing technology-intensity in the non-physical economy

In the previous chapter, it was found that, the non-physical economy is at least twice less polluting than the physical economy even after their direct and indirect effects are taken into account. However, the difference between the physical and the non-physical economy is likely to diminish if the non-physical economy grows more technology-intensive over time. The purpose of this chapter is to examine (a) whether this is the case, and (b) whether this lowers or increases the environmental pressure created by the non-physical economy.

Existing studies of the environmental effects of high-tech solutions in the non-physical economy tend to take a partial (micro) rather than a macro- or economy-wide approach (as discussed in section 5.1.1). The approach taken in this chapter is to study the *economy-wide* environmental effects of high-tech solutions in one important sector of the non-physical economy: health care. To examine the environmental effects of high-tech health care, I first compare U.S. health care in the year 2015 with U.S. health care in 1995. During the years 1995−2015, has U.S. health care become increasingly technology-intensive (meaning, relying more on medicine, medical technology and telecommunications (digital health)), and how has this influenced direct and indirect emissions? Next, (high-tech) U.S. health care will be compared with health care in Canada, which supposedly (roughly) equals U.S. health care in terms of quality, although it is less high-tech. The first comparison will show whether there exists a trend towards higher technology-intensity in health care in the U.S. health care system, and what this implies for the environment. The second comparison (between the U.S. and Canada) will give a (preliminary) indication regarding the universality of this trend.

5.1 Environmental impacts of ICT: Results from existing studies

Adoption of information & communication technologies in economic activities is commonly perceived as a strategy to deal with the climate change crisis. For example, Yellowlees et al. (2010) discusses how telemedicine, in combination with EHR and e-prescribing technologies can make health care activities greener. These technologies are generally seen as a way to optimise energy consumption of routine tasks, reduce people's need to travel for work etc. which can consequently benefit the environment (Belkhir & Elmeligi, 2018). However, the direct and indirect impacts of ICTs themselves and their system-wide impacts on energy consumption and GHG emissions are hardly recognised by institutions and businesses before implementing them to *virtualize* goods and services and/or *optimise* processes (Belkhir & Elmeligi, 2018; Court & Sorrell, 2020).

ICT systems comprise of end-user devices such as desktops, laptops, tablets, smartphones etc., broadband wired and wireless communication networks and data centres (Belkhir & Elmeligi, 2018). These devices and their associated communication networks are found to have a significant impact on energy consumption and subsequent GHG emissions. For example, the end-user devices consume a relatively high portion of energy during its manufacture while their use lasts only for short period of about 2-8 years. When it comes to the associated communication networks and data centres, these systems are found to contribute to more than two-thirds of the carbon footprint of the ICT industry (Belkhir & Elmeligi, 2018). Figure 21 shows the contribution of the ICT industry to global GHG emissions.

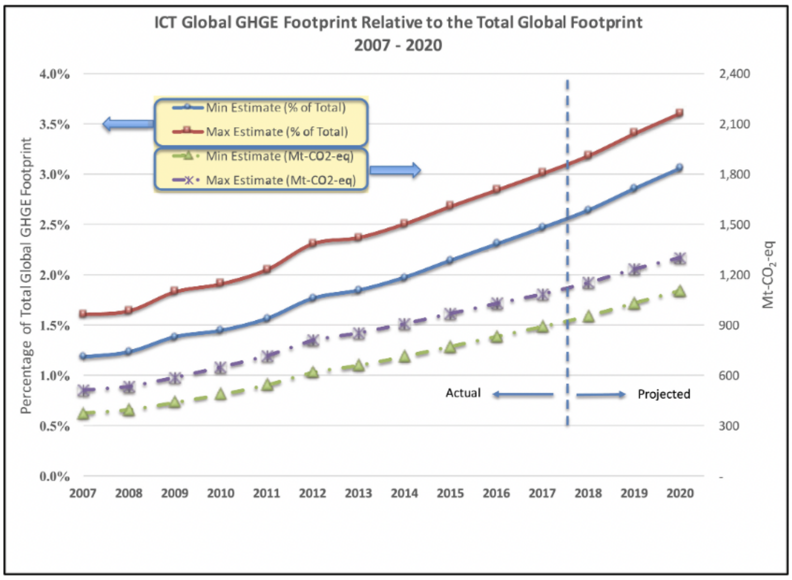

Figure 21: ICT Global GHG emission footprint to the total global footprint for the period 2007-2020. **Source:** Belkhir & Elmeligi (2018)

From Figure 21, it can be seen that the GHG emissions from ICT as a percentage of total emissions have increased by more than two times in a span of just over 10 years. Court & Sorrell (2020) also found that in 2015, the ICT industry consumed about 3.5-7% of total global energy consumption and this consumption rate will be rising at 5-10% every year. Therefore, the energy consumed and the subsequent GHG emitted by ICTs themselves are rising steadily. A recent study by Deloitte (2019) found that an average household in the United States owns 11 connected devices[11] and that consumers have to boost their home network bandwidth to accommodate so many devices. With the kick-off of a more powerful fifth generation (5G) communication network shortly, which could by itself be potentially harmful due to increased electromagnetic radiations on the planet (Naydler, 2019), the number of connected devices owned by consumers are only bound to increase (Deloitte, 2019). Unless energy supply becomes completely renewable in the short run, this trend of energy consumption by ICTs cannot support the International Resource panel's strategy to "decouple" GDP growth of countries from their environmental burden to meet their climate goals (see Chapter 2) (The Shift Project, 2019).

Based on current trends, although energy supply is not fully renewable yet, it is definitely getting increasingly more efficient (Galvin, 2015). This can be considered good news. However, increases in energy efficiency means one pays less for the same amount of energy used previously by the ICT device. The cost savings from this increase in energy efficiency gives the opportunity for consumers to spend more on ICT devices (similar or complementary devices) and/ or energy services (e.g. bandwidth of the internet) which can subsequently lead to more energy consumption (Galvin, 2015). This is termed the 'rebound effect' (Galvin, 2015). Additionally, Galvin (2015) finds that consumers do not simply get *enough* of ICT devices and related services. For example, people seem to have a limit to the number of hours they want to drive their cars in a day or a year whereas when it comes to the amount of storage

[11]This refers to devices connected to the Internet. Although the term 'Internet of Things' (IoT) was coined in 1999, Cisco (2011) considers IoT to be "born" only when there became more connected devices than people on the planet (around 2008 and 2009).

space or processor speed they want on their ICT device, there seems to be no limit. Besides this, ICTs also seem to create new wants for people continuously and faster than their old wants are satisfied (Galvin, 2015). All of these aspects of ICTs can make people behave like insatiable consumers. We saw that this is not environmentally sustainable (see Chapter 1). In sum, although ICT and its related technologies are invading every sphere of life faster than we can imagine, it is essential for policymakers, businesses, institutions and consumers to become more conscious of the system-wide environmental impacts of ICTs before adopting them as a strategy to 'green' economic activities.

It is true that the widespread adoption of ICT in the physical economy may have an environmental burden. But the technologies are found to at least improve the efficiency and labour productivity (λ) of activities. For example, the concept of "Intelligent Manufacturing" is to facilitate the entire product life-cycle with the use of ICT, Internet of Things (IoT) and artificial intelligence technologies (Zhong et al., 2017). This can improve the efficiency of the production process and quality of products and reduce the need for human engagement in the manufacturing activity (Zhong et al., 2017). However, when ICT and related technologies are adopted in cultural activities like health care, education, research and the fine arts, various studies suggest that this may have negative implications for consciousness, creativity, intelligence and morality for human beings (see Chapter 3). As seen in Chapter 3, unlike the physical economy, evidence for the improvement of the quality of outcome in the non-physical economy (e.g. quality of health care or quality of education) when the creative and cognitive tasks of human work in these activities are replaced by technological solutions is not widely found. This is why it becomes even more essential to study the environmental burden of technology-intensity in the non-physical economy as they not only not provide any meaningful benefits but may also psychologically harm people (e.g patients, students).

5.1.1 Environmental impacts of technology-intensity in the non-physical economy

The trends in the non-physical economy, specifically the ICT revolution in health care (e-health), education and research (e-learning) can have three main types of environmental impacts, namely, first order, second order and third order effects (Horner et al., 2016). This classification can have different names such as 'direct' and 'higher order effects' or just as 'direct' and 'indirect' effects (Horner et al., 2016). However, I choose to use the first order, second order and third order classification originally provided by Hilty et al. (2006) in order to avoid confusion with the empirical analysis in the previous chapter. The *first order effect* refers to the energy consumed during the production, operation and disposal of the ICT devices along with the energy consumed by the related data centres and communication networks (Horner et al., 2016). The *second order effects* refers to the change in processes such as increase in efficiency or energy saved or consumed from the substitution of a good or service with ICT. Finally, the *third order effects* refers to the wider structural, economic and behavioural change or 'rebound' resulting from the adoption of ICT (Horner et al., 2016). To illustrate the various impacts ICT systems have on the environment, an example given by Court & Sorrell (2020) of e-books, a kind of technology that is gaining traction in schools as an instructional aid, is shown in Table 7. Table 7 suggests that the substitution and rebound effects of the use of ICT devices can be significant. These results correspond to the literature discussed above (about rebound effects of the use of ICT devices in general).

Most studies related to the environmental impacts of ICTs found in the literature are commonly concerned only with first order effects and to a certain extent, second order effects. For example,

Table 7: First order, second order and third order effects of e-books. **Source:** Court & Sorrell (2020)

Effect	Impact mechanism	Case
First order effects	Embodied energy	**Energy consumed** in the manufacture of devices such as desktops, tablets, smartphones etc. that are used for digital content. **Energy consumed** by the associated infrastructure (data centres and communication networks) to produce, deliver, store, download and read e-books.
First order effects	Operational energy	**Energy consumed** to operate the ICT device
First order effects	Disposal energy	**Energy consumed** to dispose the ICT device
Second order effects	Efficiency	Does not apply for e-books
Second order effects	Substitution	**Energy consumed or saved** when traditional paper books are replaced by e-books. For example, although at first glance it may appear that energy can be saved with e-books, Enroth (2009) found that the net global warming impact highly depends on various factors such as type of paper used, number of times a paper-based book is used, energy efficiency and life-span of the ICT device.
Third order effects	Direct rebound effect	**Energy used** in reading an additional book promoted by cheaper and improved utility of e-books
Third order effects	Indirect rebound effect	**Energy consumed or saved** in producing and consuming goods, whose demand has increased as a result of the expense saved from adopting e-books in place of paper-based books. This will depend on the energy intensity of the complementary goods.
Third order effects	Economy-wide rebound	**Energy consumed or saved** when hitherto investments in the paper and book industry are channelled towards other more or less energy-intensive sectors.
Third order effects	Transformational change	**Energy consumed or saved** as a result of far-reaching society wide changes in industrial, organisational and social structures following the adoption of e-books. The example used by Galvin (2015) for electronic journals can be applied here. With further adoption of e-books, social practice and socio-technical structures in schools will be changed; remote servers for internet use, systems of access rights; remote cloud storage and its servers; and people to maintain these technologies, generally with additional layers of ICT.

studies on e-health technologies such as EMR and tele-health or robotic technologies could only be found to include the first order and/or second order effects. This is one of the reasons why energy-savings through the adoption of ICT are found to be overestimated (Bieser & Hilty, 2018; Court & Sorrell, 2020). The study "SMARTer 2030" by GeSI (2015) estimated that carbon footprint from decreased travel and lower use of physical health care resources (e.g. space in office buildings) with the adoption of e-health technologies could be reduced by 200 mega tonnes globally by 2030. They also estimated 100 mega tonnes of CO_2 emissions to be reduced globally per year due to e-learning technologies like e-books, MOOCs, e-learning apps etc. (GeSI, 2015). Although the study did include a 7% rebound effect for these technologies, this figure was taken from a secondary data source not specific to e-health and e-learning technologies. Bieser & Hilty (2018) also points out that GeSI (2015) considers e-health, e-learning etc. as individual and separate studies that is assumed to not interact with one-another. For example, even if e-learning provides the opportunity to save travel time and its emissions, a student studying from home will still need to make a trip to the supermarket to buy groceries which (s)he would have previously done on the way from school or college. Even if this trip can be cancelled with the adoption of e-commerce technologies, the student may still prefer to go out (Bieser & Hilty, 2018). Therefore, there are much wider "systemic effects" associated with the adoption of ICTs to also be considered before concluding their environmental impacts (Bieser & Hilty, 2018).

The EE-IO analysis carried out in Chapter 4 captures only the first order effects for the United States in 2009 as the technical coefficients are fixed for a given period. However, if I-O tables can be compared between different points in time, the change in technical coefficients will be able to capture first-order effects as well as the effects of substitution that has already taken place. Additionally, when their total (direct+indirect) upstream emissions are compared, substitution and rebound effects based on final demand will also be included. Similarly, when I-O tables are compared between two different countries, the difference in technical coefficients will capture all effects at a particular point in time. However, a limitation is that such an analysis does not decompose the total change into first, second, and third-order effects, that is, the three kinds of impacts are not explicitly distinguished. But implicitly, when one compares two different I-O tables, all effects will be included. This leads to the investigation of the environmental burden resulting from the rising technology-intensity in health care based on a comparative EE-IO analysis.

5.2 Empirical analysis

As explained in section 3.2, the United States has the highest health care spending, both as a percentage of GDP and per capita, among all the developed countries. Figure 22 shows the national and per capita spending in constant 1997 prices on hospital services, physician and nursing services, medicines, medical technology and administrative activities from 1960 to 2018. It is to be noted that although it may be more ideal to compute the 'per patient' expenditures since part of the U.S. population does not have an insurance and may not be using the medical system much, data for it was not available.

From Figure 22, it can be seen that health care spending trends between national and per capita expenditures, although upward for all sub-activities, differ in growth rates for some of them. Expenditures on hospital services such as fee charged to cover operating room services, in patient and outpatient care services, in patient pharmacy and hospital-based nursing and home health care (CMS, 2019) have grown the highest over the years on a national and per capita basis. This can hint at an increasing use of energy resources in hospitals as patients are generally charged for electricity use of medical equipment. For example, a study by Power et al. (2012) found that CO_2 emissions from the operating room specific to minimally invasive laparoscopic procedures at an institution increased with rise in robot assisted surgeries and another study by Thiel et al. (2015) found that robotic surgical method consumes

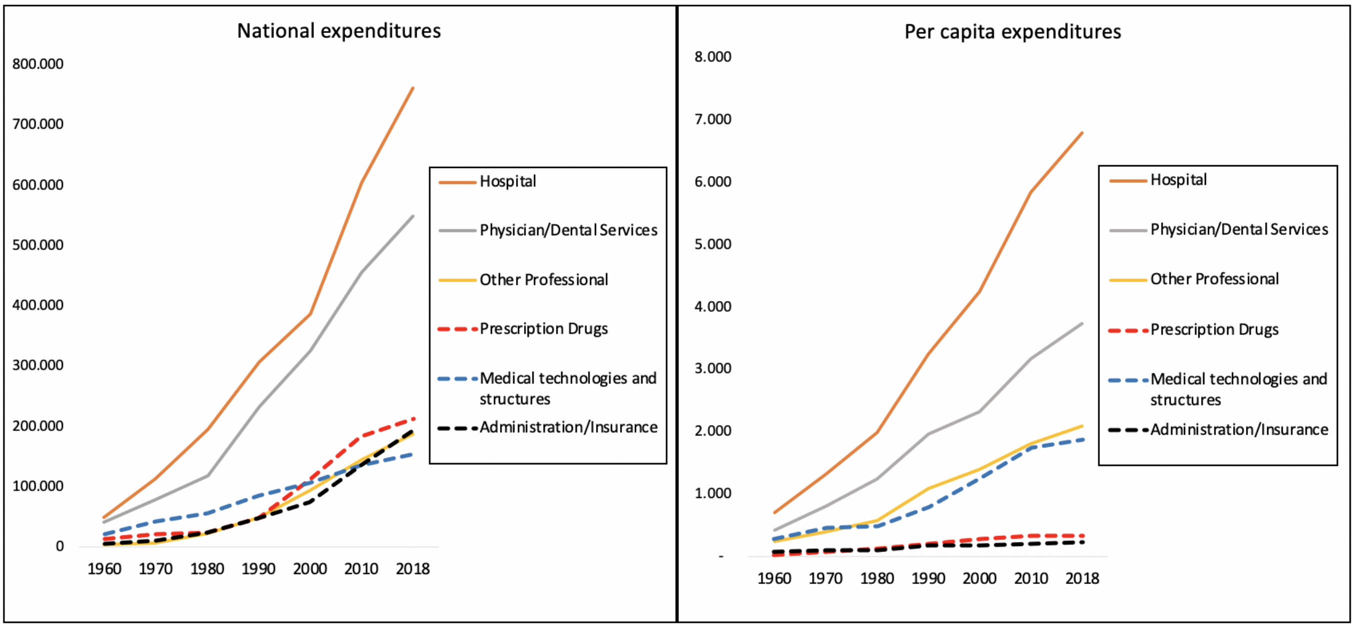

Figure 22: National and per capita expenditures on various sub-activities of health care in 1997 prices. **Country:** United States. **Source:** CMS (2019)

3 times more energy and emits 2 times more GHG than the average of other regular surgical methods like abdominal, vaginal, laparoscopic during a procedure like hysterectomy. On the national level, spending on administrative services, prescription drugs and medical technologies & structures (including capital equipment like software) have grown by almost 33 times, 15 times and 7 times respectively with sharp increases from 1980. A possible explanation for this is the push for deregulation during the (Reagan-Thatcher) neo-liberal era and the lack of investment in health education programs (Frakt, 2018). On a per capita basis, the spending on prescription drugs and administrative activities have not grown much relative to other activities whereas the spending on medical technologies has grown by 6 times from 1960 to 2018. Irrespective of the different trends, Figure 22 illustrates the growing size of the health care sector and its sub-activities in the United States. When a sector grows in size, the carbon footprint associated with the different sub-activities is also bound to increase (unless energy use becomes completely renewable). Figure 23 depicts the CO_2 emissions associated with the rising expenditures in health care by simply multiplying the spending trends of the different sub-activities with their fixed CO_2 intensities taken from the EIO-LCA[12] model developed by the Carnegie Mellon University Green Design Institute (2020) available at www.eiolca.net. It is to be noted that the carbon intensities taken from the EIO-LCA model are based on the 1997 purchaser price model (same base year as the expenditure data) and cannot reflect any changes in energy efficiency of technologies or other changes in the production of output over time that may have had an impact on the carbon footprint of health care. In other words, the carbon footprint is assumed to vary linearly with expenditure trends. This exercise is done to paint a picture of the growing size of health care activities such as medical technologies, pharmaceuticals and hospital services and their possible environmental burden.

Figure 23 shows that the carbon footprint associated with hospital services, medical technologies and prescription drugs are very high. On the other hand, the carbon footprint associated with physicians

[12]Environmental Input-Output Life Cycle Assessment

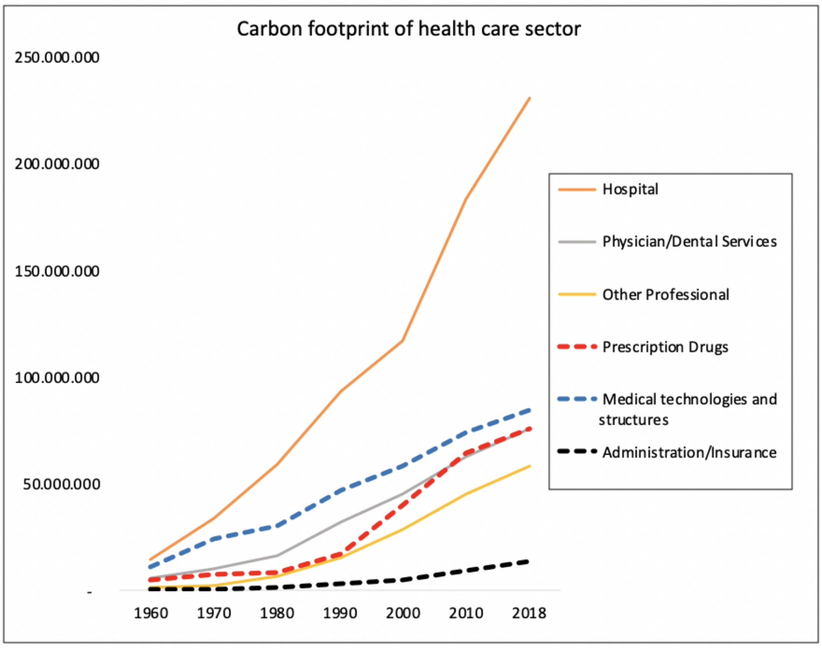

Figure 23: National CO_2 emissions based on expenditures in health care. **Country:** United States. **Source:** Carnegie Mellon University Green Design Institute (2020); CMS (2019). **Reference:** Chung & Meltzer (2009)

and other professional services (such as services offered in the offices of therapists etc.) are relatively lower. This validates that human work in health care is less polluting. If the environmental burden of health care technologies did not improve in energy efficiency over the years, then the plot in Figure 23 can illustrate the growing environmental burden of the health care sector. However, in reality, technologies must have gotten more efficient and the kind of material inputs purchased by health care activities must have changed over time (for example, the plot does not explicitly depict the increased adoption of ICT devices). Therefore this will require an investigation of the changing technical coefficients *per unit of health care output* over the years. For this, one would need to compare input-output or technical coefficients of the health care sector based on an EE-IO analysis.

5.2.1 Comparison of technology trends and their environmental burden between 1995 and 2015 in the United States

The first empirical investigation is to examine whether technology-intensity in terms of adoption and use of medicines, medical technologies and ICTs have increased over the years in the health care sector in the United States. To do this, I track the changes in the technical coefficients derived from the Input-Output tables between the years 1995 and 2015 for the United States. I choose to use the OECD.stat database for the I-O tables in this investigation instead of the WIOD database that was used in Chapter 4 due to the following reason. The industry classifications of the I-O tables are different for the years 1995 and 2015 in both OECD.stat and WIOD databases, that is, the 1995 I-O table is based on ISIC Rev.3 (see section 2.3.1) and the 2015 I-O table is based on ISIC Rev.4 (a slightly more detailed classification than the ISIC Rev. 3). However, in OECD.stat, the two I-O tables are more comparable as they have almost the same I-O matrix dimensions than the ones in WIOD.

To begin my investigation, I need to first adjust the I-O tables of 1995 and 2015 for price changes. To do this, I use the method of "double deflation" provided by Miller & Blair (2009). In this method, all the outputs of an industry, i.e., the outputs sold to other industries (intermediate sales) and to final demand (final consumption), are multiplied by the price index for that industry's output (Miller & Blair, 2009). The biggest limitation of this method is that the outputs to other industries and to final consumers are deflated by the same price index. In the real world, this may not be too accurate as inter-industry prices may differ, especially when the analysis is done at an aggregated industry-level (Miller & Blair, 2009). However, due to the lack of I-O tables at highly disaggregated product levels in publicly available databases, double deflation seems to be the most appropriate method. The I-O tables for the years 1995 an 2015 are adjusted to constant 1997 prices using the price indices provided by the EU KLEMS database.

If technology-intensity in the health care sector did increase over the years, then it could be visible in the changing technical coefficients of the Leontief Inverse matrix. To analyse this, steps 1 to 3 of the EE-IO analysis taken in section 4.2.4 are carried out for the inflation-adjusted I-O tables of 1995 and 2015. From the resulting Leontief inverse matrices, the column for the health care sector in 1995 and 2015 are taken out and compared. These two columns represent the total (direct+indirect) inputs purchased by the health care sector from all industries (including itself) to produce $1 of its output in 1995 and 2015 respectively. This is shown in Figure 24.

The difference in the technology-intensities between 2015 and 1995 is computed in the fourth column in Figure 24. If the difference associated with a particular industry in the fourth column is found to be *positive*, it means that the health care sector has purchased more of that industry's output (directly + indirectly) in 2015 than in 1995 to produce $1 of its output. Based on the trends discussed in Chapter 3, I have highlighted the difference in technical coefficients for five industries that may be the most relevant to my study. The descriptions of the selected industries are given in appendix A.6. Out of the highlighted industries, the total inputs purchased from computer, electronic and optical equipment industry, electricity and water supply industry, telecommunications industry and renting activities (includes administrative services) per unit of output by the health care sector are found to be **higher** in 2015 than in 1995. Now it should be noted that the differences are very small because the comparisons are between 'technical coefficients' that are represented per $1 of health care output. However, percentage changes are in some cases considerable. For example, the intensity of use of electricity, gas, and water has increased by 27% and that of telecommunication services has increased by 104%. These results indicate that the technology/ material-intensity in terms of purchase of medical technologies, ICT technologies, administrative technologies, and electricity by the health care sector have **increased** from 1995 to 2015. For example, the increased purchase of electricity by hospitals (a significant part of the health care sector) could hint at a higher use of medical equipment, surgical procedures (possibly due to robotic assisted procedures) etc.. Yet, each specific trend discussed in Chapter 3 such as digital health, robotic-assisted procedures etc. cannot be identified at such an aggregated industry-level. Perhaps if the I-O tables are taken in terms of distinct products instead of industries, one may be able to trace the adoption of specific trends like robot-assisted surgical procedures in health care. However, as mentioned before, this is not possible in my study due to the lack of such detailed I-O tables.

An unexpected outcome is that the inputs purchased from the chemicals and pharmaceuticals industry

Comparison of technology intensities	USA 1995 health care technology coefficients taken from Leontief inverse matrix	USA 2015 health care technology coefficients taken from Leontief inverse matrix	Difference (2015 health care-1995 health care)	Percentage change
Agriculture, forestry and fishing	0,005	0,005	0,000	9%
Mining & quarrying	0,006	0,007	0,001	9%
Food products manf.	0,012	0,012	0,000	2%
Textile products manf.	0,004	0,002	-0,002	-56%
Wood products manf.	0,004	0,002	-0,002	-49%
Paper products manf.	0,033	0,009	-0,024	-72%
Coke, refined petroleum products manf.	0,006	0,004	-0,002	-31%
Chemicals & pharmaceutical products	0,054	0,032	-0,022	-40%
Rubber & plastics products	0,010	0,006	-0,004	-38%
Other non-metallic mineral products	0,005	0,003	-0,003	-49%
Basic metals	0,004	0,002	-0,003	-61%
Fabricated metal products	0,007	0,004	-0,003	-44%
Machinery and equipment	0,005	0,004	-0,002	-33%
Computer, Electronic & optical equipment	0,009	0,023	0,014	162%
Electrical machinery and apparatus	0,002	0,001	-0,001	-39%
Motor vehicles, trailers & semi-trailers	0,005	0,001	-0,003	-74%
Other transport equipment	0,001	0,001	-0,001	-62%
Manufacturing nec; recycling	0,012	0,007	-0,005	-44%
Electricity, gas & water supply	0,011	0,014	0,003	27%
Construction	0,006	0,001	-0,006	-92%
Wholesale &retail trade	0,058	0,065	0,007	13%
Hotels & restaurants	0,013	0,011	-0,002	-15%
Transport & storage	0,021	0,016	-0,005	-25%
Post & telecommunications	0,023	0,046	0,024	104%
Financial intermediation	0,057	0,131	0,075	132%
Real estate activities	0,059	0,095	0,036	60%
Renting & other business services	0,105	0,121	0,016	16%
Public administration &defence	0,010	0,012	0,002	18%
Education	0,007	0,007	0,000	3%
Human health & social work	1,017	1,025	0,009	1%
Arts, entertainment, recreation & other services	0,017	0,005	-0,012	-68%

Figure 24: Comparison of the technical coefficients of health care sector of USA in 1995 and 2015. Author's calculations.

by the health care sector seem to have decreased from 1995 to 2015. What could explain this decline? Two possible explanations come to mind. Firstly, the production of chemicals & pharmaceutical products may have shifted from the United States to other countries. For example, since the late 1990s, there has been high growth of pharmaceutical imports from countries like China, India and few European countries to the United States largely due to the 'offshoring' of their manufacturing facilities (Byers & Ferry, 2020). However, this cannot be reflected in Figure 24 as the technical coefficients are taken to represent only domestic inputs and not international inputs (associated with imports). To account for imports, the change in the technical coefficient of chemicals & pharmaceutical products associated with total production (domestic production and imports) using 'Total' I-O tables (taken from OECD.stat) from 1995 to 2015 is computed. The result shows that the percentage change in the use of chemicals & pharmaceutical products by health care to produce $ 1 of output from 1995 to 2015 is actually -32% (up from -40%). Therefore, an increase in purchase of pharmaceuticals imports explains 20% of the decrease in the purchase of domestic pharmaceutical inputs from 1995 to 2015.

Secondly, if trends such as pharmaceuticalisation and direct-to-consumer advertising are associated with the purchase of medicines and prescription drugs by *final household consumers* and not so much by the health care sector itself, the change in the outputs purchased from the chemical and pharmaceutical industry by final households from 1995 to 2015 need to be analysed. It is found that the percentage of sales of the chemical and pharmaceutical industry to final household consumers out of their total sales (part of the final demand vector) has **increased** from 23% in 1995 to 39% in 2015. However, this is not conclusive evidence because it could also be that the population of the country increased faster than the output of the pharmaceutical industry which has resulted in an increased share of total sales to households. To verify this, the final demand for chemicals and pharmaceuticals is computed per capita for the years 1995 and 2015 which again showed an increase in purchases by almost 2 times.

In sum, the technology/ material-intensity of health care has increased from 1995 to 2015 in the United States on an industry-level. The results found could also be used as preliminary empirical support to the more general and growing trend of 'fixing' people's health with medicines and medical technologies.

The next step is to compute and compare the environmental burden resulting from the increased technology-intensity in health care. Although four different environmental impacts were calculated in Chapter 4, only CO_2 emission intensities are computed here to keep things simple. The direct CO_2 emissions (only domestic) of each economic activity are taken from two separate environmental databases provided by the WIOD i.e. the 2013 and 2016 release. It is found that the direct emissions from health care sector *declined* by 45% from 1995 to 2015 in spite of an *increase* in total output by 95% during the period. This is shown in Table 9. A possible explanation for this decline in direct emission intensity of health care is the adoption of clean-energy practices by hospitals and clinics in the United States such as energy efficient equipment and other energy conservation initiatives (Association of American Medical Colleges, 2019). For example, Kaiser Permeate, one of America's leading integrated health care systems, uses renewable energy sources such as solar and wind to power 27 of its hospitals as of 2018 (Kaiser Permanente, 2018). Similarly, Cleveland Clinic maintains funds to invest in projects such as LED retrofits, intelligent automation of energy use in operating rooms etc. that improve their energy footprint (Association of American Medical Colleges, 2019). Additionally, the increased adoption of telemedicine could have also contributed to the decreased direct effect (GeSI, 2015). These recent developments hints that the carbon footprint may not have increased linearly with the size of the health care sector as shown in Figure 23. This may be considered good news for the environment. However, this cannot be fully concluded yet as direct emissions still represent emissions from sector of origin perspective and it is also essential to investigate it from sector of use perspective. This requires the total (direct+indirect) emission intensity vector B for both the years which can be computed as per step 4 given in section 4.2.4. The total emission intensity vector B for health care in 1995 and 2015 is shown in Figure 25.

From Figure 25, it is seen that the total emission intensities have also decreased from 1995 to 2015. This is primarily because of the decreased direct emission intensity. But even as direct effects in 2015 has become nearly 1/3rd of that in 1995, what is surprising is that the indirect effects have not reduced proportionately. The indirect effects in 2015 is almost as big as that in 1995. This requires a further investigation of the direct and indirect effects. To do this, I breakdown the total intensity vector B for health care similar to the analysis in Figure 18 for both the years. Figure 26 shows the emission contribution from various economic activities including health care in producing $1 million of health care output.

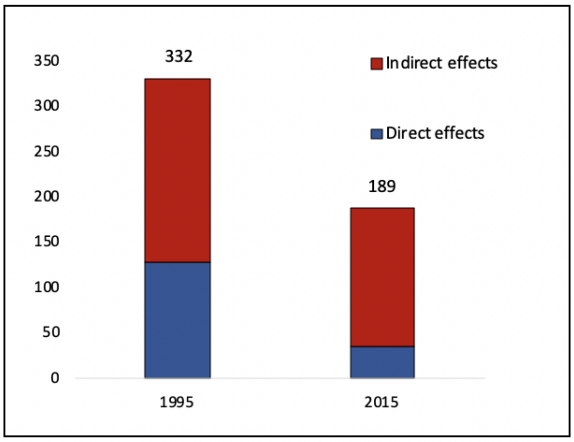

Figure 25: Direct and Indirect CO_2 emission intensities (in tonnes/ million \$) for the health care sector in 1995 and 2015. Author's calculations.

Comparison of total emission intensities	Total intensity vector 'B' of health care 1995	Total intensity vector 'B' of health care 2015	Difference (2015 health care-1995 health care)
Agriculture, forestry and fishing	1,348	0,966	-0,381
Mining & quarrying	5,299	3,289	-2,010
Food products manf.	1,314	1,156	-0,158
Textile products manf.	0,533	0,081	-0,452
Wood products manf.	0,703	0,132	-0,571
Paper products manf.	5,846	1,598	-4,249
Coke, refined petroleum products manf.	8,131	2,779	-5,352
Chemicals & pharmaceutical products	23,866	11,752	-12,114
Rubber & plastics products	0,495	1,129	0,634
Other non-metallic mineral products	8,703	3,818	-4,885
Basic metals	2,704	1,046	-1,658
Fabricated metal products	3,449	0,100	-3,349
Machinery and equipment	0,429	0,255	-0,174
Computer, Electronic & optical equipment	0,292	0,057	-0,235
Electrical machinery and apparatus	0,197	0,037	-0,159
Motor vehicles, trailers & semi-trailers	0,165	0,009	-0,156
Other transport equipment	0,162	0,019	-0,143
Manufacturing nec; recycling	0,664	0,335	-0,329
Electricity, gas & water supply	88,351	94,336	5,986
Construction	0,540	0,033	-0,507
Wholesale &retail trade	7,726	1,728	-5,999
Hotels & restaurants	2,375	0,730	-1,645
Transport & storage	18,828	18,765	-0,063
Post & telecommunications	1,312	0,497	-0,815
Financial intermediation	2,270	1,200	-1,070
Real estate activities	0,745	0,413	-0,333
Renting & other business services	8,209	3,752	-4,456
Public administration &defence	3,526	1,610	-1,916
Education	0,207	0,144	-0,062
Human health & social work	130,595	37,224	-93,371
Arts, entertainment, recreation & other services	3,071	0,230	-2,842

Figure 26: Total emission intensity vector B for 1995 and 2015 breakdown: Author's calculations.

The difference in the total emission intensity of health care between 2015 and 1995 (fourth column) in Figure 26 represents how much more (or less) CO_2 emissions is contributed from a particular industry to produce \$1 million of health care output in 2015 than in 1995. Further, when the difference for a particular industry is found to be *positive*, it means that the indirect emissions from that industry to health care is more in 2015 than in 1995. Considering the same relevant industries, it is seen that the indirect emission contribution from **(domestic)** chemical and pharmaceutical industry, computer and optical equipment industry, telecommunications industry and administrative services in producing $1 million of health care output is lesser in 2015 than in 1995. This decrease in emission intensities in these industries is observed despite an increase in their technology-intensities (except for pharmaceutical industry) from 1995 to 2015. To understand why, it may be useful to compare the direct intensity vectors b for the two years. The table for this comparison is presented in Appendix A.7. The CO_2 emission intensities of all the economic activities except the transportation industry have decreased from 1995 to 2015. This is expected as in Chapter 2, section 2.2, I did find relative decoupling in CO_2 emissions in the United States while emissions from the transportation sector increased. One of the explanations for this improvement in intensities was found to be the switch made from the use of coal to natural gas, a newer fossil-fuel with lower CO_2 emissions. This essentially means that during the period of my study, the reduction in the indirect emission contribution from the selected industries to health care may be due, not to decreased energy use (per unit of output), but to substitution between sources of energy. This claim is supported by the rising technical coefficients of the mentioned industries from 1995 to 2015 as seen in Figure 24.

Therefore, from an environmental point of view there are at least three reasons to remain concerned with the increased technology-intensity of health care. Firstly, to the extent that the decline in CO_2 emissions is due to substitution between coal and natural gas, it should be noted that natural gas now includes shale gas whose share in U.S. gas production has increased rapidly (from 8% in 2007 to 63% in 2018 (EIA, 2020a)). While the production of shale gas was at its all-time high in 2019 in the U.S., several environmental problems associated with drilling for shale gas have been reported in the literature such as higher methane emissions (at least 25 times more polluting than CO_2) than coal, contamination of surface and ground water and most importantly, the continued dependence on earth's finite natural resources (Annevelink et al., 2016; Howarth et al., 2011; Kusnetz, 2020). Interestingly, the fracking[13] boom since 2007 in the U.S. was made possible only by extremely low interest rates and not because the industry is profitable which means that if at some point interest rates would go up (highly likely), most firms in the shale gas business would go bankrupt (Mikulka, 2018). This goes on to show that the substitution of coal with natural gas is not really good news for the environment since the shale gas industry is environmentally and economically unsustainable to even bridge the gap between coal and fully renewable energy sources. Secondly, a more conclusive assessment of the environmental effects of increased technology-intensity will require a complete investigation into substitution between domestic and international production, that which will depend on the different carbon intensities of industries in the exporting countries. For example, it is observed that total consumption-based emissions (includes emissions 'offshored' elsewhere) of the U.S. is higher than total production-based emissions (only domestic emissions) (Ritchie, 2019). This means an increase in 'imports' and decrease in domestic production, for instance, of pharmaceuticals in the U.S. could lead to reduced domestic and increased international emissions (the environmental burden of pharmaceutical manufacturing is higher in developing countries like India due to lax environmental regulations (Bruni, 2016)) which is not going to solve the environmental problems. However, it is not feasible to compute the international

[13]The process of drilling for shale gas

emissions from imports in this study due to time constraints. Thirdly, however much the carbon-intensity of energy production declines, ultimately, it will not be possible to compensate for the rising energy-intensities of production. This is illustrated in Table 8 below.

Table 8: Comparison of the CO_2 emissions from increased use of energy per unit of output

	1995	**2015**	**Percentage change**
Carbon intensity of electricity & water supply industry (domestic only!) (in tonnes/ million $)	7897,85	6616,73	-16%
Technical coefficient $(I-A)^{-1}$	0,011	0,014	+27%
Total emission intensity $b^*(I-A)^{-1}$ (in tonnes/ million $)	88,35	94,34	+7%

Figure 26 shows that the electricity industry indirectly contributes almost 6 tonnes **more** CO_2 emissions to produce $1 million of health care output in 2015 than in 1995. This may be surprising because one might expect the emission contribution from the electricity industry to be smaller due to its switch to less carbon-intensive energy sources which is visible in the decline of its direct intensity (about 7.898 tonnes/ million $ in 1995 and 6.617 tonnes/ million $ in 2015). However, the direct intensity of the electricity industry compared to that of other industries is still very high that even a small increase in the technical coefficients associated with it (27% in this case) will show a significant increase in environmental burden. Therefore, the increase in the purchase of energy per unit of output from 1995 to 2015 in health care (possibly due to increased use of medical technologies) has resulted in a higher environmental burden despite most industries making the switch to less carbon-intensive energy sources.

As a final step, the EE-IO analysis is extended to include the total emissions associated with final demand f of health care (i.e. the total upstream emissions vector E in step 5 in section 4.2.4) in 2015 and 1995. The results of this step are shown in Table 9. It is seen that health care sector's total upstream emissions in 2015 is 27 million tonnes **more** than that in 1995. This means that the total (direct+indirect) environmental burden has actually **increased** (although slower) with increase in size of health care sector. This trend is opposite to what is observed with direct emissions from health care. One important reason for this increase is the health care sector's increased demand for inputs from the electricity and water supply sector. Therefore, the environmental burden of health care has increased from 1995 to 2015 largely due to the increase in energy intensity, possibly due to increased use of ICT and related medical technologies, despite the electricity sector becoming less carbon-intensive.

Table 9: Comparison of total upstream emission intensity of health care

Indicator	**1995**	**2015**	**Percentage change**
Total output of health care (in million $)	728.825	1.420.762	+95%
Direct emissions from health care (in tonnes)	93.633.162	51.590.760	-45%
Total upstream emissions from health care (After EE-IO) (in tonnes)	234.727.784	261.909.467	+12%

To conclude, the technology-intensity of health care (in terms of medicines, medical technologies, ICTs and administrative technologies) has increased. This has not led to higher CO2 emission intensity of health care, mainly due to an economy-wide shift from carbon-intensive to less carbon-intensive energy sources. However, this does not necessarily imply lower pressure on the environment, since most technical coefficients (including the energy-intensity) of health care (as well as most of the industries supplying to health care) increase over time. Table 8 illustrates this point: the environmental burden from the increased use of electricity and water resources in health care services is found to have increased, despite substitution between energy sources. Also, if computed, the international emission intensities for the purchase of imports by health care could offset a portion of the decrease in emission contribution from some industries (like pharmaceuticals). Lastly, the total upstream CO_2 emissions from health care is found to have increased from 1995 to 2015 despite a decline in its direct emissions which suggests that the increased purchase of energy inputs per unit of health care output, likely due to the increase in use of medical technologies and equipment, has increased the environmental burden of health care.

To strengthen this empirical evidence, it may also be useful to compare the technical coefficients of the health care sector between the United States and Canada. From a brief literature review in section 3.2.3, it was found that the Canadian health care system is less technology-intensive (in terms of ICTs and medical technologies) than the United States' health care system with similar or sometimes slightly better quality of health care. If this difference can be observed in the I-O tables of the U.S. and Canada, one can compare their respective environmental burden.

5.2.2 Comparison of technology trends and their environmental burden between the United States and Canada

To investigate the different technology-intensities in health care between Canada and the United States, the technical coefficients of the health care sector from the Leontief inverse matrix are compared for the year 2014. The database used for this analysis is the WIOD 2016 release that classifies economic activities based on ISIC Rev. 4 (a slightly more detailed classification than the ISIC Rev. 3 given in section 2.3.1). An analysis similar to the one performed in the previous section is carried out with just one difference, that is, instead of comparing the technical coefficients of the health care sector between two time periods, they are compared between two countries for the same year. Figure 27 shows the technical coefficient column of the health care sector in the U.S. and Canada taken from their respective Leontief inverse matrices.

The difference between the two countries (the fourth column) in Figure 27 represents how much more (or less) of each industry's output is purchased by the health care sector of the U.S. than that of Canada in order to produce $1 of its output. Similar to Figure 24, I have highlighted the difference in technical coefficients for six relevant economic activities (refer appendix A.6 for their descriptions). The results found in the fourth column in Figure 27 shows that the health care system in the United States purchases **more** chemical products, pharmaceutical products (includes prescription drugs), medical technologies such as CT, MRI equipment, consumer electronics, telecommunication services, information services (includes software applications, streaming services) and administrative services in order to produce $1 of health care output than Canada. Interestingly, U.S. health care also uses less 'human health and social work' than Canadian health care. However, if there is a difference in the way the U.S. and Canadian hospitals are organised, for example, if IT services are outsourced by hospitals to

Comparison of technology intensities	USA Health care technology coefficients from Leontief inverse	Canada Health care technology coefficients from Leontief inverse	Difference (USA health care-Canada health care)
Crop & animal production, hunting	0,006	0,003	0,0032
Forestry & logging	0,001	0,001	0,0000
Fishing and aquaculture	0,000	0,000	0,0000
Mining and quarrying	0,007	0,006	0,0007
Food products manf.	0,018	0,007	0,0109
Textile and leather manf.	0,002	0,001	0,0018
Wood products manf.	0,002	0,001	0,0013
paper prod manf.	0,006	0,003	0,0036
Printing & reproduction of recorded media	0,004	0,003	0,0012
Coke & refined petroleum products manf.	0,012	0,009	0,0028
Chemical products manf.	0,016	0,003	0,0139
Pharmaceuticals products manf.	0,008	0,003	0,0056
Rubber & plastic products manf.	0,008	0,002	0,0061
Other non-metallic mineral products manf.	0,003	0,001	0,0019
Basic metals manf.	0,004	0,002	0,0019
Fabricated metal products manf.	0,006	0,003	0,0026
Computer, electronic & optical products manf.	0,005	0,003	0,0020
Electrical equipment Manf.	0,001	0,001	0,0005
Machinery and equipment manf.	0,002	0,004	-0,0013
Motor vehicles, trailers & semi-trailers manf.	0,003	0,002	0,0008
Transport equipment manf.	0,001	0,000	0,0008
Other manuf.	0,016	0,021	-0,0055
Repair & installation of machinery and equipment	0,001	0,000	0,0010
Electricity, gas, and steam supply	0,009	0,012	-0,0028
Water collection, treatment and supply	0,000	0,000	0,0003
Sewerage; waste collection & treatment	0,003	0,002	0,0017
Construction	0,006	0,015	-0,0091
Wholesale and retail trade	0,006	0,037	-0,0318
Wholesale trade	0,030	0,021	0,0096
Retail trade	0,004	0,014	-0,0105
Land transport	0,009	0,009	0,0003
Water transport	0,001	0,000	0,0004
Air transport	0,003	0,001	0,0015
Support activities for transportation	0,005	0,002	0,0033
Postal & courier activities	0,003	0,005	-0,0013
Accommodation & food service activities	0,016	0,004	0,0119
Publishing activities	0,005	0,001	0,0039
Motion picture, video and broadcasting	0,006	0,003	0,0036
Telecommunications	0,015	0,014	0,0014
Computer programming, information services	0,014	0,005	0,0093
Financial service activities	0,020	0,014	0,0051
Insurance, reinsurance and pension funding	0,057	0,006	0,0514
Activities auxiliary to finance	0,018	0,000	0,0182
Real estate activities	0,080	0,029	0,0515
Legal & accounting activities; management consultancy	0,053	0,009	0,0437
Architectural and engineering activities	0,015	0,002	0,0132
Scientific research & development	0,008	0,003	0,0054
Advertising & market research	0,009	0,010	-0,0017
Other professional, scientific & technical activities	0,003	0,005	-0,0023
Administrative & support service activities	0,062	0,025	0,0366
Public administration & defence; social security	0,018	0,007	0,0108
Education	0,002	0,002	-0,0007
Human health and social work	1,011	1,028	-0,0170
Other service activities	0,015	0,014	0,0007
Activities of households	0,001	0,000	0,0005

Figure 27: Comparison of the technical coefficients of health care sector of USA and Canada from Leontief inverse. Author's calculations.

the IT service sector in the U.S. whereas they are developed in-house by hospitals in Canada, then the technical coefficient representing intermediate purchases by the health sector from the IT service sector would indeed be lower for Canada. This is because the 'in-house' IT would be recorded as 'value added' or payment for labour (at the bottom of the I-O table, not captured by inter-industrial transactions). But even in this case, equipment related to IT services, like computers, telecommunication services etc. would still have to be purchased from other industries (for example, manufacturing). Computers being capital goods, the purchase of computer equipment would not show up in the intermediate deliveries. In the row, it would be recorded under final demand; in the production column, it would be recorded as part of capital costs (i.e. as part of value added or 'factor' payments). So, if Canadian hospitals do develop their own IT, this will imply a redistribution within the production column (from 'external deliveries of IT services' to (internal) value added.). Although these types of differences in health care organization cannot be captured when comparing the technical coefficients of the health care sector between the two countries, it should be noted that this has no implications for my emission analysis, at least not in the aggregate (further explanation in subsequent paragraphs). Besides the higher technical coefficients in the U.S. than in Canada for the relevant industries, the final demand per capita for pharmaceutical products is found to be 1,5 times higher in the United States than in Canada. In sum, the health care in the U.S. is observed to be more technology/material-intensive than Canada on an industry-level.

The next step is to compare the corresponding environmental burden for the health care sector in the U.S. and Canada. To carry out this step, the total (direct + indirect) emission intensity vector 'B' as per step 4 of the EE-IO analysis (see section 4.2.4) is computed for the two countries. The CO_2 emission intensities or the direct intensity vector 'b' for both the countries required for this step are taken from the WIOD database. Figure 28 shows the direct and indirect emission intensities of the health care sector in the U.S. and Canada.

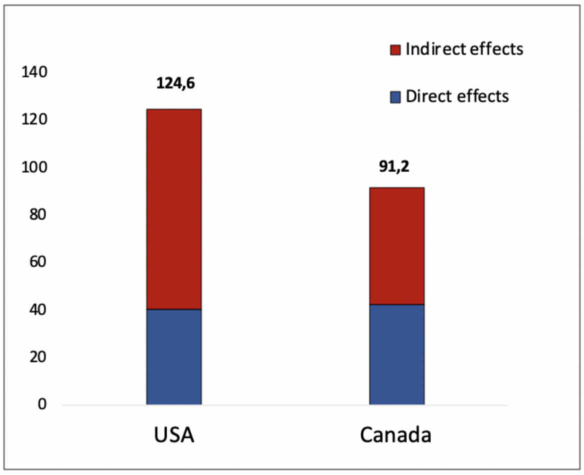

Figure 28: Direct and Indirect CO_2 emission intensities (in tonnes/ million $) for the health care sector in the U.S. and Canada. Author's calculations.

It can be seen that while the direct effects are almost equal for both the countries, the indirect effects of health care are almost two times higher in the U.S. than in Canada. Now, if the organisation of health care is different between the two countries, that is, if Canadian hospitals do increasingly use (in-house) IT services, whereas U.S. hospitals buy (external) IT services, the direct emissions of Canadian hospital will be higher than those of U.S. hospitals, and U.S. hospitals will have higher indirect emissions than Canadian hospitals. Therefore, only the relative importance of direct and indirect effects may be affected while the aggregate effects will remain the same. Since the highly aggregated I-O tables cannot capture such differences in organisational structures between health care systems, their impact on technology-intensity and the relative importance of direct and indirect effects will remain a limitation of my study. Now referring to Figure 28, the large difference in indirect effects between U.S. health care and Canadian health care calls for a further investigation of the computed total emission intensity vector B. Figure 29 shows the breakdown of the health care total emission intensity vector value for both the countries (similar to the analysis in Figure 26).

The difference between U.S. and Canada in the fourth column in Figure 29 represents how much more (or less) emissions are contributed from each economic activity to produce $1 million of health care

Comparison of total emission intensities	Total intensity vector 'B'of health care (USA)	Total intensity vector 'B'of health care (Canada)	Difference (USA-Canada)
Crop & animal production, hunting	0,71	0,54	0,17
Forestry & logging	0,05	0,20	-0,15
Fishing and aquaculture	0,02	0,00	0,02
Mining and quarrying	1,36	3,12	-1,77
Food products manf.	1,08	0,29	0,79
Textile and leather manf.	0,11	0,03	0,08
Wood products manf.	0,14	0,14	0,00
paper prod manf.	1,06	0,43	0,63
Printing & reproduction of recorded media	0,14	0,11	0,03
Coke & refined petroleum products manf.	1,90	2,18	-0,28
Chemical products manf.	4,43	1,47	2,96
Pharmaceuticals products manf.	0,04	0,02	0,02
Rubber & plastic products manf.	1,04	0,20	0,84
Other non-metallic mineral products manf.	2,85	0,78	2,07
Basic metals manf.	1,49	0,72	0,77
Fabricated metal products manf.	0,15	0,05	0,10
Computer, electronic & optical products manf.	0,06	0,07	-0,01
Electrical equipment Manf.	0,04	0,03	0,01
Machinery and equipment manf.	0,14	0,14	0,00
Motor vehicles, trailers & semi-trailers manf.	0,02	0,02	0,00
Transport equipment manf.	0,04	0,01	0,03
Other manuf.	0,61	0,40	0,20
Repair & installation of machinery and equipment	0,07	0,00	0,07
Electicity, gas, and steam supply	45,10	21,28	23,82
Water collection, treatment and supply	0,40	0,00	0,40
Sewerage; waste collection & treatment	0,29	0,18	0,11
Construction	0,30	0,45	-0,15
Wholesale and retail trade	0,19	1,18	-0,99
Wholesale trade	0,51	0,84	-0,33
Retail trade	0,18	0,93	-0,75
Land transport	4,34	3,18	1,15
Water transport	0,66	0,81	-0,15
Air transport	2,94	2,32	0,62
Support activities for transportation	0,58	0,16	0,42
Postal & courier activities	0,23	0,34	-0,11
Accommodation & food service activities	1,12	0,21	0,91
Publishing activities	0,00	0,01	-0,01
Motion picture, video and broadcasting	0,00	0,05	-0,05
Telecommunications	0,08	0,20	-0,11
Computer programming, information services	0,37	0,07	0,30
Financial service activities	0,32	0,36	-0,04
Insurance, reinsurance and pension funding	0,59	0,08	0,51
Activities auxiliary to finance	0,17	0,00	0,17
Real estate activities	0,37	1,00	-0,62
Legal & accounting activities; management consultan	0,95	0,24	0,71
Architectural and engineering activities	0,44	0,05	0,39
Scientific research & development	0,24	0,08	0,16
Advertising & market research	0,25	0,05	0,19
Other professional, scientific & technical activities	0,08	0,33	-0,25
Administrative & support service activities	3,39	0,83	2,56
Public administration & defence; social security	1,26	0,19	1,07
Education	0,11	0,10	0,01
Human health and social work	40,89	43,68	-2,78
Other service activities	0,64	1,04	-0,40
Activities of households	0,00	0,00	0,00
Total	124,6	91,2	

Figure 29: Total intensity vector B breakdown: Author's calculations.

output in the U.S. than in Canada. Considering the same relevant industries as in Figure 27, it can be seen that there is a significant positive difference in the indirect emissions from the chemical industry and administrative services to health care. Since the technical coefficient associated with the chemical and administrative industries for health care is also found to be higher in the U.S. (refer Figure 27), it can be inferred that the high technology-intensity from these two industries has contributed to a higher environmental burden in health care in the U.S.. Similarly, the difference in the indirect emissions from the pharmaceutical industry and computer programming and information services to health care are small yet positive. This again suggests that the higher technology inputs from these industries to health care has contributed to a slightly higher environmental burden in the U.S.. However, two industries that do not follow the observed trends are computer, electronic and optical products manufacturing and telecommunications. In spite of the U.S. health care having a higher technology-intensity in these two industries than Canada health care, their resulting indirect contribution to U.S. health care's total emission intensity are found to be less than that to Canada health care's. A possible explanation for this could be that these two industries are less carbon-intensive in the United States than in Canada. For example, the assessment for the greenest global companies published by Newsweek Green Rankings (2017) ranks American telecom companies like Sprint corp., AT & T, Verizon etc. and computer and medical technology companies like Apple, HP, Abbott etc. in the top 300 whereas Canadian telecom and technology companies did not even make it to the top 500. Yet, in order to prove this justification, highly disaggregated/ detailed I-O tables are required. Since such detailed level of data are not found in publicly available databases, this will remain a limitation of my study. Apart from these industries, one industry that stands out clearly in this analysis is the electricity and steam supply. The difference in the indirect contribution from the electricity industry to health care sector's total emission intensities between the U.S. and Canada is found to be the highest. That is, the emissions from the electricity industry in the U.S. contributes 23,8 tonnes more to produce $1 million of health care output than Canada. This is mainly because the electricity industry's direct carbon-intensity is almost three times more in the United States than in Canada. A possible explanation for this is that 17% of energy supply comes from renewable sources (especially hydroelectric power) in Canada (Government of Canada, 2020) whereas only 11% comes from renewable sources in the United States (EIA, 2020b). This result also explains the large difference in the indirect effects between the two countries as found in Figure 28.

In sum, the difference in trends between the U.S. and Canada in terms of purchase of medicines and medical technologies, adoption of ICTs and administrative activities are observed on an industry level. The health care sector in the U.S. is found to be more technology/ material-intensive than Canada while reliance on health and social work is lower. Further, the total (direct + indirect) environmental impact per unit of output of the health care sector was found to be higher in the U.S. than in Canada, part of which could be explained by the difference in technology-intensities between the two countries. An important insight from this exercise is that even though increased purchase of ICT and related medical technologies by health care activities in the U.S. between 1995 and 2015 has not led to higher overall CO_2 emission intensities, we know that as of 2014, high-tech health care in the U.S. is still more polluting (in terms of CO2 emissions) than Canada's health care.

5.2.3 Limitations of the empirical work

Although the empirical results obtained support my main argument that the technology-intensity of health care (or the non-physical economy) has increased, thus increasing pressure on the environment, they suffer from several limitations. They are:

- The biggest limitation of this study is that the results are derived from relatively highly aggregated I-O tables which does not allow for a detailed analysis of the effects of different medical and ICT technologies (as discussed in Chapter 3). For example, the sector 'renting, administrative and support' also includes legal and accounting services, security and investigation services etc. If I found that the purchase of administrative services has increased in the U.S. from 1995 to 2015 or that it is higher in the U.S. than in Canada, it could also be that the use of legal or security services have increased which does not exactly fit the trend of increased administrative burden (like increased use of EHR, e-prescribing etc.) in the health care sector. Therefore, the classification of sectors in both the analysis cannot be considered ideal to answer my second sub question. One could expect to get even more stark results at lower levels of aggregation such as product by product I-O tables. Additionally, any differences in the organisation of health care systems over time and between countries (for example, in terms of outsourcing services) cannot be captured in the aggregated I-O tables, which is why an analysis at a more disaggregated analysis will be useful. However, due to lack of highly detailed and publicly available I-O tables for different time periods and countries, these limitations could not be overcome within the time constraints set for this thesis.

- Although the purchase of pharmaceutical imports offset 20% of the decrease in technology-intensity of the chemical & pharmaceutical industry, their corresponding international emission intensities could not be computed due to time limitations. If computed, one could expect the indirect emission contribution from such industries to health care from 1995 to 2015 to be higher than the results found.
- The inherent limitations of the EE-IO research approach mentioned in section 4.1.3.
- The classification mismatch between 1995 and 2015 I-O tables and their corresponding environmental accounts could lead to misinterpretation of the results. Finally, there is also the possibility for discrepancies in the data collected from the WIOD and OECD databases due to reporting or human errors.

5.3 Chapter conclusions

Technology adoption in terms of ICTs in all economic activities is commonly recognized as a greener choice. Yet, the energy consumed by ICTs and related devices are found to be increasing every year. This is because, even when ICTs get more and more energy efficient, they tend to cause a rebound effect. In Chapter 3, it was found that ICTs and related technologies are increasingly being adopted in the non-physical economy, namely, health care and education without any significant improvement in the quality of outcome. Since it is established that there is an environmental burden associated with ICTs, their adoption in health care and the consequent total environmental impact are investigated. The first exercise that was carried out was a detailed study of the expenditures in health care and its sub-activities. The results showed that spending on medicines, medical technologies and administrative activities have increased from 1960 to 2018 at different rates on a national and per capita basis in the United States. The carbon footprint associated with the growing size of the health care sector was computed by taking the fixed CO_2 emission coefficients of each of the sub-activities from the EIO-LCA model made available at www.eiolca.net. The results provide two insights. The first is that the carbon footprint of hospital services are the highest among other activities and the second is that the environmental burden of medicines and medical technologies are higher than that of physician services. However, this exercise did not indicate the increase in the use of ICTs and related medical technologies per unit of health care output and did not account for any change in carbon-intensities of technologies over time.

To carry out this investigation, the technical coefficients of the health care sector taken from the Leontief inverse matrix for the year 1995 and 2015 were compared. The results showed that the health care sector in the United States purchased more medical technologies, electricity, telecommunications and other administrative services in 2015 than in 1995. However, the purchase of (domestic) pharmaceuticals per unit of health care output decreased. Two explanations were provided- a small portion of this decrease was offset by the increase in purchase of pharmaceutical imports and that the increase in the purchase of pharmaceuticals by final households fit better with trends like pharmaceuticalisation that was discussed in Chapter 3. These results supported the increased adoption of medicines, ICTs and related medical technologies in the United States. To determine the consequent environmental burden, the total (direct+indirect) emission intensity vectors of health care for both the years were compared. The results for this were not very straightforward as the direct emission intensities of all but one industries decreased from 1995 to 2015 possibly due to the switch from coal to the less CO_2-intensive, yet environmentally damaging shale gas. However, even when the carbon-intensity of the electricity industry decreased during the period studied, its indirect emission contribution to health care increased from 1995 to 2015 indicating that the environmental burden from the increased *energy use* (observed from the changing technical coefficients) in health care has increased. Finally, the total upstream emissions from health care increased from 1995 to 2015, mainly due to increased energy intensity, countering the declining trend observed with its direct emissions.

To strengthen this empirical support, the difference in technology-intensities between the United States and Canada was analysed. Again, the result showed that the U.S. health care is more technology-intensive in terms of medicines, medical technologies, ICT and administrative services than Canada health care. If U.S. and Canadian health care are of roughly the same quality, while Canadian health care is less technology-intensive, this could be an indication that different kinds of health care systems co-exist alongside one another, and that, rather than a single or linear path, multi-linear developments in health care may be possible. When the total intensity vectors B were studied, it was found that the indirect emission contribution from industries like electricity, pharmaceuticals, information and administrative services to health care was more in the United States than in Canada. This could again be used as empirical support to the argument that increasing technology-intensity in health care increases pressure on the environment. Since high-tech health care is found to be more polluting (from an economy-wide perspective), while it also raises concerns regarding possible negative effects on both providers and recipients of these services (as discussed in Chapter 3), this would be a case for allowing or promoting 'multi-linearity' or plurality in health care, and for avoiding policies that promote a one-sided or linear, increasingly high-tech approach in health care. Reflections on this will be discussed in the next chapter.

6 Conclusions

The aim of this thesis was to investigate (based on an Aristotelian perspective on human development) whether the further development of the human being (from material to increasingly non-material interests) could help solve the world's environmental problems? The question was explored by answering two sub-questions:

1. *What is the impact on the environment of the non-physical economy (defined as activities that meet non-material needs, such as knowledge, health, art) as compared to that of the physical economy (defined as activities that meet material needs, such as food and shelter)?*

   The idea behind this sub-question is that if it is in the nature of human beings to develop (especially after a certain standard of living has been reached) from being mainly interested in the growth of material or bodily well-being, to being interested in non-material growth (for example, by enjoying a classical dance performance, studying mathematics or engaging in therapy), then one would expect a growth of economic activities like health care, education, research, arts or other cultural activities (as sources of growth of consciousness, creativity and morality) relative to the physical economy. On this basis, economic activities were classified as physical/ goods-producing economy and non-physical economy, and their (relative) environmental effects were analysed. I first compared the 'direct' environmental burden of the physical economy with that of the non-physical economy in producing \$1 million of output in the United States in 2009. By 'direct', I refer to pollution by 'sector of origin', i.e. by the sector producing the output. The results showed that the physical economy is 3,5 times more polluting in terms of global warming potential, 11 times more in terms of acidifying potential, 4 times more in terms of tropospheric gas emissions and 5 times more in terms of energy consumption than the non-physical economy.

   However, since the 'direct' environmental impact may not fully reflect the responsibilities of environmental burden (as the physical economy produces some goods also to meet demand from the non-physical economy), an Environmentally Extended Input-Output (EE-IO) analysis was applied to compute the 'direct' and 'indirect' emissions in producing each activity's output. By indirect, I refer to the emissions caused, for example, in the manufacturing sector as it produces and supplies inputs to the health care sector, and for which the health care sector (as sector of use) is (indirectly) responsible. This way, emissions are reallocated from sector of origin to sector of use. The EE-IO analysis requires two types of data: firstly, an *input-output (I-O) table* that represents inter-sectoral transactions in an economy, and that also includes the sector's sales to final demand, and secondly, the *direct environmental accounts* of each economic activity. The I-O table was first used to compute a *technical coefficient matrix A* that shows the technical coefficients of each industry (per unit of output, so ignoring its size). The A matrix was then used to compute the *Leontief Inverse matrix* $[I\text{-}A]^{-1}$ which represents the direct and indirect inputs of each industry in producing \$1 of output. Next, the *direct intensity vector b* computed from the environmental accounts is multiplied with the Leontief inverse matrix to arrive at the *total (direct + indirect) intensity vector B*. By analysing this vector, it was found that certain industries (for example, construction, health care, education, few industries in manufacturing) had higher indirect effects than direct effects whereas certain other industries (like electricity, transportation, agriculture) had much higher direct effects than indirect effects. This gave an important insight that some activities in the economy like health care are responsible for some of the pollution caused by other industries like electricity. When this total intensity vector B was further multiplied with the final demand vector, the emissions were reallocated based on sector of use. When these emissions were again divided between the physical and the non-physical economy in producing $1 million of their respective outputs, it was found that the physical economy was still at least two times more polluting than the non-physical economy in terms of global warming potential, acidifying potential, tropospheric gas emissions and energy consumption. This suggests that, if human beings became increasingly interested in non-material rather than material growth (once their material needs are met), it could lower overall pressure on the environment (compared to when consumption continues to grow). This confirms my 'material threshold hypothesis' that a shift from material to non-material growth in the rich parts of the world would mean good news for the environment. However, this argument will remain true only to the extent that non-material needs continue to be met in largely non-material ways.

2. *What is the environmental impact of the non-physical economy when this consists mainly of human work as compared to when this human work is replaced with technical solutions?*

In the non-physical economy, especially health care and education, human work remains indispensable in meeting people's non-material needs according to many authors. For example, doctor-patient communication and teacher-student interactions are considered vital in providing holistic care for patients and in instilling curiosity, morality etc. in students respectively. However, in recent years, some of the creative tasks of doctors and teachers are being replaced with software and other ICT technologies, allegedly to reduce the rising costs, improve productivity and quality of the services in the non-physical economy. Yet, since the nature of work in the non-physical economy is very different, it is not certain that these technologies actually reduce the costs and/ or improve the quality of services, and on this point there is lack of conclusive evidence. The different nature of work in the non-physical economy may explain, at least partly, the system-wide "productivity paradox", which is the slow growth of productivity, especially in the non-physical economy, despite heavy investment in ICTs. Besides its impact on costs and quality, technology adoption in the non-physical economy may also have implications for the environment. To investigate whether the technology-intensity of the non-physical economy has increased, and to assess the implications of this development for the environment, the same EE-IO method was applied to two comparative studies.

In the first study, two consecutive I-O tables for the U.S. (for the years 1995 and 2015) were taken and the health care sector's technical coefficients were compared (after adjusting for price changes, based on Miller & Blair's (2009) "double deflation" method). The results showed that the technology-intensity in terms of purchase of medical technologies (CT, MRI scanners etc.), ICTs (telecommunications, software services, computer and electronic devices) and energy use (electricity and water resources) per unit of health care output and medicines (chemicals and pharmaceuticals) per capita increased from 1995 to 2015. However, evidence regarding the corresponding environmental burden was found to be mixed and less conclusive. On the one hand, an increased indirect emission contribution from the increased purchase of ICTs and medical technologies per unit of health care output could not be observed mainly due to the economy-wide switch from coal to the less carbon-intensive, yet environmentally damaging, natural gas. On the other hand, an increased indirect emission contribution from the increased purchase of energy inputs, likely due to the increased *use* of ICT and medical technologies, was observed despite the electricity sector becoming less carbon-intensive. The net effect was higher total emissions from health care in 2015 than in 1995 (despite the opposite trend in its direct emissions). Therefore, total CO_2 emissions have increased in health care, most likely due to the increased *use* of ICTs, medical and administrative technologies in hospitals and health care clinics.

In the second study, the technology-intensity of health care in the United States was compared with that of Canada in the year 2014, and their emission intensities were computed. The results showed that the technology-intensity of health care in terms of purchase of medicines, medical technologies and ICT & administrative technologies per unit of output and medicines per capita were higher in the United States than in Canada. The indirect CO_2 emission contribution to the health care sector was also higher from medicine, electricity, administrative and software service industries in the United States than in Canada. This means that the high-tech U.S. health care is more polluting than the (relatively) low-tech health care in Canada. These findings suggest that the replacement of human work with technical solutions in the non-physical economy may lead to a higher environmental burden of the non-physical economy.

Despite the supporting results, a major limitation in both these studies were the use of highly aggregated I-O tables that do not explicitly reflect the different ICT and medical technologies such as EHRs, tele-health, e-prescribing, robot-assisted surgeries discussed in my thesis. However, considering the time limitations for my thesis, this could not be explored.

Based on the empirical investigation of the two sub-questions, the main research question could be answered. The further development of the human being (from material to increasingly non-material needs) could potentially lower the stress on the environment, if non-material needs such as knowledge, health and art are met in more non-material ways (that is, through human work rather than in technology-intensive ways). If the non-material needs of human-beings are met in increasingly material or technology-intensive ways, without due consideration for the true purpose of such needs, it could not only result in a "progressive atrophying of the human soul" (Naastepad & Houghton Budd, 2019), but also a drastic worsening of the world's environmental problems. In other words, careful management of technological progress in the non-physical sphere − meaning progress that does not displace human capacities unduly − may function as a 'double-edged sword': it could enhance human beings' ability to develop their capacities further while reducing pressure on the environment.

6.1 Reflections on choice of technology in the non-physical economy

From my study, although it may be clear that the physical economy has become increasingly productive due to the increased use of technology, my question for the non-physical economy has been whether it is going, and should be going, a similar path. From the literature discussed, three factors seem to play an important role in the **choice of technology** in the non-physical economy - *economic factors* (the drive to reduce costs and/or increase profits), *the impact on human beings* (the quality of the service), and *environmental effects*. However, as seen in the literature, there tends to be a bias in the choice of technology, or a certain hierarchy in the weights given to the economic, human, and environmental arguments. When high-tech solutions are introduced in the non-physical economy, this is often done with the argument that they lower cost, and such economic arguments tend to have more weight than environmental or human arguments. For example, environmentally-friendly alternatives that are technically possible tend to be ignored when they are less profitable in financial terms. Similarly, concerns regarding possible negative effects on human beings tend to be more easily dismissed when positive environmental arguments are available. For example, studies showing that patients benefit from face-to-face interactions with real doctors, psychologists, and therapists, or that students benefit from interaction with teachers and peers have more chance of being ignored when other studies show that digital health applications and digital learning software are better for the environment (for example, telemedicine and online learning are regarded to be better for the environment as they involve less travel). In other words, when high-tech solutions are claimed to reduce costs, this tends to 'crowd out' environmentally-friendly alternatives, and when high-tech solutions are claimed to reduce costs as well as pressure on the environment, human concerns regarding technological progress such as those discussed in Chapter 3 tend to get neglected. It seems that freedom of choice regarding technology in the non-physical economy requires that one first needs to show that there are neither compelling economic reasons nor pressing environmental reasons to pursue a high-tech path in the non-physical economy.

Regarding economic reasons for choosing a high-tech path in the non-physical economy (such as lowering health care costs), Baumol (1993, 2012) has argued that **we can afford** the expensive 'personal services' (the non-physical economy) as long as the productivity gains that are made in the (technologically progressive) physical economy are made available for funding education, health care, and other 'personal services' that are essential to human well-being. This means that, economically, there is no compelling reason to reduce the high costs of health care. Moreover, in practice, there is no conclusive evidence that the rising technology-intensity has actually reduced health care costs. For example, various studies of health care in the United States suggest that (due to trends such as technology-arms race and direct-to-consumer advertising) higher technology/ material-intensity of health care increases overall health care costs without any substantial improvement in the quality of service. A possible explanation for this is that the nature of work in the non-physical economy is very different from the nature of work in the physical economy (as explained in section 2.3.1) and, it may simply not be possible to increase productivity and lower costs in the non-physical economy (through labour-capital substitution) without causing a deterioration in quality. This could in fact be an explanation for the system-wide 'productivity paradox' (the slowdown in productivity growth despite rapid development in the field of ICT) which holds especially for the non-physical economy.

If there are no compelling economic reasons to choose high-tech solutions in the non-physical economy, this creates space for free choice regarding how health care, education, and other services are provided in the non-physical economy - unless there exist environmental reasons for choosing a high-tech trajectory. Environmental arguments for choosing a high-tech trajectory in the non-physical economy would be valid if rising technology-intensity results in lower economy-wide environmental pressure, or if high-tech solutions generate lower environmental pressure than low-tech for the same quality of services. However, we found from the EE-IO analysis in Chapter 5 that the increased energy-intensity of health care over time in the United States could not be compensated (even as carbon-intensity of energy production decreased) and that the high-tech health care system in the U.S. is *more* carbon-intensive than the relatively low-tech Canadian health care system even though they provide roughly the same quality of care. So, empirical support to choose a high-tech path for environmental reasons in the non-physical economy were not found from the aggregated, macro- or economy-wide perspective taken in this thesis.

If there is no compelling economic reason for choosing a high-tech trajectory in the non-physical economy, and if there is no robust and consistent evidence of improvement in quality due to increased technology-intensity, while there are environmental benefits from not raising technology-intensity, could this be a case for **free choice of technology** in the non-physical economy? For example, if a patient were free to choose between a 'real' doctor or an 'online' doctor, and if parents were free to choose between 'live' education or 'digital' education for their children, then the technology-intensity of health care, education and other personal services need not rise so much. If there is no economic need for high-tech health care and education, while in many instances the impact on human beings is ambiguous and possibly negative, there would seem to be no reason for choosing a linear (progressively high-tech) path in health care and education, or for restricting freedom of choice in health care and education. On the contrary, the concerns that are being raised regarding possible negative effects of high-tech solutions on both providers and recipients of services in health care and education (see Chapter 3) could be taken as a case for exploring multi-linearity or plurality in the non-physical economy, and to encourage diversity and freedom of choice regarding how health care, education and other personal services are provided. For example, if the 'superabundant' financial capital can be directed towards schools and doctors, alternative solutions such as reduction in the size of classrooms (or student to teacher ratio) to enhance teacher-student relationships, promotion of holistic health education by doctors that can help transform unhealthy lifestyles of the people instead of 'end of pipe' solutions etc. could be facilitated. Rather than promoting a general (country-wide or even world-wide) transition to high-tech non-physical economy, individual doctors, teachers, artists etc. could be given freedom to determine how health care and education are provided, and how art is created. The resulting diversity, or mix of low-tech and high-tech approaches in health care, education, art, etc. would be less polluting than a linear high-tech approach in the non-physical economy, while leaving providers as well as recipients of services in the non-physical economy free to explore different technological paths.

6.2 Limitations and directions for future research

This study is based on a strong assumption that people's needs (as distinguished from wants) grow increasingly non-material once their material needs are met. Although this assumption was supported to a certain extent by the empirical evidence of the rising importance of the non-physical economy relative to the physical economy, this aspect of human nature is still being debated in the literature. Therefore, it may be useful to explore different views, using a variety of research methods, to empirically test this philosophical foundation.

My translation of the ISIC classified economic activities based on the types of need met, and the nature of the work that is involved, is not commonly found in the literature. An insight one may get from this classification is that human beings need not only physical goods to live; they also long to develop their capacities and to grow in knowledge, intellect and other 'higher' faculties. However, this insight is not shared by everyone. For example, health care may be seen as an activity that meets a physical or material need of people or generally as a part of the "service sector", if its purpose is not understood in the way explained in section 2.3.1 and section 3.2 (that is, to enable human beings to develop intellectually and spiritually). In this case, my classification of health care as part of the non-physical economy may be contested.

This study has focused predominantly on the impacts of the rising technology-intensity in health care in the United States. It may be interesting to study technology-intensity in health care in other countries that have a better state of general health. For example, Nordic countries, Spain etc. are found to have the healthiest people in the world while at the same time, ICT and related medical technologies have also been adopted widely. Further studies could analyse to what extent these technologies have played a role in improving the health of the people. Additionally, technology-intensity in education and other cultural activities like performing arts, music in different countries and their impact on the quality of outcome could be studied.

Finally, the aggregated sector classification of the EE-IO analysis in the first and second empirical work seem to be a major limitation in my study. Due to time and resource constraints, it was not possible to re-classify the I-O tables to lower levels of aggregation to make it more tailored to my research questions. In the future, the empirical work could be repeated with more disaggregated I-O tables and/or different data sources to verify the validity and reliability of my results. For example, currently, in the Bureau of Economic Analysis (BEA) there are 405*405 (commodity by commodity) ‘supply’ and ‘use’ tables for the years 2007 and 2012. If these tables become available in a symmetric input-output form for the years 1995 and 2015 (or more spaced out time periods) and if price indices of commodities (that is, at such a disaggregated level) for the respective years are also found, then trends such as Electronic Health Records (EHRs) or health apps or telemedicine could be matched better (although an exact match may still not be possible). That is, I can find if purchase of commodities like “communications equipment”, “data processing, hosting related services”, “Internet publishing broadcasting and Web search portals”, “computer related facilities management services” etc. by the health care sector has increased over time. However, regarding total emissions (that is, for health care as a whole), one may not find very different results even with further analysis. As another example, it may also be interesting if (much more) disaggregated I-O tables become available for different kinds of activities in health care, education etc.. For example, if I-O tables can represent purchase of inputs for surgery, physiotherapy, old-age care activities etc., then comparison of such tables between countries may provide insight into where human work would be more useful (in which kinds of activities) and where technology would be appropriate. However, to really understand why this is so, and what degree of technology-intensity would be appropriate (humanly and environmentally) in different kinds of activities, the input-output analysis would need to be complemented by more detailed and more encompassing case studies.

A Appendix

A.1 Formula

Table 10: Formula to convert emission accounts to the necessary indicators. **Source:** Eurostat (2020)

Indicator	**Formula**	**Applied Factors**
Global warming potential	CO_2 + N_2O in CO_2 eq. + CH_4 in CO_2 eq	CO_2:N_2O:CH_4=1:298:25
Acidifying gases	SO_x in SO_2 eq. + NOX in SO_2 eq. + NH_3 in SO_2 eq.	SO_x:NH_3:NO_x=1:1,9:0,7
Tropospheric ozone precursors	NMVOC + NO_x in NMVOC eq + CO in NMVOC eq. + CH_4 in NMVOC eq.	NMVOC:NO_x:CO:CH_4=1:1,22:0,11:0,014

A.2 Mapping

Table 11: Economic activity-to-number mapping

Economic activity	Number	Type of economy
Agriculture, Hunting, Forestry and Fishing	1	Physical economy
Mining and Quarrying	2	Physical economy
Food, Beverages and Tobacco	3	Physical economy
Textiles and Textile Products	4	Physical economy
Leather, Leather and Footwear	5	Physical economy
Wood and Products of Wood and Cork	6	Physical economy
Pulp, Paper, Paper , Printing and Publishing	7	Physical economy
Coke, Refined Petroleum and Nuclear Fuel	8	Physical economy
Chemicals and Chemical Products	9	Physical economy
Rubber and Plastics	10	Physical economy
Other Non-Metallic Mineral	11	Physical economy
Basic Metals and Fabricated Metal	12	Physical economy
Machinery, Nec	13	Physical economy
Electrical and Optical Equipment	14	Physical economy
Transport Equipment	15	Physical economy
Manufacturing, Nec; Recycling	16	Physical economy
Electricity, Gas and Water Supply	17	Physical economy
Construction	18	Physical economy
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	19	Physical economy
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	20	Physical economy
Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	21	Physical economy
Hotels and Restaurants	22	Physical economy
Inland Transport	23	Physical economy
Water Transport	24	Physical economy
Air Transport	25	Physical economy
Other Supporting and Auxiliary Transport Activities	26	Physical economy
Post and Telecommunications	27	Physical economy
Financial Intermediation	28	Rest of the economy
Real Estate Activities	29	Rest of the economy
Renting and Other Business Activities	30	Rest of the economy
Public Admin and Defence; Compulsory Social Security	31	Rest of the economy
Education	32	Non-physical economy
Health and Social Work	33	Non-physical economy
Other Community, Social and Personal Services	34	Non-physical economy
Private Households with Employed Persons	35	Rest of the economy

A.3 Direct global warming potential.

Economic activities		Direct Global warming potential (in tonnes)
Agriculture, Forestry and Fishing	1	498.790.997
Mining & Quarrying	2	414.881.444
Food products manf.	3	61.448.535
Textile products manf.	4	8.958.755
Leather products manf.	5	156.745
Wood products manf.	6	14.766.609
Paper products manf.	7	62.230.100
Coke, refined petroleum products manf.	8	188.122.144
Chemicals & pharmaceutical products	9	152.660.778
Rubber & plastics products	10	5.343.018
Other non-metallic mineral products	11	110.119.592
Basic & fabricated metals	12	102.175.611
Machinery and equipment	13	16.579.815
Electrical & Optical Equipment	14	11.014.450
Transport Equipment	15	20.402.744
Manufacturing, Nec; Recycling	16	3.808.642
Electricity, Gas & Water Supply	17	2.077.554.029
Construction	18	42.693.410
Repair of Motor Vehicles	19	5.978.516
Wholesale Trade	20	31.701.973
Retail Trade	21	79.628.471
Hotels & Restaurants	22	63.102.231
Inland Transport	23	247.420.034
Water Transport	24	57.348.254
Air Transport	25	157.960.239
Supporting Transport Activities	26	56.744.199
Post & Telecommunications	27	31.675.712
Financial Intermediation	28	31.013.847
Real Estate Activities	29	9.836.163
Renting & Other Business Activities	30	105.113.447
Public Admin and Defence	31	256.689.393
Education	32	15.576.451
Health and Social Work	33	88.540.997
Other Community, Social and Personal Services	34	228.300.655
Private Households with Employed Persons	35	-

Figure 30: Direct global warming potential. **Unit**-Tonnes; **Country**-Unites States; **Year**-2009. **Source:** WIOD (2013)

A.4 I-O Table

I-O Table	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	56.334	0	154.625	784	4	10.320	2.496	6	1.611	1.161	2	2	1	8	5	141	1	824
2	1.551	12.458	957	44	0	35	1.208	125.934	7.671	147	5.307	9.149	186	272	1.948	150	34.568	10.314
3	26.825	57	139.474	122	533	46	1.120	75	4.509	654	74	109	38	93	85	69	2	118
4	262	34	281	7.897	38	333	2.729	66	850	1.768	194	65	456	688	2.113	2.068	2	1.136
5	0	0	1	257	0	1	129	0	0	5	1	0	1	2	6	7	0	3
6	708	129	325	86	0	12.676	3.236	4	345	649	389	538	445	414	1.843	5.246	90	27.579
7	576	1.320	23.665	569	13	596	55.635	433	6.069	3.286	1.635	3.987	2.127	5.228	4.257	2.043	497	6.282
8	13.974	2.359	1.903	338	3	495	2.582	21.297	20.729	2.044	582	2.074	900	920	788	332	2.390	36.172
9	15.110	3.531	6.120	7.094	80	1.393	11.208	2.824	133.497	36.640	2.083	6.659	2.482	5.775	5.398	4.013	152	7.945
10	1.129	1.370	13.931	236	77	525	3.991	153	7.529	9.090	730	2.045	6.039	4.609	11.974	4.913	215	16.121
11	65	1.450	2.451	53	0	765	183	759	929	875	8.008	2.576	1.199	1.508	3.075	364	278	39.951
12	1.853	6.800	13.841	445	22	1.727	6.180	515	6.309	4.101	2.460	120.520	41.365	24.075	63.700	11.241	625	62.618
13	1.649	2.373	1.661	36	1	404	1.325	104	1.755	894	180	4.235	12.558	2.643	10.412	801	372	16.718
14	454	486	1.411	225	4	376	2.600	173	2.710	1.424	406	4.363	7.924	20.486	18.650	1.739	386	16.417
15	737	812	1.081	64	1	217	679	83	543	243	172	1.795	3.467	781	108.269	229	123	5.076
16	116	205	243	128	2	244	271	25	883	336	114	420	1.182	1.445	3.651	3.114	59	5.801
17	5.532	3.440	15.083	1.109	13	1.962	9.133	2.876	15.203	3.491	3.910	11.248	1.904	2.581	4.290	1.181	230	3.784
18	1.856	6.989	2.502	133	4	645	2.157	1.252	2.411	820	733	3.048	783	805	1.288	503	7.931	1.166
19	293	97	462	31	1	120	557	69	383	155	136	565	166	164	299	115	71	3.971
20	16.388	3.203	45.847	2.824	83	5.285	16.150	13.993	25.258	5.951	2.755	17.766	13.669	22.478	24.180	5.682	874	30.657
21	863	500	2.122	101	9	414	1.711	457	3.169	563	474	1.856	1.156	1.191	2.669	777	293	47.665
22	187	239	1.851	136	6	543	3.413	227	708	817	477	2.189	998	1.113	1.210	731	2.274	2.653
23	5.522	5.877	19.441	836	21	2.238	6.294	5.211	9.165	2.143	4.781	10.766	2.751	2.543	6.188	2.149	18.097	13.234
24	347	66	726	2	0	2	21	59	103	3	30	137	10	13	31	5	60	175
25	121	80	680	54	2	117	1.010	35	411	220	112	558	258	345	545	196	140	730
26	1.040	331	2.043	161	3	938	6.000	437	969	600	753	1.597	876	1.030	1.294	804	982	547
27	962	1.229	3.745	270	8	876	7.244	389	4.166	1.062	871	3.033	1.603	2.706	3.008	1.189	733	10.606
28	21.313	13.959	9.417	595	32	1.071	15.663	579	8.061	2.770	1.829	13.380	5.779	7.879	9.837	4.086	4.944	23.667
29	6.224	1.466	5.148	301	10	1.148	7.267	191	1.577	1.384	669	3.905	1.624	2.025	1.816	2.067	1.085	8.413
30	5.886	17.783	46.102	2.506	77	5.924	56.012	3.282	61.622	9.228	7.037	33.444	17.294	44.035	47.360	9.518	10.437	98.392
31	3.240	1.148	5.378	347	6	1.204	3.765	948	4.481	1.202	1.264	5.771	739	934	1.617	577	895	2.146
32	1.034	0	3	0	0	0	125	6	1	2	1	3	1	4	3	0	85	66
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	973	1.647	5.367	295	11	833	5.340	458	4.961	1.308	909	4.429	1.771	2.846	4.048	1.218	1.056	16.159
35	25	8	39	3	0	10	48	6	33	13	12	48	14	14	26	10	6	339
Value added	134.914	241.421	209.180	26.244	1.351	20.686	165.939	125.281	204.227	55.416	37.567	163.165	118.328	276.559	168.007	59.896	265.090	575.500
Total Input	342.488	349.301	776.070	59.336	2.735	78.755	425.812	473.610	600.707	167.664	91.550	479.242	277.201	483.732	590.906	137.914	387.527	1.155.286

I-O Table	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	Final demand	Total Output
1	1	8	174	3.820	2	0	0	9	118	28	52	553	917	134	64	454	0	107.827	342.488
2	51	214	193	455	1.513	168	660	370	496	120	672	1.953	13.069	75	687	778	0	115.926	349.301
3	13	570	162	60.940	8	17	36	6	1.087	4	27	1.250	25.064	3.859	17.096	2.605	0	489.325	776.070
4	67	547	2.539	187	24	54	0	6	116	19	75	679	3.444	49	1.843	1.259	0	27.448	59.336
5	1	62	106	0	0	0	0	0	18	0	0	43	481	6	227	132	0	1.245	2.735
6	26	800	957	2.304	810	2	1	58	328	58	3.366	1.693	3.418	39	576	1.478	0	8.141	78.755
7	865	5.752	7.468	8.877	1.060	87	414	520	3.657	16.856	1.480	28.075	42.926	2.099	9.973	10.291	0	167.194	425.812
8	677	3.976	1.978	3.219	26.844	4.680	19.614	10.435	2.897	1.634	874	22.038	59.366	164	2.997	2.226	0	200.107	473.610
9	539	822	1.174	1.550	835	64	252	312	449	287	1.647	7.407	19.417	543	32.740	3.199	0	277.466	600.707
10	2.705	2.825	4.569	5.045	1.631	7	7	385	1.503	527	1.061	4.065	8.255	345	8.985	1.334	0	39.737	167.664
11	300	162	817	2.896	72	5	22	37	704	24	1.039	1.752	3.473	49	1.012	1.112	0	13.585	91.550
12	2.094	1.282	3.687	5.927	4.239	1.307	458	399	3.655	456	2.466	7.019	11.765	233	2.062	3.749	0	60.048	479.242
13	977	402	2.215	1.089	736	36	22	416	696	88	719	3.221	4.762	648	553	1.580	0	200.919	277.201
14	1.029	1.206	3.270	1.690	638	42	59	214	4.554	3.162	1.064	10.097	24.868	587	22.835	2.840	0	325.339	483.732
15	17.184	1.366	2.867	644	5.684	1.318	1.436	1.081	1.361	278	71	3.031	41.130	139	953	1.158	0	386.831	590.906
16	61	407	946	853	56	9	19	47	249	463	1.820	1.467	5.276	162	6.688	1.423	0	99.731	137.914
17	1.183	2.433	7.952	12.596	780	115	41	1.137	3.910	5.064	10.231	8.253	24.069	8.790	9.338	5.706	0	198.958	387.527
18	319	1.070	3.754	4.121	4.808	0	20	760	10.192	15.447	31.833	8.365	68.749	529	4.610	5.789	0	959.894	1.155.286
19	882	845	1.603	1.395	575	5	11	163	991	4.874	4.088	4.868	4.765	302	2.890	3.340	0	171.124	210.376
20	2.951	24.214	14.429	19.981	6.002	558	1.958	1.692	4.067	2.524	2.046	22.415	44.538	2.610	15.618	5.401	0	584.821	1.008.868
21	3.245	2.928	5.773	6.170	2.938	165	44	843	2.697	12.179	6.834	15.301	17.597	1.203	9.479	7.815	0	1.022.627	1.183.830
22	986	1.901	3.899	8.901	199	6	2.377	618	3.531	31.559	3.544	39.963	22.761	1.381	14.241	8.855	0	597.491	761.985
23	822	2.509	7.221	4.006	16.812	299	506	887	2.069	3.221	1.346	9.044	23.348	405	5.763	3.711	0	141.570	340.795
24	3	14	7	24	92	18	63	34	97	6	8	1.667	1.263	1	23	7	0	28.638	33.753
25	180	837	739	896	656	44	4	248	1.069	4.506	340	5.931	4.675	243	1.231	1.761	0	104.053	133.026
26	2.212	17.345	22.924	6.494	15.918	2.540	11.685	9.771	1.096	9.292	178	14.509	9.331	1.059	7.965	7.606	0	35.813	196.145
27	2.790	12.671	17.157	12.935	8.046	1.186	5.589	4.843	60.825	36.636	4.036	49.505	44.665	2.597	18.222	18.978	0	274.265	618.645
28	4.385	22.860	44.444	28.335	19.194	959	4.249	3.299	13.534	574.962	295.078	131.335	41.454	3.964	66.170	72.044	0	958.223	2.429.351
29	7.285	11.948	52.674	31.836	3.642	821	989	4.514	8.207	58.896	131.264	82.115	51.884	19.956	122.435	40.587	0	1.627.400	2.302.772
30	11.920	71.161	83.889	67.656	26.268	2.690	14.340	11.199	56.962	269.847	66.359	366.991	347.214	15.358	161.120	111.697	0	708.246	2.868.855
31	1.088	2.467	6.529	6.147	2.188	286	793	1.323	4.431	3.983	6.850	8.706	25.796	3.118	11.164	12.045	0	2.814.245	2.946.823
32	0	489	3.539	0	50	0	8	3	547	146	0	290	11.654	726	142	2.070	0	202.872	223.871
33	0	0	0	0	0	0	0	0	0	0	0	363	11.916	0	30.571	1.293	0	1.643.237	1.687.379
34	2.972	6.983	10.935	15.803	2.772	638	1.015	2.010	35.189	32.527	22.464	45.002	53.513	4.342	19.738	80.334	0	568.762	958.630
35	75	72	137	119	49	0	1	14	85	416	349	416	407	26	247	285	0	14.609	17.960
Value added	131.100	793.412	844.825	415.810	174.471	13.968	61.581	135.138	369.601	1.287.946	1.687.673	1.902.096	1.781.083	145.305	1.041.994	513.480	17.960		
Total Input	210.376	1.008.868	1.183.830	761.985	340.795	33.753	133.026	196.145	618.645	2.429.351	2.302.772	2.868.855	2.946.823	223.871	1.687.379	958.630	17.960		

Figure 31: I-O Table. **Country:** United States. **Year:** 2009. **Source:** WIOD (2013)

A.5 Direct global warming intensity (b-vector)

Economic activities		Direct emission intensity b (in tonnes/ million $)
Agriculture, Forestry and Fishing	1	1.456,4
Mining & Quarrying	2	1.187,7
Food products manf.	3	79,2
Textile products manf.	4	151,0
Leather products manf.	5	57,3
Wood products manf.	6	187,5
Paper products manf.	7	146,1
Coke, refined petroleum products manf.	8	397,2
Chemicals & pharmaceutical products	9	254,1
Rubber & plastics products	10	31,9
Other non-metallic mineral products	11	1.202,8
Basic & fabricated metals	12	213,2
Machinery and equipment	13	59,8
Electrical & Optical Equipment	14	22,8
Transport Equipment	15	34,5
Manufacturing, Nec; Recycling	16	27,6
Electricity, Gas & Water Supply	17	5.361,1
Construction	18	37,0
Repair of Motor Vehicles	19	28,4
Wholesale Trade	20	31,4
Retail Trade	21	67,3
Hotels & Restaurants	22	82,8
Inland Transport	23	726,0
Water Transport	24	1.699,1
Air Transport	25	1.187,4
Supporting Transport Activities	26	289,3
Post & Telecommunications	27	51,2
Financial Intermediation	28	12,8
Real Estate Activities	29	4,3
Renting & Other Business Activities	30	36,6
Public Admin and Defence	31	87,1
Education	32	69,6
Health and Social Work	33	52,5
Other Community, Social and Personal Services	34	238,2
Private Households with Employed Persons	35	-

Figure 32: Direct emission intensity vector 'b' for global warming potential (The vector is shown as a column to fit the page). **Unit**-Tonnes/ million $. Author's calculations.

A.6 Description of selected activities

Table 12: Description of selected activities. **Source:** (United Nations, 1990)

Economic activity	**description**
Chemical products manufacturing	Manufacture of basic chemicals, plastics and synthetic rubber etc.
Pharmaceutical manufacturing	Manufacture of pharmaceuticals (includes prescription drugs), medicinal chemical and botanical products
Computer, electronic and optical products manufacturing	Manufacture of electronic components and boards, computers and peripheral equipment, communication equipment, consumer electronics; measuring, testing, navigating and control equipment; irradiation, electromedical and electrotherapeutic equipment **(CT scanners, MRI, PET Scanners, pacemakers, medical ultrasound equipment)**; optical instruments and photographic equipment
Electricity, gas and water supply	Electric power generation, transmission and distribution; Manufacture of gas; distribution of gaseous fuels through mains; Water collection, treatment and supply;
Telecommunications	Telecommunications (Wired telecommunication, Wireless telecommunications, Satellite telecommunications;
Computer programming, consultancy; information service activities	Streaming services, application hosting, web portals, software applications etc.
Renting & other business activities or Administrative and support service activities	Renting of machinery and equipment, office administrative, office support and other business support activities
Human health and social work	Hospital activities (services of medical and paramedical staff), Medical and dental practice activities, residential care activities, social work activities

A.7 Comparison of direct intensity vectors 'b' between 1995 and 2015

Comparison of direct emission intensities	Direct intensity vector 'b' of health care 1995	Direct intensity vector 'b' of health care 2015	Difference (2015 health care-1995 health care)	Percentage change
Agriculture, forestry and fishing	276	182	-94	-34%
Mining & quarrying	835	767	-68	-8%
Food products manf.	110	94	-15	-14%
Textile products manf.	146	51	-95	-65%
Wood products manf.	197	73	-125	-63%
Paper products manf.	178	174	-4	-2%
Coke, refined petroleum products manf.	1353	673	-680	-50%
Chemicals & pharmaceutical products	440	363	-77	-18%
Rubber & plastics products	49	178	129	265%
Other non-metallic mineral products	1643	1417	-226	-14%
Basic metals	624	616	-8	-1%
Fabricated metal products	473	24	-448	-95%
Machinery and equipment	79	70	-9	-11%
Computer, Electronic & optical equipment	33	2	-30	-93%
Electrical machinery and apparatus	101	32	-69	-69%
Motor vehicles, trailers & semi-trailers	35	7	-28	-80%
Other transport equipment	108	34	-75	-69%
Manufacturing nec; recycling	54	48	-5	-9%
Electricity, gas & water supply	7898	6617	-1281	-16%
Construction	89	65	-24	-27%
Wholesale &retail trade	133	26	-107	-80%
Hotels & restaurants	190	68	-121	-64%
Transport & storage	906	1196	291	32%
Post & telecommunications	58	10	-48	-83%
Financial intermediation	40	9	-31	-77%
Real estate activities	13	4	-8	-65%
Renting & other business services	383	31	-352	-92%
Public administration &defence	336	130	-206	-61%
Education	31	21	-10	-32%
Human health & social work	128	36	-92	-72%
Arts, entertainment, recreation & other services	180	42	-138	-77%

Figure 33: Comparison of direct intensity vector 'b' between 1995 and 2015. Author's calculations

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