Does Carbon Pricing Work?

A qualitative review of Carbon Pricing's ex-post results, and policy-design suggestions for improving its efficacy.

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Abstract:

The world is currently heading for 3°C of global warming due to global excessive carbon emissions, and while science is producing the knowledge necessary to combat it, the radical change needed is not coming fast enough.

Current political and economic paradigms hail carbon pricing as either *the,* or part of the solution to our carbon emissions problem.

This thesis looks at the available (although limited) ex-post research on carbon pricing and sorts the results into several themes. The evidence shows that carbon pricing is *Marginal, Ambiguous, Uncertain, Non-transformative, Insufficient, Uneven and Superficial*. This thesis then tries to offer solutions to the problems presented, these include pricing, dealing with carbon leakage, and revenue spending.

However, serious questions surround carbon pricing's efficiency and ability to radically reduce emissions within the timeframe necessary. This thesis argues that carbon pricing should not be seen as a silver bullet, but as an important tool in the climate policy toolbox.

Keywords: Carbon pricing, ex post, policy design, decarbonisation, sustainability, environmental economics

Acknowledgements:

This thesis has been one hell of a journey. One that would not have been possible if it weren't for the support of a few people. To my dad, Jamie & Jasmine, thanks for always picking up the phone whenever I'm in panic-mode.

This thesis could have been a lot of things. Primarily, it would not have been complete if it weren't for my supervisor, Kim. For your emotional and professional encouragement, for going above and beyond in supporting me, and for helping me realise what's actually important, thank you.

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1 Introduction

1.1 All the world's a stage

In order to be in line with the Paris Agreement, and limit the worst effects of global warming, we need to drastically reduce our emissions during this decade (IPCC, 2018). A decrease in 50% of GHG emissions in the span of 10 years will be needed in order to meet the 1.5°C target. Exceeding, or missing this target will have widespread and severe impacts around the world, from extreme weather and costly natural disasters, to wide-spread biodiversity loss. Furthermore, these changes my lead to irreversible negative impacts for human and natural life and systems (ibid.). In order to reduce our emissions at an unprecedented scale and speed, a wide-ranging, global transition is necessary in all sectors and throughout the societal structure.

Unfortunately, nations are, as of yet, not on track to meet the GHG emissions mitigation goals of the Paris Agreement (Climate Action Tracker, 2021). The latest assessments of the current emissions pathways suggest that the emissions budget of 1.5 °C may be exhausted as early as 2027 – with the 2 °C budget not far behind (UNEP, 2021; Luderer et al., 2018).
The majority of nations have put legislative measures and climate targets in place (Iacobuta et al., 2018), but the implementation of effective and stringent policies still seems to be lacking. Frighteningly, fossil fuel use and global emissions continue to rise, despite it getting closer to a decade since the Paris Agreement was signed (Friedlingstein et al., 2020).

1.2 Carbon pricing – What is it and why should it work?

Carbon Pricing can have many meanings, in this thesis, carbon pricing is referred to as a tool for climate change mitigation. According to the World Bank (2017), these tools are defined as *"initiatives that put an explicit price on greenhouse gas emissions, i.e., a price expressed as a value per ton of carbon dioxide equivalent (*tCO_2e*)"* (P.20). Note, most carbon pricing schemes cover several Greenhouse Gases (GHGs), and so carbon-equivalents might be a better term. However, the equivalents are implicit, and for the remainder of this paper, I will refer to it as simply carbon pricing.

Carbon pricing is theoretically popular and has been for quite some time. The current zeitgeist highlights (neo)classical economic thinking as a source for solutions, and currently none more so than that of Pigouvian taxes (Pigou, 1920). Pigouvian taxes can, in economic lingo be shortened to: 'internalizing externalities by pricing them'. In this case, emitting carbon is an externality that nobody pays for, if we *internalize* that cost for the polluters, i.e., put a price on it, many economists believe we have solved the problem (*Economists' Statement*, 2019). Carbon pricing theoretically makes it cost-effective for companies to decarbonize, assuming that the price is high enough, as every ton of carbon emitted costs money.

1.3 Theoretical Background and entry point

Pigouvian taxes have been touted as a market-based solution to different environmental problems since the 1960s. Numerous economic heavy-weights such as Kneese (1964), Georgescu-Roegen (1960), and Solow (1965) all having weighed in on the subject. This tradition has been kept until today, with modern economic celebrities such as Stiglitz and Stern (2017), and the plethora of economic professors who have all contributed to the book 'Global Carbon Pricing' (Cramton et al., 2017), still discussing its benefits, costs and implications.

The market and economic logic behind carbon pricing is appealing, and today spans 40 nations, 20 cities, and covers around 13% of the world's annual emissions (World Bank, n.d.).The EU ETS, the largest in the world, will be going into its 4th phase, claiming that carbon pricing is a key policy in their "fit for 55 package", which aims to reduce emissions by 55% by 2030 (EU, 2022).
China, who has had several ETS pilot projects since 2013, launched its national ETS in 2020, targeting the power sector (IEA, 2020). From the world's 61 schemes, over half of them are pricing carbon at less than $10, with the world average sitting at $2 (Parry, 2019).

Thousands of articles have also been written on this topic, however, an exorbitant number of these are ex-ante articles. Ex-ante articles generally use economic models to explain how the economy *should* act when carbon pricing measures are introduced. The opposite to ex-ante, is ex-post; this means looking at how the economies *have* acted, once a carbon price, was introduced. There are very few ex-post articles on this topic and those that do exist are varied in their methods and variables, making generalisations hard to infer. Despite potentially difficult, this thesis aims to understand what can be summed up from the existing ex-post literature regarding carbon pricing, what hurdles the concept faces, and how potential difficulties can be overcome.

In this thesis I will thus aim to answer mainly two RQ's:

1. What results does the ex-post literature show regarding carbon pricing schemes?
2. Based on the results and literature, what (policy-design) choices could further reduce emissions for carbon pricing schemes?

Firstly, I will explain how carbon pricing generally works, what mechanics and logic it follows, before going into the results.

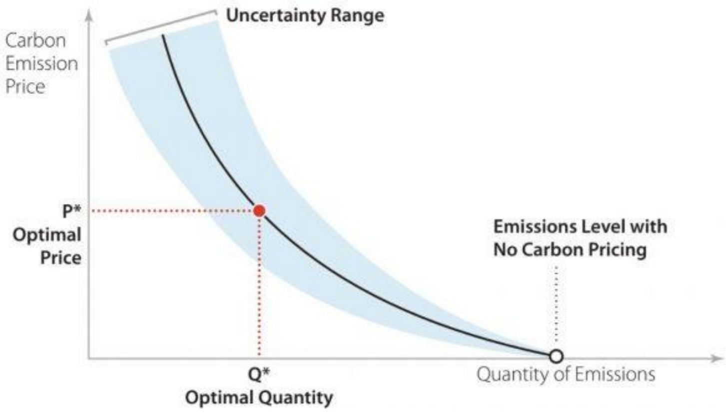
1.3.1 Theoretical Background: The difference between a Carbon Tax and an ETS

Two main routes exist within carbon pricing, and they are opposite sides of the same coin. One is a carbon tax, based on the 1960s thinker's adaptation of Pigou's earlier work (Banzhaf, 2020). A carbon tax means that you put a flat price, per ton, on all carbon emitted. The other alternative is an Emissions Trading Scheme (ETS), also called a 'cap-and-trade'; an idea which also originated in the 1960s from Crocker's dissertation "Some Economics of Air Pollution Control" (1968). A cap-and-trade means that you put a cap, or upper limit, on the emissions that you will allow from a sector, or the economy at large. You can then give or sell emission allowances to companies, allowing them to trade these allowances freely, with the goal of every company within the scheme needing to have enough allowances to cover their emissions at the end of the year; or suffer heavy fines. Both accomplishes the same feat, namely putting a price on co2, with the aim of reducing emissions.

A price on carbon theoretically makes companies invest in low-carbon futures, to a certain point.
In Figure 1, we see a Marginal Abatement Cost curve. In this graph, for every step one takes leftward on the X-axis, emissions decrease, and cost goes up. Generally, most firms and economies find that emissions can be lowered quite substantially for a low cost initially but reaching zero can be difficult and expensive. For example, switching to LED lights at the office is a low-cost intervention that reduces a firm's emissions, but to get to zero they might have to redo the entire office with second hand materials and source all energy from renewables, which is a sizable investment (Gillingham, 2019; Harvey et al., 2018; Stiglitz, 2007). Following the graph, if we change either the Price (P*), or the Quantity (Q*) in a given direction, the other one will theoretically follow (Harvey et al., 2018). For instance, if we put at carbon tax at the price P*, we can expect the emissions to be reduced to quantity Q*, but no further, since a company will likely do what makes most financial sense. If an investment into renewable energy is cheaper than paying a carbon tax, it makes financial sense to invest, lowering company emissions in the process. If the cost of reducing emissions is *higher* than the tax, the company will simply opt to pay the tax, and continue polluting.
Likewise, if we put a Cap at Q*, meaning that we allocate emissions permits across all companies, and allow a system-wide amount of co2 to be emitted. Companies are then allowed to trade permits freely within the system. Here, we can expect the trading price to reach P*, but no higher, for similar reasons as outlined above; a company will buy allowances until it makes financial sense to invest in an emissions-free alternative.

Figure 1. (Harvey et al. P.259)

A Marginal Abatement Cost (MAC) Curve of Carbon Pricing



Note. The MAC can be used to find the optimal quantity of emissions reductions and/or the optimal price. Moving either the Price (P*) or Quantity (Q*) will make the other follow suit. The cost of reducing emissions tends to be cheap initially, before it gets progressively more expensive. Reprinted from: Designing Climate Solutions by Hal Harvey. Copyright © 2018 Hal Harvey, Robbie Orvis, and Jeffrey Rissman. Reproduced by permission of Island Press, Washington, D.C.

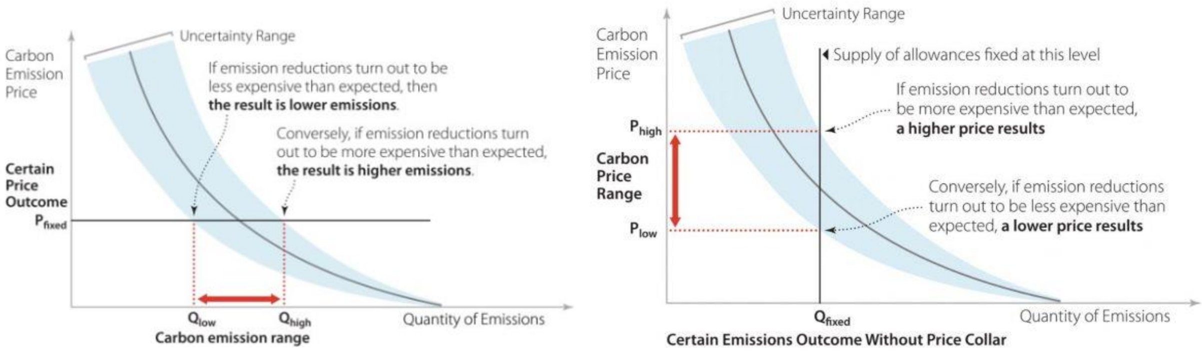
We can never know exactly how much any level of abatement will cost, so there is an uncertainty range. ETS and taxes deal with this differently. It might turn out to be more or less expensive than predicted, as we can never know what works best for each individual company, or what technological and cultural breakthroughs will happen. Therefore, in the graph (Figure 1) there is an uncertainty range regarding how expensive abatement is. Here is where the crucial difference comes into play, a tax and an ETS deal with price uncertainty differently, by following the uncertainty range along the different axes.

The elasticity of the price, or emissions, is the main difference between a tax and an ETS. In the case of a carbon tax, the price is fixed, which makes the emissions quantity elastic (see Figure 2). Elastic meaning that it changes depending on other variables (such as price). In a hypothetical carbon tax, it turns out that Company A's abatement is cheaper than they expected. Their emissions reductions will be greater as they will reduce emissions to meet the tax level, because they want to pay as little as possible. The same is true on the other end, if the abatement turns out to be more expensive than expected*,* the emissions reductions will be lesser, as Company A will opt to pay the tax instead of the more expensive abatement price (Harvey et al., 2018; Stiglitz et al., 2017). There are currently carbon taxes in 40 countries in the world, with a price range of $2-$115 (Parry, 2019).

In a trading scheme, the uncertainty regarding price is the same, but in this case the emissions *quantity* is fixed, meaning the price is elastic. In a similarly hypothetical ETS, Company B finds it cheaper to reduce emissions than expected, which means they will sell more allowances to other firms. This will result in the price of tradable allowances decreasing, as there is more supply in the market. The opposite is also true, if it turns out to be more expensive to reach the emissions target than expected, the price of the tradable allowance will increase. In both cases, the cap is at the same level. The largest and most famous ETS is the one that the EU has developed. The EU ETS covers all EU member states, sectors such as industry and energy, and covers around 40% of EU carbon emissions (EU, 2022). Note, in order for an ETS to function, there needs to be a heavy fine if a company reaches the end of a year without the correct number of allowances for their emissions, or else the system loses credibility (*EU Emissions Trading System (EU ETS)*, n.d.; Harvey et al., 2018; Stiglitz et al., 2017).

Figure 2. (Harvey et al. P. 260-261)

The Different Effects on Uncertainty When Using a Tax, or ETS.



Note. With a tax, the emissions reductions are uncertain since the price is constant. With an ETS system, the quantity is fixed, and the price is thus uncertain. Reprinted from: Designing Climate Solutions by Hal Harvey. Copyright © 2018 Hal Harvey, Robbie Orvis, and Jeffrey Rissman. Reproduced by permission of Island Press, Washington, D.C.

If a tax or ETS is more effective, and which should be used, has been debated for by economists and thinkers since the 1970s (Weitzman, 1974). Suffice to say that there is no *correct* answer, but rather, it is situational, and both *can* work if they are sufficiently well designed and implemented in the right sector (Hafstead et al., 2016; Harvey et al., 2018; Tvinnereim & Mehling, 2018).

2 Methodology

2.1 Data collection

Research Question 1 (RQ1) for this thesis were instigated by articles of Green (2021), Lilliestam et al. (2021), and Lamb et al. (2020), who had done systematic ex-post literature reviews previously. RQ2 was inspired by Harvey et al. (2018). Using these articles as starting points, data to answer the RQ's was further collected using two main alleyways: a systematic literature review, and Backward Snowballing. Thus, this thesis will only be using secondary research as a basis for answering the RQ's.

2.1.1 Systematic literature review

In order to answer RQ 1, ex-post literature regarding carbon pricing needed to be found. The ex-post literature is meagre with many of the articles having previously been analysed by the above-mentioned authors. However, in order to safeguard from articles being missed, a systematic literature review of scientific, peer-reviewed articles was conducted. The year 2018 was chosen as the start year, as one of the above-mentioned articles used data up until 2019. Web of Science was chosen as the database as the researchers had used other databases. Both of these choices were made to fill potential gaps in the literature reviewed.

The used search string was:

1. (1) Synonyms for 'Carbon Pricing'; carbon taxes, ETS, cap-and-trade, emissions trading,
2. (2) AND Synonyms for 'emissions reduction'; climate, environment, co2, GHG, emissions, carbon,
3. (3) AND 'ex post',
4. 2018-current

This string yielded 18 results. Based on the low number, the evaluation criteria were lowered than had there been more results. The following criteria were used to sort the articles.

1. The paper must be related to a qualitative analysis of carbon pricing schemes.
2. The article must be related to quantifying emissions reductions or other climate improvements.
3. The article must be an ex-post evaluation.

From the 18 articles, 6 met the above criteria.

2.1.2 Backward Snowballing

In order to gain in-depth knowledge surrounding RQ's 1&2, Backward Snowballing – the act of examining references in previously identified studies for further relevant articles– was the main method used. Due to the paucity of ex-post literature on carbon pricing, this method was deemed the most effective. Starting with the above-mentioned authors and the articles from the review, Backward Snowballing was used to find further information. While many articles were cross-referenced, in total, this yielded over 50 relevant articles.

2.2 Data analysis

The data analysis was conducted in two stages. First, all relevant articles were organised into one of two groups, meta-analyses reviews and in-depth reviews. Second, drawing primarily from the meta-reviews, the results from the articles were qualitatively analysed, compared and combined in order to answer RQ1. Third, all articles were qualitatively searched for policy and/or solutions recommendations in order to flesh out RQ2.

2.3 Ethical Considerations and conflicts of interest

There are no conflicts of interests present in this thesis, economic or otherwise, however, as a student of sustainability science I have implicit and personal biases about the topic at hand, which may have influenced the outcome of this thesis. These have been limited by following results and data, but biases regarding which articles and solutions were relevant may, despite a systematic plan, have been biased in a certain direction.

3 Results

3.1 RQ1: What does the ex-post results say about carbon pricing?

Based on the articles, the results have been sorted into 7 general themes.
The ex-post literature on carbon pricing is somewhat surprisingly meagre, with Gren (2021), Lamb et al., (2020), Rafaty et al., (2020) and Lilliestam et al. (2021) doing an excellent job of compiling and analysing a lot of the available data. Between them, they have analysed 84 articles (with overlap), ranging between 2000-2020, covering most ETS's and carbon taxes where there is data. Europe, the Nordics and North America have most mentions.
This result section is thus a compilation of all the currently available ex-post articles on carbon pricing. For this reason, this thesis will try to highlight a few major themes found through-out the academic literature.

I have identified seven key problems with carbon pricing.
The evidence suggests that carbon pricing is:

I. **Marginal**
II. **Ambiguous**
III. **Uncertain**
IV. **Non-transformative**
V. **Insufficient**
VI. **Uneven**
VII. **Superficial**

For every bulletin, there will be a number of authors cited that argue for this case. It is worth bearing in mind that some of these articles are meta-analysis (see e.g., Green, 2021b). In these situations, I have opted to reference fewer meta-analysis studies, as opposed to all the articles that showcase the same result.

I. **Marginal.**
Carbon pricing does not live up to expectations, with most results showing single digit emissions reductions per year compared to busines-as-usual (BAU), with change happening in specific sectors. (Green, 2021b; Lilliestam et al., 2021; Lin & Li, 2011; Pretis, 2019; Rafaty et al., 2020).

Across all ex-post carbon pricing literature, the effects on reducing observed emissions have been reported as underwhelming. The aggregate decrease according to 37 papers of the current Western pricing schemes is between 0-2% per year compared to BAU (Green, 2021b).

Firms in certain sectors (energy and transport) have reduced emissions between 3-28% relative to unregulated firms. This is mainly due to fuel switching (Abrell et al., 2022; Green, 2021b; Lilliestam et al., 2021; Pretis, 2019). Another positive example, the carbon tax established in 2008 in British Columbia, Canada, has reduced emissions somewhere between 5–15% compared to BAU over seven years (Murray & Rivers, 2015).

Carbon pricing seems to have an effect on the transport sector, though the amount varies depending on jurisdiction and method used. The biggest impact being demonstrated by Andersson (2019) in Sweden, showing a 6.3% emissions reduction per year. Pretis (2019) shows a similar 5% decrease in emissions from the transport sector in British Columbia, but says this was change is not large enough to affect the aggregate emissions in Canada.

On the other end, Rafaty et al. (2020) demonstrate that after a carbon price was implemented, each marginal price increase of $1 per ton of CO2 temporarily lowered the *growth rate* of Co2 emissions by around 0.01%.
All authors reviewed point out low prices and excessive allowance allocation and/or exemption from taxes as their main reasons for the low results.
It should also be noted that there is one outlier among the grey literature, Fernando (2017), who estimated that the carbon tax decreased emissions by 17.2% in Sweden, and 19.4% in Norway since the implementation in 1990 and 1991, respectively. Why her conclusion differs is uncertain. Bayer & Aklin (2020) use a similar model and argue that the EU ETS reduced emissions by 3.8% between 2008-2016 (with a bigger effect within the affected sectors).

II. Ambiguous.
Ex-post modelling suffers from a lack of uniformity and clarity; making comparison, replication and analysis fraught with difficulty (Abrell et al., 2022; Green, 2021b; Lilliestam et al., 2021).

Most articles compare carbon pricing results to BAU, the problem with BAU comparisons is that you need a counterfactual, which you use as a baseline for measuring the policy effectiveness. As most authors note, estimating a reasonable and likely counterfactual is not a straightforward endeavour, as there are no countries that have zero climate policies. This makes it difficult to create/find a suitable control group for BAU-simulation and researchers have chosen different variables to include, making it hard to compare results. Most of the ex-post studies look at if the policy has had an effect compared to BAU (Green, 2021b, 2021b; Haites et al., 2018; Lilliestam et al., 2021; Rafaty et al., 2020).

Carbon pollution is generally determined by a myriad of economic and social forces, that can be both global and local in nature. This makes causal identification of specific policies hellacious. Mildenberger (2020) writes that we can't compare estimates across jurisdictions and time or translate policy content, "Even identical carbon prices have different effects based on variation in sectoral cost exposure and sectoral differences in the elasticity of carbondependent (sic.) activities." (P.12) The combination of looking at different sectors, using different methods, looking for different outcomes, using different variables, and the paucity of studies, makes large-scale generalisations, or systematic inference, difficult (Rafaty et al., 2020).

III. Uncertain.

In areas with carbon pricing, emissions have generally been reduced compared to BAU. 12 out of 27 jurisdictions with carbon pricing have reduced actual emissions. However, there is no jurisdiction where carbon pricing is the only environmental measure taken. Most regions have several environmental regulations in place, making it hard to disentangle carbon pricing's effect from other policies, as well as global or local events. (Haites, 2018; Lilliestam et al., 2021; Pretis, 2019; Rafaty et al., 2020)

The emissions covered by the EU's ETS have fallen by 20% between 2004–2014 (Ellerman et al., 2016), but the reductions are not necessarily due to effective carbon pricing.

The EU has a number of other climate policies in place, in fact, it has more climate policies than any other region (Delbeke & Vis, 2015), making causal links hard to elucidate.

Haites et al. (2018) show that 6 of 17 taxes, and 6 of 10 ETS's have reduced actual emissions, though they attribute this to other factors.

In fact, one of the most interesting comparisons is done by Haites et al. (2018), where they compared 14 European nations that have a carbon tax, to 16 countries that do not (all nations compared are affected by the EU ETS); the nations *without* a carbon tax decreased their non-ETS emissions at a higher rate than those *with* a carbon tax, casting serious doubts on the efficacy of current carbon taxes, or, at the very least, showing that other policies are more efficient at reducing emissions. They go on to say that due to the many uncertainties surrounding price and emissions, they were unable to disentangle the effect of carbon pricing from other environmental policies (P.112).

Some researchers have tried to disentangle carbon pricing's effect from other factors. Schäfer (2019) compares the impact of the EU ETS on German emissions from the electricity sector during 2005-15, using a counterfactual emissions scenario. They find that a yearly reduction of 1.2-4.6% between 2005-2010 was due to the ETS, but, the German Renewable Energy Subsidy had a 50% greater impact than the ETS in 2010, and a 460% greater impact in 2015. This large increase is explained by the subsidy continuously reducing emissions, whereas Schäfer claims the EU ETS didn't reduce emissions between 2010-2015. Furthermore, Bel & Joseph (2015) claim that during the years 2005-2012, the majority of the abatement in the EU came from the economic crisis of 2008/09. They calculated that the EU abated 254 MgT (megatons) during said period, and only 12% of that was due to the ETS. Other policies may thus affect carbon pricing's outcome. But so can recessions, conflicts, price hikes, natural disasters and other unforeseen events.

IV. Non-transformative

Ex-post evaluation shows carbon pricing currently has little to no effect on technological innovation (Calel & Dechezleprêtre, 2016; Haites et al., 2018; Lilliestam et al., 2021).

Lilliestam et al (2021) compare and review the ex-post literature on carbon pricing schemes and find that aside from fuel switching, there is little to no evidence of carbon pricing inducing technological innovation. This is based on data from New Zealand, British Columbia, Scandinavia, and the EU. However, all but one articles reviewed by Lilliestam et al. looked at the period pre-2015, meaning there is a substantial gap in the recent research. Calel & Dechezleprêtre (2016) points out that firms affected by the EU ETS have increased their percentage of filed low-carbon patents by roughly 8%, compared to 0.8% of EU firms not affected by ETS. This is an increase of EU-wide innovation by 2% post 2005. While they claim there has been a strong increase in patents, they cannot conclude causality. This is corroborated by Martin et al. (2016), who show that companies within the EU ETS that sit just below the threshold free allowances conduct significantly more research into 'clean technology' than those just above, showing that free allocation has a negative impact on renewable R&D.

V. Insufficient.

Carbon pricing on its own, even if it was implemented globally, will not be enough to bring emissions within the 1.5, or even 2°C target. (Calel & Dechezleprêtre, 2016; Green, 2021a, 2021b; Haites, 2018; Haites et al., 2018; Lilliestam et al., 2021; Pretis, 2019; Rafaty et al., 2020, 2020)**.**

Drawing from the above results, carbon pricing is insufficient as a decarbonisation tool. The results so far show emissions reductions 0-2% per year, and no visible effect on technology, in all known jurisdictions. The effect that has been seen is hard to quantify and causally trace to carbon emissions. In order to meet the 1.5°C Paris Agreement, a 43% decline in carbon emissions must be reached by 2030, meaning around a 6% decrease annually. (IPCC, 2022) Based on these factors, carbon pricing on its own does not have the capability to radically decarbonise society that is necessary.

VI. Uneven.

Carbon taxes seem to work well in sectors where emissions reductions can be achieved through incremental optimisation. This is effective in sectors such as transport, manufacturing, heat, and electricity. But, these sectors also seem to be the only sectors where we have seen any effect (Andersson, 2019b; Green, 2021b; Pretis, 2019; Tvinnereim & Mehling, 2018).

As shown above (Results I), Andersson (2019) and Pretis (2019) demonstrate reductions of emissions in the transport sector in Sweden and British Columbia, respectively. However, as Tvinnereim & Mehling (2018) showcase, since 2017, gasoline and diesel cars have increased in Sweden, despite their carbon tax being the highest in the world. Articles looking at British Columbia show a reduction of emissions in the transport sector; however, none state explicitly where the reduction comes from. Looking at the small percentage of electric cars, however, means shifts are likely operational, meaning from gasoline to diesel or hybrid cars, or potentially a decrease in driving in favour other travelling means (Lilliestam et al. 2021). Lilliestam et al. further argue that the uptake of electrical vehicles is not dependent on the fuel price but is more affected by lack of electric infrastructure. This means that without infrastructural investment, carbon pricing will likely continue to have a limited effect on transport.

Rafaty et al. (2020) show that the biggest reduction in emissions *growth* - due to carbon pricing - has come in the electricity and heat sector, with up to -6% per year. They argue that emissions were on average being reduced 1-2.5%, and that a $1/tco2 increase in price means a 0.26% decrease in emissions growth in these sectors. However, the electricity and heat sector seem to be especially prone to leakage (when industry moves out of jurisdiction instead of lowering emissions) when the carbon price is introduced in a sub-national state or province, such as British Columbia or California (Green, 2021b; Lilliestam et al., 2021).

In the electricity and heat sector, fuel-switching has been a common reply to introductions of carbon pricing (ibid.), as exemplified in the UK where the introduction of a carbon tax caused 15% of coal to be replaced by natural gas, reducing emissions from the electricity sector by 6.2% (between 2013-2016) (Abrell et al., 2022)

There have also been reductions in the manufacturing sector due to carbon pricing. In Germany, ETS-covered industry reduced emission around 25% relative to unregulated firms between 2008-2010; In France there was a 13-19% decrease, in both cases fuel-switching was given as the primary source of reduction (Green, 2021b).

Many of the biggest emitters in carbon priced regions tend to be 'trade-exposed' and thus given free carbon allowances or carbon tax exemptions (Haites et al., 2018; Lilliestam et al., 2021; Lin & Li, 2011). In a sentence, carbon taxes are inefficient, and in the sectors where they would be efficient, the firms are exempted.

VII. Superficial

For energy companies, large-scale investments into renewables has not happened, the biggest has been from oil/coal to natural gas, so-called fuel switching.

In the electricity and heat sector, fuel-switching has been a common reply to introductions of carbon pricing, as exemplified in the UK where the introduction of a carbon tax caused 15% of coal to be replaced by natural gas, reducing emissions from the electricity sector by 6.2% (between 2013-2016) (Abrell et al., 2022). In the EU, which reduced emissions 3-6% compared to BAU between 2005-15, and at least half of these reductions came from fuel switching according to Calel & Dechezleprêtre (2016).

Fuel switching could potentially decrease worldwide emissions by 3% and reduce specific GHGs by 50% if widely adopted. While this can be argued to be an important stepping-stone towards decarbonization (Lilliestam et al., 2021), natural gas still emits roughly half of the GHG of oil and coal (EIA, n.d.), meaning that it cannot be a permanent solution if our goal is a full decarbonization (IPCC, 2022).

As mentioned above (Results VI), transport sectors affected by carbon pricing have also generally fuel-switched from gasoline to diesel as opposed to electric. The reason why is unclear, but carbon price and lack of renewable infrastructure seem to be the main arguments (Lilliestam et al., 2021)

3.2 RQ2: What policy-design improvements are possible?

Looking at the ex-post results, we can conclude that the carbon pricing schemes are by and large not working to the intended efficacy (in terms of emissions).

Based on design principles from Harvey et al. (2018), Stiglitz et al. (2017), and Cullenward & Victor (2020), as well as the problems articulated in the ex-post literature, there are six likely design-flaws for not seeing predicted results.

Design flaw in carbon pricing	**Source**
A. Carbon Leakage	(Stiglitz, 2007)
B. The carbon price is 'inaccurate'.	All sources
C. The policies are imperfectly designed. I.e., they have loopholes, exemptions, uncertain reward and punishment structures, and/or difficult administrative systems.	(Harvey et al., 2018)
D. Revenue use is ineffective	(Cullenward & Victor, 2020; Harvey et al., 2018; Stiglitz et al., 2017)
E. The timeframe of the policy is uncertain.	(Harvey et al., 2018)
F. Carbon pricing is sectorally (in)effective.	(Cullenward & Victor, 2020)

A. Problem: Leakages and exemptions.
Solution: Implement a BCU, carbon club, or similar system where imported goods and energy is taxed for its carbon usage. Phase out exemptions and allowances.

When introducing carbon pricing, it generally incurs an extra cost on firms. This means their wares become more expensive and they become less competitive compared to firms in jurisdictions without carbon pricing. What typically happens then is that the firm will shift its production from a regulated jurisdiction to one with weaker policies. This is commonly referred to as carbon leakage (Haites et al., 2018). What's worse, in many situations the emissions may end up *increasing* due to the leakage, The jurisdiction with the more stringent policy is economically punished; the laxer region is rewarded, and pollution increases. For example, if Company C produces wares in Sweden, Swedish laws prohibits certain chemicals and practices from being used for different environmental reasons. A carbon tax is in place to 'nudge' companies into making further investments into sustainable technology/practices. However, if this cost seems too high, company C may decide to relocate to another country where the climate laws and policies are laxer. Due to the relocation, global emissions have actually gone *up,* as the relocation costs energy, new factories need to be built, and the practices are now less environmentally friendly.

In order to avoid this, big firms that are a large part of the economy - who often emit significant emissions – are given tax exemptions and/or free ETS allowances (Haites et al., 2018; Lilliestam et al., 2021; Lin & Li, 2011). These firms are known as Emissions Intensive Trade-Exposed (EITE), and virtually all carbon pricing schemes to date have free allowances or exemptions for EITE's (ibid.). The idea is that exemptions level the playing field for the firms, reduces carbon leakage, and reduces local economic loss.

However, there is an alternative to exempting local firms from the tax, and that is to put a tax on imported wares that corresponds to the local carbon price. The idea of putting a tax on imported energy from firms that operate in less stringent economies has been around for at least 15 years (Stiglitz, 2007), usually under the name of Border-Carbon Adjustment (BCA). BCA's are a "hot potato" topic, as it involves taxing international companies differently than national ones, which is often labelled protectionism, and is seen as counter-productive in a free-market oriented global economy (Furceri et al., 2020). However, in systems with carbon pricing, they dis-incentivise carbon leakage (Xing & Kolstad, 2002).

The results from North American ETS's are mixed, but there is evidence to suggest carbon leakage is common. Despite the California cap and trade scheme existing since 2013, there is only one ex-post article that has looked at this carbon pricing scheme, and it estimates that between 24% and 43% of emissions from electricity generation were moved out of state in order to avoid regulations (Cullenward, 2014). However, Harvey et al. (2018) argue that the program accounts for imported electricity (P. 275). Although, what they base this claim on is unclear.
Similarly, when Quebec introduced their ETS system, industrial facilities in the area decreased their employees and carbon emissions by 6.8% and 9.8% respectively. They also saw carbon intensity decrease of 3.4%, meaning that there were technology improvements implemented, but primarily the evidence suggests that the facilities affected by the ETS downscaled and moved production to an area without carbon pricing (Hanoteau & Talbot, 2019). None of these areas use BCA's or similar import taxes, which would theoretically explain leakage.

A step further from BCA's are "carbon clubs" where within the "club" you agree on a carbon price, and have trade benefits, whereas nations outside are subjected to higher import taxes (Harvey et al., 2018; Mehling et al., 2018; Nordhaus, 2019). These clubs can look differently, some, like Nordhaus' model - which is similar to the structure of the World Trade Organization - where members put a tariff on *all* imported goods from nations outside the club (Nordhaus, 2015). Or like Al Khourdajie & Finus (2020), who argue that if treaties have open membership, and only have import costs on good's carbon content, the BCAs could lead to stable climate agreements, including full participation from the members.

A similar idea to carbon clubs is "linking" different ETS schemes, which means that two separate ETS systems are connected, so that emissions allowances can be bought and sold between the two jurisdictions. These links are so far relatively uncommon, with California, Quebec and Ontario the only 'linked' group currently in operation. This seems to be working smoothly, as far as trading credits are concerned (Harvey, 2018, P. 275).
Linking ETS's and creating a global carbon market with a global carbon price makes sense from a market-based globalization perspective. However, authors such as Green, has, in her obscurely named article "Don't link carbon markets" (2017), argued for the opposite. She argues that links cause unnecessary complexities and interdependencies and have so far yet to yield any significant effect on emissions reductions. With that said, Green (2021b), and subsequently I, found no ex-post studies that have been done on the effect of linkages, therefore we can't know what the results from linking are. The fact there are no ex-post studies is, in itself, very surprising, especially considering the number of researchers who support it (Doda & Taschini, 2017; Mehling et al., 2018).

Finally, in a system of free allowances, the questions of 'who gets allowances and why' become essential. Currently, EU bases free allowances on emission efficiency benchmarks and the sectoral risk of carbon leakage (Marcantonini et al., 2017). These are, in turn, based on carbon and trade intensity. However, when evaluated, these criteria have been shown to be overly conservative, and free allowances were often given to installations in sectors that were not actually at risk of carbon leakage (ibid.). While phase 4 of the EU ETS will implement more stringent criterion for free allowances, they are still highly contentious, and free allowances or tax exemptions can undermine public and corporational trust in the scheme (Harvey et al., 2018; Stiglitz, 2007; Stiglitz et al., 2017).

Whichever system is adopted, leakage needs to be addressed in order for the carbon pricing to be effective. This can be done locally through carbon taxes with BCA's, or be done internationally through carbon clubs or linking of ETS's (Harvey et al., 2018; Mehling et al., 2018; Stiglitz, 2007).

B. Problem: Globally, carbon pricing is set too low, incentivising spending money on taxes and allowances, instead of decarbonisation.

Solution: Increase carbon prices to at least $100/ton, context and sector dependent. Communicate long-term progressive price rise. And/or end fossil fuel subsidies.

Putting the right price on carbon is tricky, as there are many factors to take in. From the longevity in the atmosphere, the health costs of affected city-dwellers, the economic burden on firms, to the cost of incrementally increasing the risk of global disaster, there is no 'natural' price on carbon. If we set the price too low, then projects, investments and regulations won't be implemented. However, if we set the price too high, we might do something "foolishly expensive" (Stern & Stiglitz, 2021, P.1). With that said, all authors reviewed in this thesis claim that low prices are a main reason for carbon pricing's disappointing results.

Current carbon pricing can vary from $10 to $1000 per ton of emissions (Ricke et al., 2018), and with no clear authority on the matter, it's difficult to know which estimate one should listen to. Furthermore, local contexts and politics will play a decisive role in which price is feasible and desirable (Stiglitz et al., 2017). The result is that different jurisdictions have opted for different prices. These prices have also changed within the same region, depending on politics. For example, during President Obama's tenure, the EPA put the social cost of carbon at $37/t (*Refining Estimates of the Social Cost of Carbon*, 2013), this decreased to between $1-$7 under the Trump administration (Voosen, 2021). The Biden administration wants to raise this to $125, but is facing legal difficulties as of April 2022 (Joselow, 2022). While the social cost of Carbon in the USA isn't part of a carbon pricing scheme, it highlights the difference modelling and politics can have on the potential price, and the instability this causes.

The High-Level Commission on Carbon Pricing concluded that the price of carbon emissions needs to be *at least* US$40–80/tCO2 by 2020 and US$50–100/tCO2 by 2030 in order to facilitate decarbonisation and stay well below of 2°C; today they argue that around $100 will be necessary (Stern & Stiglitz, 2021; Stiglitz et al., 2017). Importantly, they also claim that in order to send a clear message to firms and population, there needs to be a long-term bipartisan agreement on price, so it doesn't fluctuate, or else willingness to invest diminishes (see Results E). Some fluctuations are expected, the estimate of the social cost of carbon have been significantly increasing yearly as emissions grow, and as our climate and economic predictions get better (Kaufman et al., 2020; Stern & Stiglitz, 2021).

Depending on economic model and discount rate, different carbon prices will emerge, which can cause some controversy. For instance, Nordhaus famously declared that a 4°C increase is the social optimum (Nordhaus, 2018). 4°C warming, would be catastrophic for human (and animal) life (IPCC, 2022). Nordhaus has since adapted his stance, saying that if we want to stay within 2°C, the carbon price had to be between $159-$279 in 2020 (Nordhaus, 2019), highlighting just how important the variables are, and what ramifications it may have for the future.

As noted in the introduction, the global average price is $2/ton, which is equivalent of adding roughly €0.009 per litre of petrol. However, we have an example of a country that has a high tax. Sweden's tax is at roughly €118 as of 2022 (Regeringskansliet, 2018), which is the highest in the world by quite some margin. However, the higher price has not had the desired effect on emissions, technology, or infrastructure (Results I), with emissions reduction results varying from statistically insignificant to 17% per year, the last one being an outlier (Fernando, 2017; Green, 2021b; Lin & Li, 2011).
There are a few other reasons for the low emissions reductions, that are important to note. One, Sweden is also affected by the EU ETS, where industries who are part of the ETS are not affected by the local carbon tax (ibid.); 2/3 of Sweden's biggest polluters have been given free allowances over the last 7 years (Winberg, 2021). Two, Sweden's energy sector is predominantly fossil free (SCB, 2022), meaning that the carbon tax doesn't have a large effect on the energy sector. Three, according to a study from the Tax Foundation, only 40% of Sweden's nationally produced GHG emissions are affected by the tax, and none of them are Sweden's biggest emitters (Asen, 2020). Four, in the year 2017, the revenue from the Swedish carbon tax was approximately 95 billion SEK (Statistics Sweden, n.d.), and the explicit subsidies for fossil fuels in 2017 amounted to 30 billion SEK according to research done by Naturskyddsföreningen (Friström, 2018), meaning the carbon price is actually only 2/3 of its stated price. The area where the tax did show a reduction in emissions, was the transport sector, which as we know, responds to carbon pricing (results I&VI). In other words, the 'high' carbon price does not necessarily reflect reality, as Swedish large emitting firms are either affected by the ETS or tax exempt. Thus, a high price is admirable, but if there is carbon leakage or tax exemptions, it will likely not be effective.

C. Problem: The policies are imperfectly designed. I.e., they have loopholes, exemptions, uncertain reward and punishment structures, and/or difficult administrative systems.
Solution: Create simple rules, standards, avoid exemptions, and focus on desired outcomes.

Intricate and/or detailed policies can create loopholes that not only makes the policy toothless, but in certain cases actually cause an emissions *increase.* One such example is when the US government differentiated between fuel taxes on 'personal vehicles' and 'light trucks'. This caused a boom in SUV sales as personal vehicle because these were classified as the latter, and had less tax on fuel, resulting in increased carbon emissions from the transport sector (Harvey et al., 2018, P.45). Keeping the standards and rules simple, focusing on the desired outcome (i.e., a reduced carbon amount, and not, for example, a reduction in combustion engines) gives companies better possibilities to find novel solutions to their own carbon problems (Harvey et al., 2018; Stiglitz et al., 2017).

Not only does the carbon pricing scheme need to be stable and simple, the combination of climate policies should also be simple and work in conjunction. In that sense, a carbon tax is simpler than a cap and trade, both to implement, uphold, and adapt (ibid). There is some evidence to suggest that ETS systems and other climate policies are at odds with each other. For example, if we return to Company B from the introduction. They have decided to invest into renewable R&D over a 10-year period, in order to bring down their emissions. They are also looking to make a profit from future allowance sales, and this is factored into their calculation. If a new climate policy comes into law halfway through the period that forces companies to lower their emissions, the ROI for Company B is lower than if the new policy would not have been enacted. The fear of lost revenue may cause companies to not invest. However, the results are mixed whether this is an actuality or a theoretical fear (Kautto et al. 2012). In the case of a carbon tax, however, this particular risk disappears.

ETS's have become increasingly complex compared to carbon taxes. Haites et al. (2018) show that cap and trade systems have globally been communicating and sharing recommendations on how to be more effective, whereas carbon taxes have been the same since their introduction. Both of these are potential strengths and weaknesses. For instance, the EU ETS has repeatedly changed, and is now in its fourth phase, which implements a host of changes and updates, such as the 'Market Stability Reserve' (MSR) that removes excess trade allowances from circulation (Appunn, 2019; European Comission, 2021). These revisions are likely to drive emissions prices up, which should *theoretically* reduce emissions. However, it does not *simplify* the ETS.

Currently, in the EU ETS, the fine for not having the necessary allowances at the end of the year in the is €100/t. With the price of an allowance trading at €91, as of May 2022 (*EU Carbon Permits - 2012-2022*, n.d.), this greatly undermines the system, as the fine is too similar to the actual price. This creates a risk of companies 'doing nothing', as that will be cheaper than engaging in the ETS (EPA, 2022).

Most importantly, whichever system is in place, there needs to be clear rules, simple rewards and punishment structures, strong accountability and a long-term plan in order to create stability for firms.

D. Problem: Revenue from carbon pricing schemes is often added to general budget, which is ineffective for emissions reductions and is unpopular among voters.
Solution: Invest revenue into renewable energy support schemes, renewable infrastructure, R&D, and/or same-sector investments. A revenue-neutral tax is theoretically a political win/win situation.

When carbon is taxed, what the accrued revenue is used for can have wide-ranging implications on both emissions and society at large. In the case of Sweden, the carbon tax goes into the general budget (Regeringskansliet, 2018). This could be used, for example, to decrease taxes on income and other wares in order to increase consumption and stimulate growth. This could potentially create a troublesome situation. Imagine a scenario where a carbon tax is levied on a company that emits co2. Instead of reducing emissions, the company decides to pay the tax. Imagine further, that the tax revenue is then used to decrease VAT on electronics in order to boost the economy. The polluting company has thus not decreased its pollution, and the revenue has been used to increase consumption, which has further increased emissions. This creates an *increase* in emissions from the carbon tax. While this situation is highly hypothetical, and simplified, it highlights the importance of carbon tax expenditure planning.

How and on what to spend revenue on, is a multi-faceted discussion. The correct expenditure will depend on the priority of the jurisdiction implementing the carbon price. Generally, 72% (around $15b) of carbon tax revenue goes into the general revenue, where around 70% of ETS spending ($4b) goes to “green spending” (R&D, deployment and development of renewables) (Carl & Fedor, 2016). Revenue earned from ETS’s tend to be significantly less, which may help explain the revenue’s limited effect on technological change. In the interest of solely reducing emissions, adding revenue to the general budget is likely not the most effective use. Large-scale and continuous support for Research and Development (R&D) needs to be implemented (Harvey et al., 2018; Lilliestam et al., 2021; Stiglitz et al., 2017). As detailed earlier, taxes and ETS’s have not had any effect on technology advancement on their own. However, through expenditure into R&D, investment into infrastructure, and paying for policies that do have a proven track record - such as renewable energy support schemes (Schäfer, 2019) - carbon pricing can have an effect on technological change, through paying for the development, and increasing the cost of carbon intensive alternatives (Lilliestam et al., 2021; Tvinnereim & Mehling, 2018).

There are risks to this, one should be careful not to introduce “belt and suspenders” policies. This means investments into policies that affect a sector that is already being affected by another policy. An example of this is if you have a carbon tax on electricity generation, a “belt and suspenders” approach would be to also have a tax subsidy on solar production, or a feed-in tariff on renewable energy. These secondary policies tend to become windfall for companies who are already investing into more sustainable practices and is thus an ineffective use of resources (Levinson, 2012).
From a welfare perspective, carbon pricing looks a little different. An introduced carbon tax in a jurisdiction that relies heavily on coal power for energy will increase costs for everyone, and the poorest part of the population’s percentage of money spent on energy will be proportionally bigger than the richest part, which is cause for concern.

One of the biggest obstacles that carbon taxes in particular faces is public support (Carattini et al., 2019; Douenne & Fabre, 2020; Green, 2021b; Mildenberger, 2020). Carbon taxes are a highly politicised topic, as has been seen in the ‘Yellow vests’-movement in France, or among both the democratic left and republican right in the US (Douenne & Fabre, 2022; Mann, 2021). One way to technically appease both groups is to redistribute the dividends back to the people in a per-capita fashion, called ‘Per-capita dividends’. The conservatives should be happy as the state is not filling up its coffins, and the left should be happy as a carbon tax with per capita dividends primarily eases the burdens of the poor (Carattini et al., 2019). For example, if a low-income household spends €50 on carbon taxes a month, and a high-income household spends €100, there is a total revenue of €150. This income is divided by two, meaning that the low-income household gets $75 back, and actually has more money than without the tax. However, as Douenne & Fabre (2022) explain, even when shown evidence that they would be better off, members of the yellow vest-movement has been reluctant to change their mind and continue holding on to negative beliefs regarding carbon taxes. Mildenberger et al. (2022) show a similar result in Canada and Switzerland, arguing that partisan ideals determine opinion on carbon taxes more than economic assessment or revenue use does.

Revenue use is of utmost importance, and where it’s invested needs to be both carefully chosen, as well as communicated clearly and transparently, and even with the best plan available, there is a substantial risk that people across the political spectrum will oppose it, even on unproven grounds.

E. **Problem:** The timeframe of the policy is uncertain.
   Solution: Create strong, bipartisan agreed-upon laws for carbon pricing (and climate policy). Long-term commitment is necessary for public and corporational trust.

Long-term, bipartisan agreed upon laws that support long-term carbon pricing schemes need to be in place for companies to be willing to invest large sums of money into sustainable practices (Harvey et al., 2018, P.41). if the laws that require them to invest in sustainable practices - or pay for not doing so - are built on shaky foundations, or there is a risk of the policy changing within the research period (often a decade), there is a large risk the firm will opt out of investment. Indeed, Wiser and Bolinger show (2016, in Harvey, 2018, P.108) that the US Production Tax Credit, where power companies were rewarded for wind power generated, created counter-productive boom-bust cycles, as well as a decreased general investment rate due to the policy having to be evaluated and renewed every 5 years. Thus, regardless of if one implements an ETS, tax or other climate policy, it needs to be clear that this policy will be kept over a long (decades) time frame.

Carbon taxes are by-and-large simpler than ETS's, this could be seen as an argument in taxes favour, as they have historically not changed structurally (Haites et al., 2018). However, the price of the carbon tax is often decided politically and can be increased or decreased without sufficient prior signals to firms, which can make long-term investment difficult (Stiglitz et al., 2017). ETS's, on the other hand, have generally shown shared learning results, a clearer long-term plan of continually improving, increasing price floor and/or decreasing allowances over time; and signalled these events years ahead. This structure may be more complex, but is generally seen as more stable, and favourable for firms (Haites et al., 2018).

F. **Problem:** Certain sectors suffer from 'split incentives' and similar market failures that carbon pricing is ill-equipped to deal with.
   Solution: Sector-specific policies and a combination of climate policies.

When evaluating specific economies, it is worth noting that certain sectors are insensitive to carbon pricing. One such example is the housing/rental sector, where a carbon tax on electricity will cause the tenants concern as their monthly payments go up; especially if they have older, more energy-demanding machines, or poor insulation at home. This further means that they have an incentive to invest to reduce their monthly cost. However, they don't own the apartment, so these additional benefits accrue the landlord when they move out. Since the landlord doesn't pay the electricity bill, they have no incentive to invest in newer machinery or insulation, as they accrue only the costs and no benefits (Gillingham et al., 2012; Harvey et al., 2018). This is known as split incentives, and in this case, carbon pricing is inefficient and should not be used. Instead, it needs to be combined with other policies to have an effect on this sector, such as efficiency requirements and building standards.

Cullenward & Victor (2020) argue that carbon pricing, as well as most environmental policy should not be applied to the entire economy, but instead be sector-specific. The argument here is that just as we saw in the example above, different sectors have a large variety in what policies would be most efficient. King et al. (2019) also show evidence that sectoral taxation is more effective than economy-wide taxation, which ties into Stiglitz et al.'s (2017) argument that carbon prices should be nationally, and not globally determined, as different jurisdictions will have different political, economic and environmental conditions.

Investments into same-sector policies can have surprisingly effective results. Gren et al. (2021) shows that adding a climate tax (€115/tco2e) on food in Sweden reduces emissions from the food sector by 4.4% when the tax went to the general budget. If the revenue instead went to same-sector investments, such as refunding farmers who enhance ecosystem services (e.g., restore drained peatlands), the emissions sequestered equal 57% of the emissions from all Swedish food consumption. Thus, there is a large potential for carbon pricing to reduce emissions, if revenue is used for same sector-investments and R&D.

Another example of a multi-sectorial problem is that of the "Waterbed effect", that has plagued the EU ETS. For example, a state in the EU ETS invests in a wind farm, which produces clean energy to local industry. The total emissions within the ETS *will stay the same* because the emissions cap is fixed. This means that the emissions allowances will simply go to other firms that can use them, calling to mind the effect of sitting on a waterbed, the water simply moves to another part of the mattress (Rosendahl, 2019). While the EU's implementation of the MSR aims to address this, sectoral climate policies (such as carbon pricing) might also be a solution.

4 Discussion

The ex-post results are mixed but tells a somewhat cohesive story. In sum, carbon pricing schemes, both taxes and ETS's have had marginal effects on emissions reductions, mainly through fuel switching in the energy and transport sector. No effect on technological change due to Carbon pricing has been seen. Furthermore, due to the interconnectedness of the economy, causality is difficult to infer. Despite the results, carbon pricing is still widely regarded as an essential climate policy tool. The main reasons that carbon pricing hasn't worked as well as intended, are pricing,

leakage, instability and revenue use, and policy design improvements have been suggested to rectify these problems.
In this discussion part, I will mainly highlight additional large-scale explanations for carbon pricing's results.

4.1 Further factors that influence carbon pricings efficacy.

4.1.1 Belief in models, and the prioritising of industry

The ex-post literature is in agreement that the emissions reductions are marginal. Despite this, modelled observations are still used to justify carbon pricing's effectiveness. This can potentially create problems as it can give a skewed view of reality. For instance, a recent OECD brochure named "Effective Carbon Rates" (2021) chose to highlight Sen & Vollebergh's (2018) results as the basis for their brochure, despite the estimation being largely hypothetical in a modelled future. They did not choose, for example, Rafaty et al.'s (2020) ex-post analysis based primarily on *current* carbon prices, and the actual emissions reduced. Importantly, Sen & Vollebergh conclude that a €1/tCO2 energy tax increase would reduce emissions from fossil fuel consumption by 0.73%. Rafaty et al., on the other hand, argue that increasing the ETS or carbon tax by $1/tCO2 (not only energy) temporarily decreased the *growth rate* of CO2 emissions by 0.01%. To clarify, according to Sen & Vollenbergh, a price increase of €100 on the energy tax would reduce emissions by 73%, whereas according Rafaty et al.'s estimation, a $100 price increase would reduce *growth rate* by 1%. These authors use different methods, and importantly, focus on one sector vis-à-vis several, however, the difference is staggering. Aside from a footnote regarding Green's 2021 article, ex-post literature was not featured in the brochure, raising question-marks as to why the ex-post results are not considered.

Verbruggen et al. (2019) explains that the EU is sitting in an uncomfortable spot where they have to choose between two goals. The π-goal, which means keeping the price of emissions low in order to save industry and growth and giving out free allowances to EITE companies to avoid leakage. The other option is the A-goal, which means drastically increasing emissions prices and other environmental policies, in order to reach the 2030 Paris goal. This will likely mean certain industries and fossil fuel companies not being competitive, having to relocate, or going bust. The ETS cannot reconcile both these goals. The authors further argue that the EU has been successful in achieving the π -goal as there has been relatively little carbon leakage from the EU, and most companies within the ETS are still economically competitive. However, as the results (this paper) show, there have been very little emissions reductions. In order for the A-goal to be feasible, the EU will need to relinquish its π-goal.

These two examples highlight the preference for ex-ante models, and that continued industry and growth, is generally prioritised over emissions reductions.

4.1.2 Fossil fuel subsidies.

Currently, fossil subsidies around the world are between 8 and 100 (!) times larger than revenue generated from carbon pricing (Figure 4).

Looking at the EU level, member states spent more than €55 billion on explicit fossil fuel subsidies. By comparison, the EU ETS earned €22 billion in revenue during 2019, meaning that the carbon price is, in fact, negative.

On the global scale, IMF reported that oil, coal, and natural gas received $450 billion in explicit subsidies in 2020, however, when you look at the implicit subsidies, the number rises to an unfathomable $5.9 *trillion*, which equates to around $11 million every minute. Furthermore, this subsidy is reported to grow by 9% by 2025 (Parry et al., 2021).

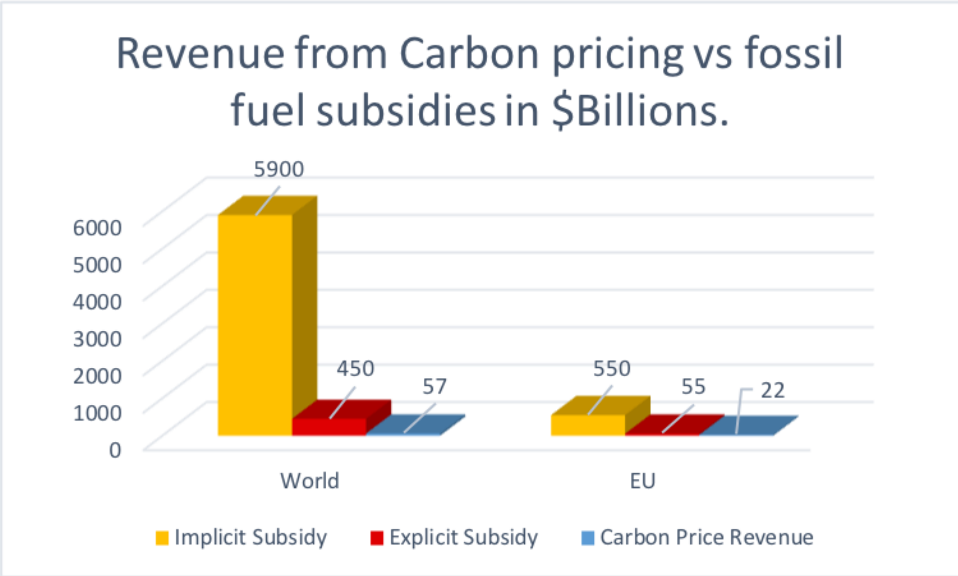
Explicit costs mean undercharging for the actual price of fossil fuels, i.e., the consumer pays less for the good at the state's expense. The report found that nearly half of natural gas, and 99% of coal is priced at *less than half* of its true cost (Parry, 2019). Furthermore, Coady et al. (2019) demonstrate that coal and petroleum companies account for 85% of all global subsidies.

Implicit costs, on the other hand, mean undercharging for the environmental and health costs, as well as foregone consumption taxes. The implicit subsidies can thus be seen as the 'true' cost of the emissions to society, whereas the explicit costs are direct subsidies to fossil fuel companies in order to lower e.g., transport and energy costs.

Removing subsidies globally would make renewable energy financially viable and put us within the 1.5°C target. Following the same neoclassical economic logic that carbon pricing does, a continued use of fossil fuels is expected as long as they are subsidized. This is especially observable in the middle east, where, due to explicit subsidies, the cost of energy from oil and gas is 55-70% cheaper than its production price. Without this subsidy, power from both wind and solar would economically outcompete oil and gas (Stiglitz et al., 2017). Parry et al. (2021) argue that if the retail cost would reflect the actual cost (production cost+explicit and implicit subsidy), global emissions from fossil fuels are projected to reduce by 36% compared to 2025 BAU levels, which would be compatible with the 1.5°C target. Fossil fuel subsidies are by-and-large due to domestic factors and can for that reason be changed by the local government, making a transition theoretically easier.

Figure 4

Revenue from vs Fossil Fuel Subsidies in $Billions.



Note. Column showing revenue from carbon taxes and ETS's in the world and EU, compared to the implicit and explicit fossil fuel subsidies. (Data from: Parry et al., 2021; Postit & Fetet, 2021)

4.1.3 Wealth inequality

Increase in wealth inequality is positively associated with carbon emissions (Hailemariam et al., 2020). Since the 1980s, the world has seen a rise in income inequality, where today the bottom half of the world population own 2% of the wealth, and of the top decile own 76% (Chancel et al., 2022). Recent studies further argue that this richest 10% of the population (633m people), are responsible for 52% of cumulative global carbon emissions (Chancel et al., 2022; Gore, 2020). Perhaps it is not strange then, that when the richest people on the planet lose wealth, co2 emissions go down. This is shown by Bel & Joseph (2015), who claim that 88% of the emissions abatement between 2005-12 came from the economic crisis in 2008, as opposed to carbon pricing or other climate policies. There is then, some merit to Green's argument that taxing the richest, closing tax havens, and redistributing wealth should be considered climate policy (Green, 2021a).

This brings back the discussion of taxes and revenue use, as individuals have stashed somewhere between $8.7 and $36 *trillion* in tax havens according to the IMF (Shaxson, 2019). At this point, it's worth remembering that the cost of *implicit* carbon subsidies was $5.9 trillion. According to work done by BloombergNEF, the cost of decarbonising the EU's energy grid by 2050 is $5.3 trillion ('Europe's Path to Clean Energy', 2022). In the US, the cost of decarbonising the grid has been predicted at $4.5 trillion by energy firm Wood Mackenzie (Shreve, 2019). While these numbers are likely inaccurate, the numbers do give us a sense of what the cost of decarbonising might be. If fossil subsidies were removed, and tax havens were reduced, there would be a substantial amount of revenue to be invested, globally. As Kevin Andersson has argued, climate change is ultimately a rationing issue (Naylor, 2018), and rationing is a question of welfare. Unfortunately, economic inequality thwarts attempts at establishing welfare states (Gärtner & Prado, 2016).

4.1.4 Trust and its impact on climate policy

Not only does Income inequality thwart welfare states, it also erodes trust (ibid.), which has a large impact on the public's climate and policy perception. In the US, for example, there is a strong partisanship when it comes to carbon taxes, with voters often following party lines (Mann, 2021), despite strong counterevidence to their claims. Conservative parties tend to argue that carbon prices stymie growth and leads to fewer jobs. Metcalf (2019) looks at the carbon tax in British Columbia and Scandinavia, with a focus on GDP impact. Based on a DiD analysis he finds no adverse impact in Canada; and in Europe, he finds, if anything, a small positive impact on GDP. He later expanded on this, together with a colleague to look at all countries within the EU ETS, finding, once again, no negative effect on GDP or jobs (Metcalf & Stock, 2020).

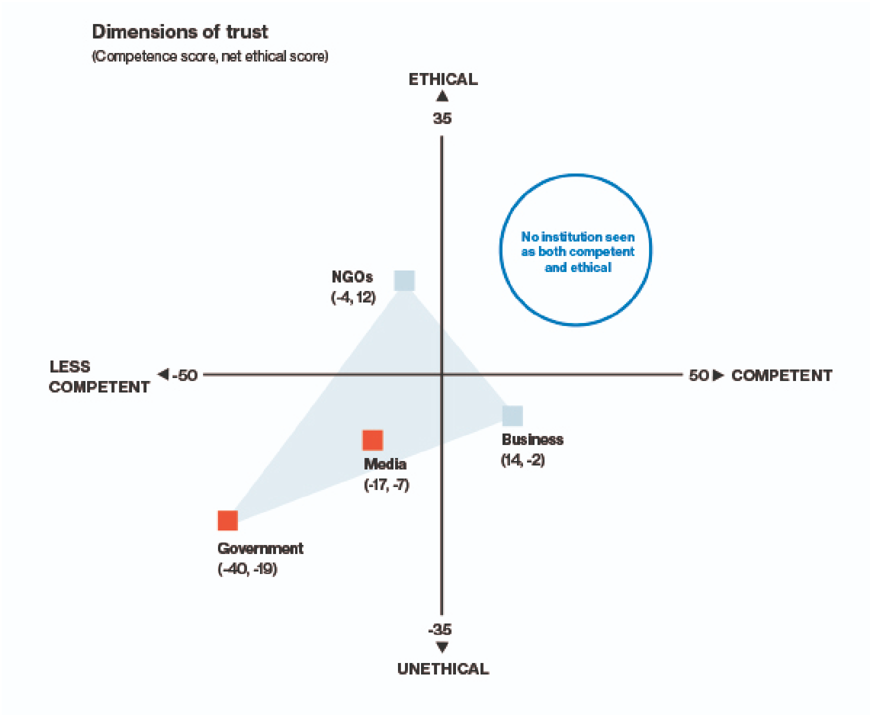
There has been a broad central coalition across the American political divide who have argued for a revenue-neutral carbon tax, with opposition on both sides. Most famously in the state of Washington where a carbon tax bill was introduced, but voted down (Amdur et al., 2014; Roberts, 2016). Surprisingly to some, opposition to carbon taxes come not only from the political right, but also from the democratic left (Aronoff, 2016; Mann, 2021; Roberts, 2016). The left worry primarily over Environmental Justice (EJ) claims and that the tax would disproportionately affect poor and communities of colour. In the state of Washington, a divided-per-capita tax was suggested in 2018 (ibid.), as mentioned, this would mean that a carbon tax is introduced, money would be given back to all individual in the state as a sales or income tax reduction, making the revenue income for the state the same. As demonstrated, this would generally benefit the poorer households. However, the progressive left would rather keep the current taxes and spend additional tax on other projects; and the right wing are opposed to any new taxes, even if they would lower other taxes as a result (Aronoff, 2016; Mildenberger, 2020; Roberts, 2016). This creates a troublesome political landscape for an American carbon tax, where those who would benefit most (Carattini et al., 2019; Douenne & Fabre, 2022), oppose it alongside those who stand to lose the most, i.e., fossil fuel companies (Mann, 2021).

In Canada and Switzerland, carbon tax opinions follow partisan lines much like in the US

(Mildenberger et al., 2022). In other countries, such as France, we see a different political landscape where climate worry is not related to partisanship, but is based on limited knowledge regarding climate change, environmental policy, and a distrust of government (Douenne & Fabre, 2020). In this last fact, there are some similarities between the US and France. According to the 2020 *Edelman Trust Barometer* (2020), only 30% of Americans believe that "the government serves everyone", and over 80% of Americans worry about losing their jobs. In Europe, 36% of French respondents believe their social situation is better than their parents (with slightly higher numbers in Italy, Germany and UK), and only 25% believe that the same rules apply to everyone (Cautrés et al., 2021). Globally, the trust for social institutions is low, and trust in government is the lowest of them all (Figure 5).

Figure 5 (2020 Edelman Trust Barometer)

Trust and Competency Measure in Social Institutions from the Global Populace



Note. Respondents around the world were asked to rank institutions based on how competent and ethical they think they are. Note that no institution is seen as both ethical and competent, and that Business holds a staggering 52 point advantage in competency over government. (Reprinted from: 2020 *Edelman Trust Barometer.* Reproduced by permission from Edelman Trust Institute.)

Gärtner & Prado (2016) argue not only that income inequality erodes trust, but also that high trust levels solve public goods problems. As seen in the USA and France, levels of climate knowledge, trust in government, and belief in institutional competency is low; whilst levels of worry regarding the future is high. This is exacerbated by strong partisanship to one's own political affiliation (Hetherington & Rudolph, 2015). Policy will then struggle to get traction, regardless of how progressive the policy is, if the public do not believe that the state serves their best interest. In Scandinavia, where trust in government and peers is generally seen as the highest in the world (Delhey & Newton, 2005), it is perhaps predictable that the carbon taxes in all the Scandinavian countries were introduced with very little protest (Olofsson, 2022).

Despite low trust for the government, there are popular carbon tax alternatives. Amdur et al. (2014) shows that there was large-scale support (60% of those asked) in the US, even among republicans, for a carbon tax when the revenue was 'earmarked' for R&D within renewables (things may have changed since the Trump administration). A tax with revenue going to the general budget was the least liked alternative, garnering 34% support. This is echoed by other scholars who have also found that the public agrees with R&D and same-sector renewable investment in France, US, South Africa, India, Australia and Norway (Carattini et al., 2019; Douenne & Fabre, 2020; Grimsrud et al., 2020).

4.2 Policy recommendations:

Evidently, reducing fossil fuel use requires better tools than we have so far. Currently, carbon pricing has not worked, but as indicated, this is likely not due to it being a flawed tool, but instead it's a tool that requires sharpening. A steeper price (and/or removed fossil subsidy), a well-designed policy (simple, long-term, without exemptions and BCAs in place), and a clear revenue plan (money spent on infrastructure, R&D, renewable energy subsidies) has the *potential* of being one of our most important tools in building a decarbonized future. However, any sophisticated building process requires more than one tool, and so does our global future economy.

The evidence from this work shows that the biggest emissions reductions we've seen have come from other policies than carbon pricing; how much they have worked in tandem is hard to disentangle. As it stands, *if well-designed*, an expensive and progressive carbon tax is technically easy to implement, and has very few negative social, economic or environmental side-effects. Despite its current limited effect on emissions. The biggest environmental 'bang for the buck' policies would be to remove the fossil fuel subsidies immediately, and charge for the implicit costs of carbon emissions. Revenue gained should be used as outlined above. As energy and transport prices will increase, some of the revenue will need to be distributed in order to help the most vulnerable; how this is done will look different depending on jurisdiction. The second biggest bang-for-buck is to stop exemptions and free allowances to EITE's, and instead implement a BCA. While there is public opposition to carbon pricing, there is support for carbon taxes if the revenue is used for R&D and same-sector renewable investment, this should be borne in mind.

4.3 Further research

First and foremost, more ex-post research is needed on this current and important topic. While this thesis has tried to highlight the general themes of the current literature, more research is needed. Importantly, better data is needed on the effects of carbon pricing on its own, but also of carbon pricing in tandem with other policies. For example, what is the effect of carbon pricing on transport on its own, and what is the effect when combined with industry standards?

As seen, there are a myriad of different methods and variables one can take into account when measuring carbon pricing's effectiveness. A systematic review and comparison of different methodologies would be an important contribution. While we are unlikely to decide on one technique that is superior, understanding the different methods and getting an overview of their implicit biases would be helpful.

5 Conclusion

Carbon pricing has been touted as a market-based solution for carbon emissions for decades and is more popular among economists than ever. More carbon pricing schemes are also continuously being implemented, globally. Despite this, there is scant ex-post research and data on the effect that carbon pricing schemes have had on emissions. This thesis has tried to sum up all the currently available ex-post research and categorise the results into several themes (RQ1). The results show that carbon pricing is currently *Marginal, Ambiguous, Uncertain, Non-transformative, Insufficient, Uneven and Superficial*. This thesis has then highlighted policy-design improvements that could alleviate problems from the RQ1 results (RQ2). The results indicate that the main problems surrounding carbon pricing concerns leakage, incorrect pricing, revenue use, exemption and uncertainties. Solutions to these problems are presented in the results section.

After reading this thesis, it should be abundantly clear to the reader, that a carbon price is not a silver bullet to reducing carbon emissions, either locally or internationally. It should be seen as a one of several tools that will be helpful, and possibly necessary, in order to build a decarbonised society. As it stands, the evidence shows that currently, this particular tool is ineffective, and needs sharpening. With the information presented in this thesis, readers will hopefully have been given a roadmap of how to design sharper carbon prices; which structural pitfalls to avoid; and the limitations and strengths of carbon pricing.

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