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Production Tax on Coal: Supply-Side Climate Policy

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I take full responsibility for any mistakes and omissions present within this thesis.

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Abstract

The reduction in coal consumption is seen as one of the key points to support 1.5-2^{o}C target under the Paris COP21 agreement. In the absence of a globally agreed governance mechanism for climate mitigation, demand-side climate polices are vulnerable to more carbon leakages and other adverse effects. Alternatively, supply-side climate policies reflect direct approach to reduce global consumption of coal by restricting the supply. This paper examines the feasibility of a production tax on coal by major coal exporting country and countries as a supply-side climate policy option. I construct a multi-period equilibrium model of the international steam coal market and model a production tax on steam coal in three different scenarios; unilateral tax by Australia (lower and higher tax growth rate) and coalition tax by major exporting countries.

The results show that the unilateral climate policy by Australia reduces of global CO_2 emissions. At the same time, unilateral policy under a lower tax rate leads to lower impact in global CO_2 emissions than the higher tax growth rate. However, the unilateral tax by Australia has little impact on global CO_2 emissions and coal prices as other countries compensate for the reduced supply from Australia. By contrast, tax coalition by major exporters would significantly reduce global CO_2 emissions from steam coal. As many countries join the coalition, reduction in extraction would be much higher and would have a greater effect on global consumption with smaller rates of carbon leakages.

I also analyse the sensitivity of the demand and supply elasticities to the tax policies. These results show that if supply elasticity is higher than the demand elasticity, then it leads to higher rises in emission in non-taxing countries (severe leakage, around 78%) under unilateral climate policy. However, if countries jointly introduce tax, then the leakage rate could be reduced and global CO_2 emissions are reduced significantly. By contrast, when demand elasticity is relatively higher than supply elasticity, then the tax policy (unilateral or coalition) would yield greater reduction in global CO_2 emissions with much lower leakage rate. Generally, demand and supply elasticities are much closer in the steam coal market. Therefore, tax on coal production leads to reduction of global CO_2 emissions under both a unilateral or a coalition tax policy. However, the emission reduction under a coalition policy appears much stronger than unilateral.

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Chapter 1- Introduction

The Australian, one of the leading newspapers in Australia released a statement on 27 October 2015, before the Paris Climate Conference, declaring that an open letter to the media had been received by them from a group of sixty-one prominent Australians, including a former Governor of the Reserve Bank of Australia, Bernie Fraser (Lewis, 2015). In the letter, the group had requested world leaders to put coal mines and exports on the agenda of the Paris Climate Summit that was took place December 2015. They also wanted the Australian Government to participate in the discussion and to negotiate a global moratorium on reducing coal exports to reduce global greenhouse gas emissions (GHG). The call made then becomes the focus of this study examining the impact of such a potential decision by Australia to restrict its coal supply on global carbon dioxide (CO_2) emissions[1].

1.1.The problem

Coal**,** is a fossil fuel. Throughout history, coal has been used as primary fuel in the energy mix to produce electricity and for other industrial purposes. In 2014, around 29% of world energy was produced from coal (IEA, 2016a). There are good reasons why coal is widely used. Coal is relatively cheap, has high energy content and therefore, a low cost per unit of energy; and coal is abundant as a worldwide resource (IEA, 2016b). However, Coal has the highest carbon content per unit of energy released of any other fossil fuel. Worldwide, coal use accounted for 46% of energy related CO_2 emissions in 2014 and world gross GHG emissions from coal usage were 14 billion tons, nearly one third of total global GHG emissions (IEA, 2016a).

Coal was the fastest-growing energy source in the world in the past decade: between 2001 to 2010, world consumption of coal increased by 45%, especially the peak demand from China and India (IEA, 2015). Recently coal use has declined in OECD countries, but a renaissance of coal has been observed in non-OECD countries (Steckel, Edenhofer, & Jakob, 2015). According to IEA[2], New policy scenario (IEA, 2016c) strong growth in coal demand is expected in South Asia, Southeast Asia and Africa in future and, thus the coal production is expected to increase by 18% through 2040.

[1] Gases that trap heat in the atmosphere are called greenhouse gases, including Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and Fluorinated gases. This study focuses only on CO_2 emissions which is the largest gas emission and account for 81% of total emissions in 2016, IPCC Emission Factor Database 2017.
[2] International Energy Agency

In December 2015, the COP21 Paris agreement made a clear commitment to reduce greenhouse gas (GHG) emissions to a level to limit the rise in global average temperatures to well below two degrees Celsius (2^oC target) and as close as possible to 1.5 degrees above pre-industrial levels. The UN Climate Change declared that we needed a strong focus on renewable energy sources and a substantial decline in fossil fuel production and consumption in order to achieve the Paris Agreement goals (UN Climate Change, 30 Jan, 2018). To limit the temperature increase, most of the proven global coal reserves need to remain in the ground. Nearly 82% of current coal reserves need to be left unburned until 2050, compared to 33% of oil reserves and 49% of gas reserves (McGlade & Ekins, 2015).

There are two types of policy options to be considered for reducing energy related CO_2 emissions; demand-side policies and supply-side policies. Demand-side policies for reducing emissions, which provide incentive to reduce coal consumption have received the most attention in the academic literature, for example carbon pricing instruments price on emission, carbon tax or cap-and-trade scheme. All these types of instruments are used across many countries. However, in the absence of full participation in global climate policy, demand-side policies are vulnerable to carbon leakage, emission reductions in the participating countries are partly offset by emission increase in the non-participating countries (Hoel, 2012). Further, the expectation of future demand-side policies could induce resource producers to increase their present rates of extraction in order to maximize net present value, which is referred as the 'Green Paradox'(Sinn, 2015). Although large number of demand-side policy instruments exist today, they are not sufficient to achieve required emission reduction (Mendelevitch, 2016).

Alternatively, a growing amount of academic research argues in favor of supply-side policies in order to reduce future coal consumption by limiting the supply of fossil fuel. Leakage can also occur in supply-side polices, increased supply from non-regulating countries as global fuel prices increase. However, Collier and Venables (2014) argue that for coal, supply-side policies may be less prone to leakage while Harstad (2012) shows that supply-side policies can completely avoid carbon leakages by collation and buy marginal foreign fuel deposit and converse them. Hoel (2012) suggested that Green paradox could be eliminated with supply-side policies. One type of supply -side policy is to direct carbon tax on production of coal[3]. Coal taxes are meant to reduce the supply from a taxing country to the international coal market.

[3] There are some other supply-side policies e.g. the no new coal mines moratorium, removal of fossil fuel subsidy which will be discussed later

Lower supply causes price rises which would lead to reduced coal consumption and global CO_2 emissions.

The contribution of this research paper is to analyses such a production tax on coal in Australia as a supply-side climate policy option. Australia is the second largest steam coal exporter in the international steam market and has a certain market power. The paper uses a hypothetical tax on steam coal production under three different scenarios; a unilateral tax by Australia with lower growth rate of tax, a unilateral tax by Australia with and faster growth rate of tax, and a tax- coalition implying a joint tax by major exporting countries. For the analyses, a multi period equilibrium model for international steam coal market is constructed and the model used to apply the tax policy. Such an analysis is undertaken in three levels. First, changes in Australia's production and impact on global coal price due to the tax policy. Second, changes in coal production of other countries (non-taxing countries) as a reaction to the Australian's climate policy. Third, impact on global consumption and thus the global CO_2 emission reduction. The focus research question of this research then is, if Australia sets a unilateral climate policy of levying a carbon tax on coal production, will global CO_2 emission be reduced? If so, by how much?

The remainder of the paper is organized as follows: the next chapter, Chapter 2 presents background information of steam coal production, consumption and trade followed by an overview of the literature in Chapter 3. Chapter 4 provides a theoretical analysis and Chapter 5 gives numerical analysis of the research. Finally, Chapter 6 presents the results and discussion followed by conclusion of the study in Chapter 7.

Chapter 2 - Background

2.1.Coal

Coal is a family name for variety of solid organic fuels and refers to a whole range of combustible sedimentary rock materials (IEA, 2016b). For convenience, coal is divided into different categories based on its value and quality. Several properties including energy content, volatile gases, sulphur, moisture and trace elements all affect the quality of coal. It is determined by the temperature, pressure and formation of time. Initially, coal is formed when dead plant matter is converted into peat. Then peat is converted to lignite or brown coal, then to increasingly mature black coals -first sub-bituminous, then bituminous, and finally anthracite. This process involves biological and geological processes. The geological process take place over millions of years. Energy content of coal is measured in kilocalories, with brown coal generating the least energy and anthracite the most as shown in the figure 1.

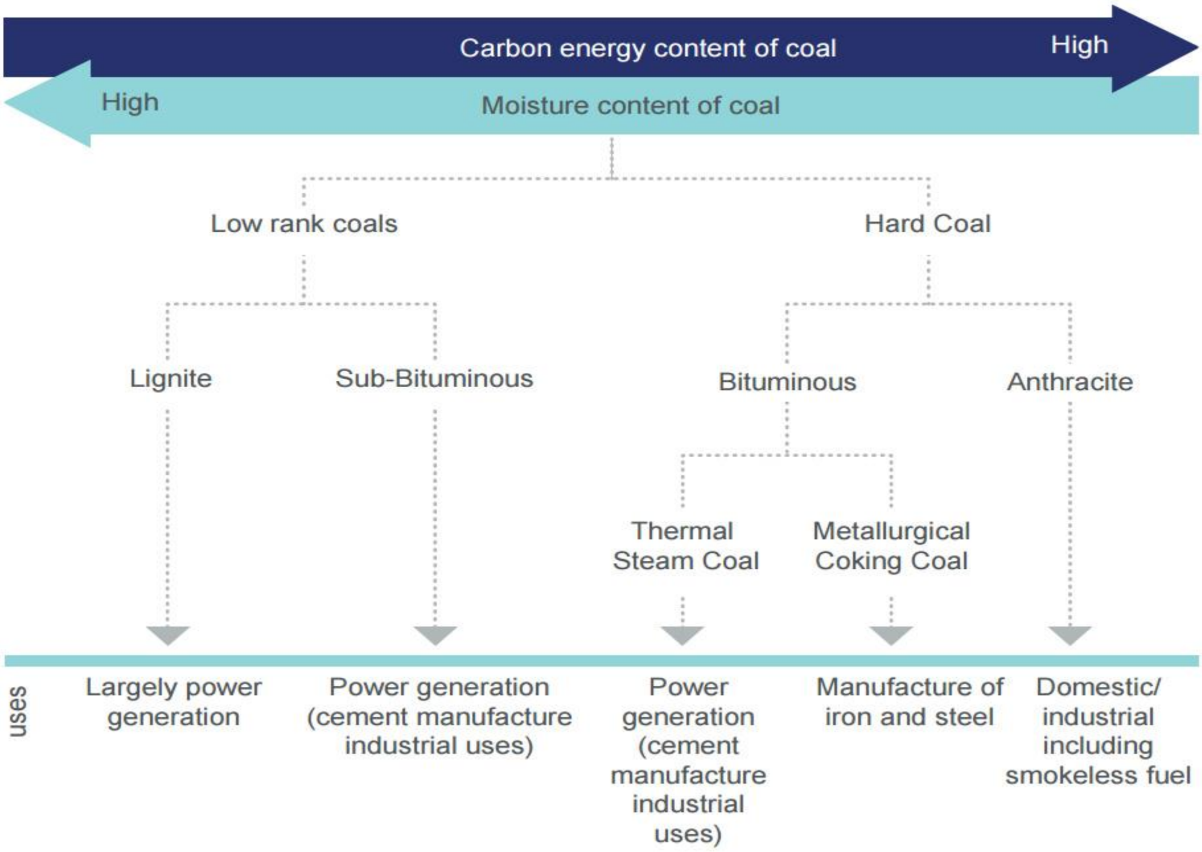


Figure 1: Different types of coal, its energy content and their uses[4]

[4] Department of Industry, Coal in India 2015, cited in http://www.abc.net.au/news/2015-11-27/fact-check-is-australias-export-coal-cleaner/6952190

Brown coal (lignite) is classed as a low-rank coal because of its high ash and moisture content, and low carbon content, which means that it produces less energy when it is heated. Therefore, it is not suitable for the export market and is used to generate power for the domestic market in many countries. Germany is the largest producer of lignite coal (178 Mt) and the world total production was 815Mt in 2014 (IEA, 2016b).

Black coals are ranked higher in quality because they are harder, have more carbon, less ash and less moisture and thus a higher energy content. There are two kinds of black coal: thermal coal and metallurgical or coking coal. Thermal coal also called steam coal has lower energy and higher moisture content and is used to generate electricity. Metallurgical or coking coal has a higher energy and lower moisture content and is used to make iron, steel and other metals. In 2014, 1112 Mt of steam coal was traded in the world market whereas coking coal was around 291Mt (IEA, 2016b). Thermal coal is the most relevant to electricity markets and represents around 80 per cent of the world's coal use (IEA, 2016c). This research focuses on steam coal production, consumption and the international trade[5].

2.2. Production and Consumption of Coal

According to IEA (World Energy Outlook, 2016), coal remained the second largest energy source worldwide, behind petroleum until 2030. Since 1983, China has been the top coal producer in the world. Nearly half of the world coal is produced in China and it is believed to remain in that position through till 2040. Other larger producers are United States, India, Australia and Indonesia (Table 1). Production in Australia, Indonesia and the Russian Federation (hereafter Russia) increases substantially through 2040, while in the United States, it would significantly reduce due to the proposed U.S clean power plant and availability of cheaper shale gas. Production in India rapidly increases to meet domestic coal demand. On average global coal production is believed to increases by 0.2% annually until 2040, from 6007Mt in 2014.

China is the largest consumer, consuming nearly 50% of the world's coal production annually. India become the second largest consumer by overtaking United Sates in 2015 (IEA, 2016c). In India coal consumption increased by 10%-15% annually since 2006, and will be increasing as India proposed about 430 new coal power stations to be built in the next five years. Strong

[5] Here after coal refers only to steam coal in this dissertation. According to IEA (Coal Information, 2016) steam coal includes all black coal that is not coking coal, as well as brown coal.

growth in coal demand is expected in South Asia, Southeast Asia and Africa in future. Increasing coal demand has resulted in increasing coal extraction globally. The extraction was over 6 billion tons in 2014, which was twice the extraction in 1983 (IEA, 2016c). World consumption of coal increases from 2014 to 2040 at an average rate of 0.2% year.

On the other hand, coal consumption has declined in OECD and developed countries, especially, in Europe, where coal usage has decreased more than 15% compared to 20 years ago. The main reason for this reduction is believed to be that the proposed climate policies to reduce greenhouse gas emissions. In Most countries in Europe, coal is declining as part of the primary fuel in the energy mix. Number of countries have closed or closing their coal fired plants (IEA, 2016c). Similarly, in USA domestic coal consumption has also declined due to the availability of the cheaper shale gas.

Table 1: Major steam coal Producers and Consumers in 2014, IEA (Coal Information, 2016)

Major coal Producers	**Mt (in millions)**
PR of China[6]	3020
United States	773
India	559
Indonesia	484
Australia	248
South Africa	257
Russia	188
Kazakhstan	89
Colombia	84
Poland	61
Rest of the world	244
World	**6007**

Major coal Consumers	**Mt (in millions)**
PR of China	3265
United States	742
India	740
South Africa	189
Japan	137
South Korea	100
Russia	77
Indonesia	76
Kazakhstan	62
Poland	59
Rest of the world	560
World	**6107**

[6] Chinese Taipei coal production and consumption are in included in the figure for China

2.3 International coal trade

Over the past ten years, Indonesia has been the largest coal exporter. According to its Ministry of Energy and Mineral Resources, Indonesia currently exports up to 80% of its production, which should increase by 10% per annum over the next 5 years. In 2005, the country overtook Australia as the world's largest steam coal exporter. Since then, Australia became the second largest steam coal exporter, and exports around 20% of world coal trade. As shown in Table 2, other major steam coal exporters are Russia, Colombia, South Africa, United States and Kazakhstan.

Table 2: Net Exporters and Importers of steam coal in 2014, IEA (Coal Information, 2016)

Net Exporting Countries	Mt (in millions)
Indonesia	408
Australia	201
Russia	111
Colombia	80
South Africa	68
United States	31
Kazakhstan	26
North Korea	16
Mongolia	07
Poland	02
World Total	**1047**

Net Importing Countries	Mt (in millions)
PR of China	326
India	181
Japan	137
South Korea	98
Germany	43
United Kingdom	31
Turkey	24
Italy	22
Malaysia	21
Thailand	17
World Total	**1047**

Asia is the predominant destination for coal export, with the regional share of total world international coal imports ranging from a low 75% in 2020 to a high of 78% in 2040. Much of the overall growth in coal imports to Asia between 2020 to 2040 is projected for South Korea, Thailand and Malaysia. In Europe, total coal imports decline to 230Mt in 2040. Coal becomes a less significant component of the region's fuel mix for electricity generation. But growth in coal imports for some countries such as Turkey, partly offset decline for other countries in the region including United Kingdom, Spain and France (IEA, 2015). The exports from some regions increase while export form other regions decline. Coal export increases from 2014 to 2040 include Australia, Colombia, Russia and Indonesia. On the other side, a decline in export is projected for United States and North Korea.

2.4. Coal Price

The global coal market consists of a number of regional sub-markets that are typically separated by geography due to transportation and infrastructure constraints. As a result, coal prices vary slightly between regions and sometimes within the country. However, the price of coal on the international market acts as a useful barometer of the dynamics within the market itself. The coal price in the international market is mainly set by Australia, US Appalachian and Russian mines, They are the leading exporters in the international steam coal market (IEA, 2015)

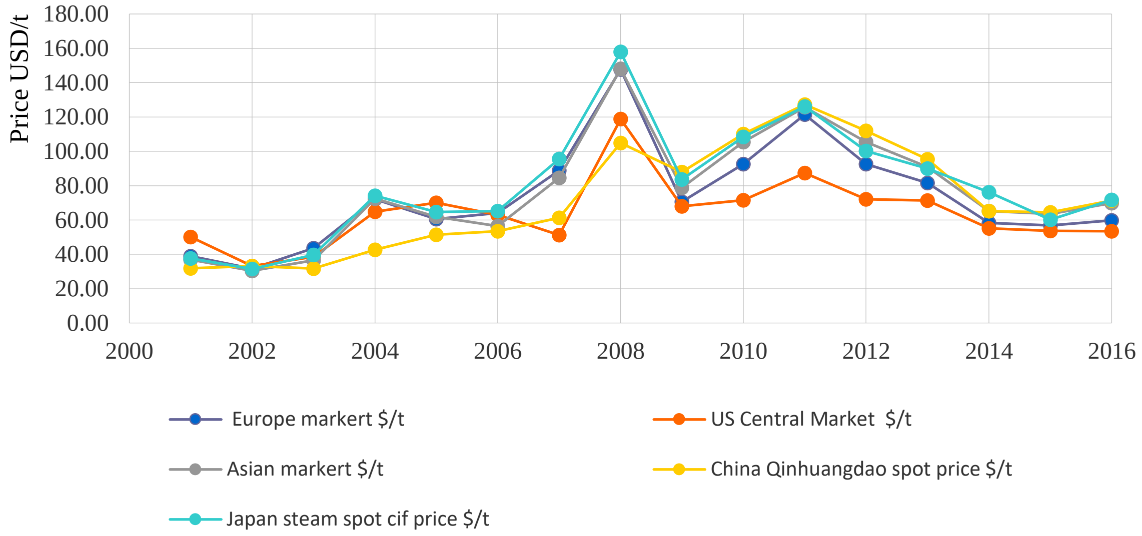


Figure 2: Steam coal prices from 2001 to 2016 (in U.S dollar per metric ton), Source: Coal information 2016 (IEA) and BP statistical review of world energy 2017

Figure 2 shows the average regional price for steam coal from 2001 to 2016. In 2008 coal price significantly increased and remained relatively higher due to peak demand from China and a similar price increase was observed in 2011 for the same reason. In 2009, global coal price dropped as an effect of the financial crisis in 2008. After 2011, coal prices have the downward pressure for the two reasons: On the supply-side, increased production from Australia, Colombia, Indonesia and South Africa to meet China's demand. On the demand-side, demand growth in China slowed down, because of the shift from coal towards gas renewable energy in the power sector, and demand in the United States has weakened because of the strong competition from cheap shale gas (IEA, 2016c).

2.5 Coal industry in Australia

Black coal was first discovered in Australia in Newcastle in 1791, and coal mining and coal exports commenced soon after in 1799. These early coal mining activities made a significant contribution to the progress of European settlement in Australia. Since the late 1700s, about 9,100 million tonnes of black coal and about 2300 million tonnes of brown coal have been mined and the Australian coal industry provides significant employment, capital investment and domestic and export income to the national economy. Coal deposits occur in all states of Australia and the Northern Territory[7] (see the map in appendix A1).

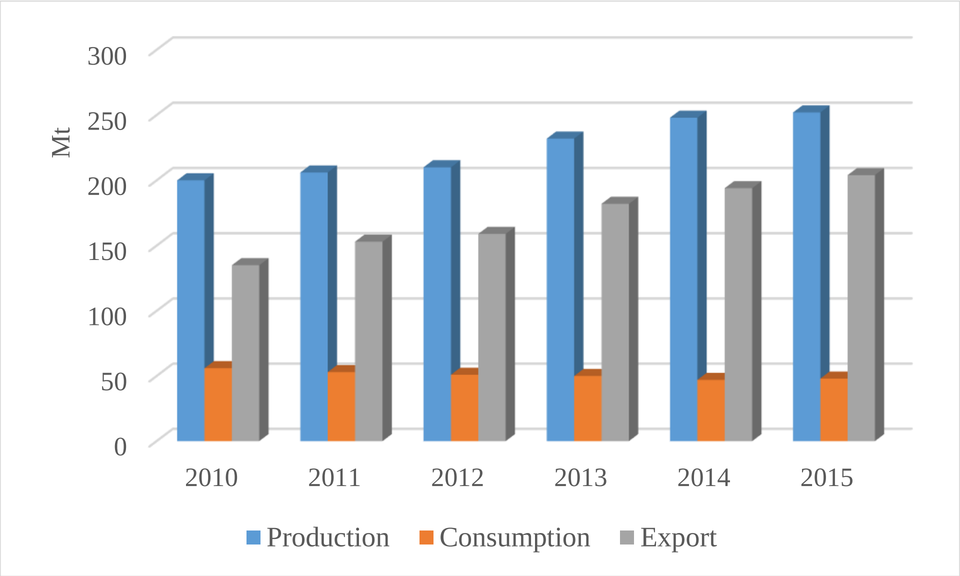


Figure 3: Coal Production, Consumption and Export in Australia, IEA (Coal information, 2016)

Today the coal industry plays a significant role in the Australian economy, and energy sector. According to the Department of Industry, Innovation and Science, Australia, coal has been the dominant source of energy mix in Australia. In 2014, around 80% (49Mt of coal) of the country electricity was generated using coal. Apart from the local economy, Australia provides about 20% (201Mt of coal) of the world coal trade as shown in Figure 3. Currently, Australia is the second largest steam coal exporter[8], fifth largest producer and has the fifth largest black coal reserve in the world. Australia has 6 per cent of the world's black coal EDR (Economic Demonstrated Resource) and ranks sixth behind USA (31%) Russia (21%) China (13%), India (8%) and South Africa (7%).Australia exports almost 75% of its production, and the export has

[7] History of coal mine by Department of Industry, Innovation and Science, Australia
[8] World's largest coking coal exporter

doubled within 7 years since 2008. Most of Australian coal is exported to the Asian region and has the leading position in Asian market. In 2014, Australia's top 3 export markets were Japan (80Mt), China (67Mt) and Republic of Korea (33Mt). Approximately, 54000 people are directly employed in the Australian coal industry[9].

2.6 Greenhouse gas emissions and Climate Change

Climate change refers to the rise in average surface temperatures on Earth. The primary cause of climate change is the burning of fossil fuels, such as coal and oil, which emits greenhouse gases into the atmosphere, primarily carbon dioxide[10]. The gases trap heat within the atmosphere, which can have a range of effect on ecosystems, including rising sea levels, severe weather events, and droughts.

Electricity and heat generation is the largest sector, which accounts for 42% of global CO_2 emissions from fuel combustion in 2014. Despite the growth of non-fossil fuel energy such as hydro power, nuclear and other renewable sources, the share of fossil fuels within the world energy supply is still relatively high. In 2014, fossil sources accounted for 82% of the global total primary energy supply (TPES) (IEA, 2016a).

Since the Industrial Revolution (1870), annual CO_2 emissions from fuel combustion have dramatically increased from near zero to over 32 $GtCO_2$ in 2014, mainly driven by increased emissions from coal and oil. Although coal represented 29% of the world TPES in 2014, it accounted for 46% of the global CO_2 emissions due to heavy carbon content per unit of energy released (IEA, 2016a). Generation of electricity worldwide still relies heavily on coal. Countries such as Australia, China, India, Poland and South Africa produce over two-thirds of their electricity and heat through the combustion of coal. Therefore, any effort to reduce emissions and mitigate climate change must include the energy sector, especially on reduction of coal use.

The Paris agreement sets the long-term goal of keeping the increase in global average temperature to well below 2^0C above pre- industrial levels and to pursue efforts to limit the temperature increase to 1.5^0C above pre-industrial levels. According to the Intergovernmental Panel on Climate Change (IPCC), to keep global warming below 2^0C, emission of CO_2 and other greenhouse gases (GHGs) must be halved by 2050 compared to with 1990 levels. Developed countries will need to reduce more between 80% and 95% by 2050: advanced

[9] Department of industry, innovation and science, Australia
[10] Other human activities, such as agriculture and deforestation.

developing countries with large emission (China, India and Brazil) will have to limit their emission growth[11]. Before and during Paris Conference, countries submitted comprehensive national climate action plans (INDCs). However, these are not yet enough to keep global warming below 2^0C. This means countries need to move from fossil fuel energy to achieving the target.

2.7 Climate policy in Australia

Australia is responsible for 1.4% of global emission, which is the 13th highest overall pollution contributor. Australia's emission is more significant than that of the United Kingdom, Italy and France for example. Australia also has the highest per capita tonnes greenhouse gases being emitted, among the OECD countries. On average 17 tonnes of greenhouse gasses being emitted per person yearly. The emission intensity is also high at around 640 tonnes per unit of GDP, due to the energy sector's reliance on coal. As per comparison, the UK, a country with emission less than Australia has an emission intensity of around 220 tonnes per unit of GDP[12].

Australia is committed to submit the post-2020 target known as Intended Nationally Determined Contribution (INDC) under the Paris agreement. The country set a target to reduce domestic emission by 26-28% below 2005 level by 2030 which build the 2020 target of reducing emission by 5% below 2000 levels[13]. Australia's target is similar to those announced by United States, European Union, Canada, New Zealand and Japan. Under the current framework, over 70 emission reduction measures are implemented and approximately 960Mt CO_2e abatement can be achieved by 2030. The country targets to cut more emission to contribute the global emission reduction target. Levying production tax on coal can be an alternative measure for Australia to reduce emission under the Paris agreement. However, it should be noted that any emission reduction in abroad due to Australia's tax policy will not be credited to Australia with respect to the Paris target.

[11] Cited at https://www.eea.europa.eu/themes/climate/policy-context
[12] Fact sheet, July 2015: Australia's emission by the Climate Institute http://www.climateinstitute.org.au/verve/_resources/TCI_Australias_Emissions_Factsheet_Final-LR.pdf
[13] Department of the Environment and Energy, Australian government http://www.environment.gov.au/climate-change/government/international/paris-agreement

Chapter 3 - Literature Review

A country can consider two options when making policies to reduce fossil fuel related CO_2 emissions to a certain level: demand-side policies and supply-side policies. The policies targeting to reduce demand for fossil fuel are referred as ‘demand-side policies’, while those targeting to reduce supply of fossil fuel are referred as ‘supply-side policies’.

Demand - side climate policies have received most attention in the academic literature and are commonly used by countries to reduce emissions. For instance, carbon pricing is one of the instruments of demand-side policy, placing a price on emission either directly to emission as carbon tax or indirectly through cap-and-trade. There are many other demand-side policy instruments such as taxing on energy use, imposing emission standard or the policy measures that promote energy efficiency and reduced energy consumption (DIW Berlin, 2017).

In the absence of full participation of countries in a global climate policy, demand-side policies may lead to "carbon leakages”, rises in emission in non-participating countries. Policy measures that reduce fossil fuel demand in regulating country or countries lead to lower global fuel price. Thus, non-participating countries increase their emission by increased fossil fuel consumption or shift the emission intensive activities to non-participating countries[14]. Therefore, the effect of demand-side climate policy would be partly eroded by increased emission in the non-participating countries (Felder & Rutherford, 1993). There is vast literature on carbon leakages in demand-side policies. However, most demand-side policy studies found only moderate rates of leakage, in the range of 5-30 percent (Hagem & Storrøsten, 2016). Maria and Van der Werf (2008) argued that the leakage rates reported in the literature may be too high as those estimates neglect the effect of price changes in the incentives to innovative. But high leakage rates over 130% are estimated by Babiker (2005), suggesting that significant relocation of energy-intensive industries away from the OECD countries, depending on the market and industry structure. Arroyo-Curras et al. (2015) identify a limited leakage rate of 16% if United States and China act (taking unilateral or joint action) as pioneer regions.

Another issue with the demand-side policies is ‘green paradox’. The expectation of future demand-side policies could induce resource producers to increase their present rates of extraction in order to maximize net present value (Sinn, 2015). Faster extraction leads to

[14] The policy reduces fossil fuel demand in regulating country lead to lower international energy prices, so nonregulating countries increase their consumption and thus emission.

increase global CO_2 emissions in short term and accelerates global warming. Furthermore, a large number of demand-side policy instruments have been implemented currently and many of them are proposed for the future. But they are not sufficient to achieve required emission reduction (Mendelevitch, 2016).

Supply-side policies were discussed in early 1990s as an alternative to demand-side policies. Initially, Bohm (1993) discussed about supply-side policy and he concluded that countries should aim at policies to reduce fossil fuel supply, rather than focusing on reducing demand. He believed that supply-side policies can be an alternative to avoid carbon leakage[15]. Another argument put forward was that carbon leakage could be completely avoided by buying marginal foreign fuel deposits for conservation (Harstad, 2012). Few other studies suggest that in practice green paradox may not be relevant to the steam coal market (Haftendorn & Holz, 2010a). Hoel (2012) stated that the threat of green paradox can be eliminated through a properly designed supply-side policy. Other benefits of supply-side policies are that they are predictable and observable with lower transaction cost (Collier & Venables, 2014). It has been also suggested that supply-side climate policies may drive greater emission reductions for a given marginal cost (Lazarus, Erickson, & Tempest, 2015)

Comparing with demand -side policies, it has been argued that supply-side policies are more effective in reducing emission than demand-side policies. In particularly, carbon leakage is minimized under supply-side policy rather than demand-side policy if the price elasticity for demand is high relative to the price elasticity of supply (Collier & Venables, 2014). Similarly. Fæhn et al., (2013) discussed that the most cost effective domestic policies in Norway to obtain global emission reduction would be to reduce oil supply. Because of carbon leakages, the global effect of demand-side ambitions is likely to be lower than domestic emission reduction. Hoel (1994) discussed the optimal combination of producers and consumers taxes as ‘second best’ in a climate coalition for a given target for global emission, the tax rate being determined by the demand and supply elasticity and term-of-trade effects.

In a domestic context, a number of studies were conducted on the possible ways or options to reduce coal supply to reduce global gas emission. One type of policy acts to directly remove coal reserve form production (Harstad, 2012). Another suggestion that has been made is the closure of entire coal industry (Collier & Venables, 2014). These authors argued that the coal is a high emission source, therefore, coal should be kept in the ground unburned. Yet another

[15] The policy reduces fossil fuel supply in regulating country lead to rise international fuel prices, so nonregulating countries increase their production and thus emission

type of supply-side policy is depletion tax (or depletion quota). Similar to the demand-side policy, tax on production or on export would be another tool to reduce supply of coal (Richter, Mendelevitch, & Jotzo, 2015). Richter et al. (2015) have analysed the effect of an export tax on coal by individual countries like Australia or by a group of major exporting countries on global emission. They argued that export tax by a group of countries may have the effect of significant reduction of CO_2 (up to 200Mt emission per year). A recent initiative directly targeting on coal supply is the 'No new Coal Mines' campaign. It was started by the President of Kiribati who urged the world leaders to support this and called for a moratorium on the opening of new mines and the expansion of existing mines (Tong, 2015). Another supply-side policy discussed removal of fossil fuel subsidies (Mendelevitch, 2016)

Globally, supply-side policies are more effective when major players join together to reduce emission. One of the biggest challenges of multi-climate agreement is the role of non-participating countries. If a climate coalition reduces demand for fossil fuel, the world price of fossil fuel goes down, and a non-participating country would find it profitable to consume more. So, consumption increases and therefore an increase in emission (Harstad, 2012). Similarly, if the coalition seeks to reduce the supply or extraction of fossil fuels, the world price increases and these countries find it optimal to supply more. Non-participant countries more likely emit more and they might undo the coalition's effort. Harstad (2012) suggested that the single best policy for a multinational climate coalition is to purchase the extraction of dirty fossil fuel in non-participating countries, and then conserve rather than exploit the deposits. Then the non-participating countries will not increase their emission. The most intuitive benefit from this policy would be that emissions are reduced if one buys and conserves the deposits. However, practically, buying coal deposits remains as a challenging proposition, such as asymmetric information, contract incompleteness and bargaining failure.

Any constraint on supply normally results in higher prices and less coal use, and therefore, a lower emission. The straightforward way of doing so from the supply-side would be to put a tax on coal exports, or ideally a tax on all production which will then also be reflected in coal export prices. The global price then goes up, and energy users switch to lower carbon alternatives which saves carbon dioxide emission (Richter et al., 2015). Coal is particularly susceptible to carbon pricing, as 'adding a carbon price of USD 20 per ton of CO_2 doubles the cost of using coal. Power sector investors see that coal power plants will become uncompetitive under carbon pricing and so will shift their portfolios towards low carbon sources of electricity (McGlade & Ekins, 2015). However, the current demand-side policy instruments in place worldwide have only generated low carbon prices, on average of 5 euro per tonne of CO_2. In contrast higher carbon prices are needed to drive substitution away from coal in the power sector, e.g. one recent estimate of the price that would drive coal to gas switching in Europe was around 40 euro per tonne of CO_2 (DIW Berlin, 2017).

In conclusion, reducing emissions from coal consumption is necessary for meeting the two-degree target. This might be achieved through policies that act to reduce the demand for coal or emerging policies that act to limit the supply of coal. In theory, supply-side policies appear to be a more effective alternative or complement well to the demand-side policies, particularly, in the absence of full global participation in climate policy.

Chapter 4 - Theoretical Analysis

4.1 Equilibrium Theory

The research model for this study is constructed based on partial equilibrium theory. In the partial equilibrium analysis, price is considered as the main determinant of supply and demand, and other economic and technological variables that determine the cost are considered to be exogenous. The price is determined in the market when supply is equal to demand. It is referred to as 'equilibrium price' and the corresponding quantity is referred as 'equilibrium quantity'. Any constraint to the supply or demand has direct impact on price and quantities of market equilibrium; if supply decreases from the equilibrium, the price increases in the short-run. The price increase is the one that gives an incentive to increase supply or reduce demand. This leads to a new equilibrium in the market.

For instance, considering Australia's tax policy, if Australia introduces a carbon tax on coal production, coal production in Australia reduces and the supply to the international market also reduces. When supply is reduced, global coal price would increase and the increased price can be a motivation to other countries which mine coal and this will lead to increase in their production. At the same time, the global demand (consumption) may go down in coal importing countries as well as in exporting countries due to the price increase. Analysing the net effect of those reactions from the market participants will determine the effectiveness of Australia's policy.

To analyses such an equilibrium reaction in the market, I consider a competitive market. International steam coal market is workably[16] competitive. A competitive market is a stylized market that satisfies a number of properties. First, there are many sellers and buyers in the market and none of them influence the price. Second, the products are sold as homogenous, such as with the case coal[17]. Third, there is free entry and exit to such a market. Fourth, perfect competition, and perfect information are expected to be present as well.

Now, assuming that, Australia wants to implement a unilateral climate policy that aims to reduce global emissions through a production tax on coal. The policy will have different partial effects in the global coal market. The impact of Australia's tax policy in reducing global CO_2 emissions is illustrated in the graph below.

[16] By Carol Dahl – Energy Demand and Supply elasticities http://www.eolss.net/sample-chapters/c08/E3-21-02-04.pdf
[17] Coal may not be considered as homogenous, the content of energy, ash and sulfur varies.

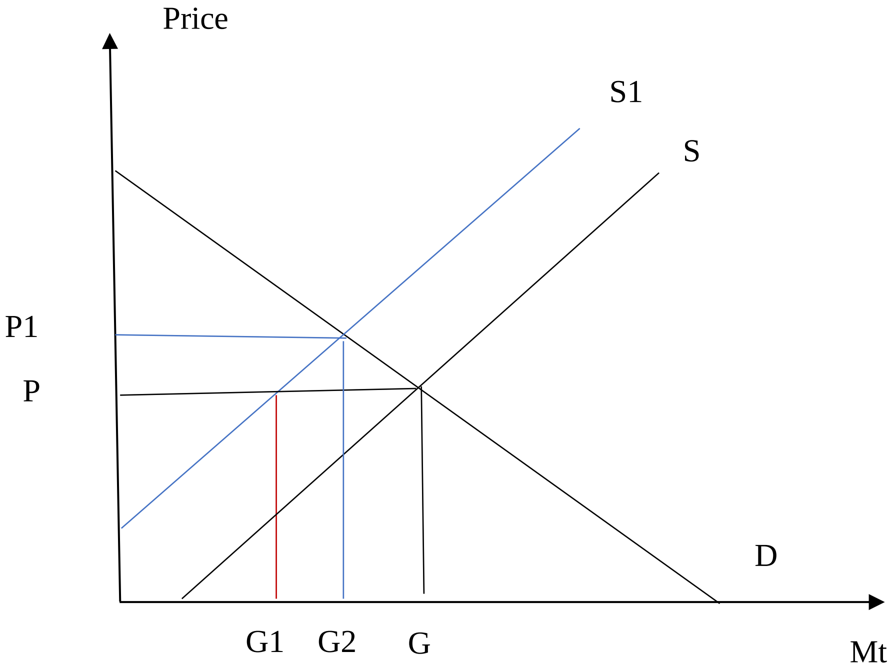


Figure 4: Australia's tax policy and its impact on international steam coal market

According to Figure 4, the initial global market equilibrium is at the point where the supply curve (S) and the demand curve (D) intersect; Equilibrium price being *P* and quantity *G*. When Australia introduces a carbon tax on coal production, and it reduces the production and the coal supply to the international market. As a result, coal supply in the global market will be reduced from *G* to G_1. At the point G_1, the global demand is higher than the global supply. Thus, other countries increase their production and exports to meet the global demand. As shown in the graph, new market equilibrium will be at the point where the new supply curve (S_1) crossing the demand curve (D), new equilibrium price will be P_1 and the quantity will be G_2.

The net reduction in global emission arising from Australia's tax policy is measured as the difference between reduced emission through reduced production from Australia and increased emission resulting from increased production by other countries. From the graph, the gap between *G* to G_1 is the amount of emission that has been reduced due to the reduction in coal supply from Australia. The gap between *G1* to G_2 is represents the increased emissions arising from the increased production by other countries. Thus, the net reduction of coal consumption and global CO_2 emission is the gap between *G2* to *G*.

4.2 Price elasticity of supply and demand

Price elasticities are quite useful and important factors for policy design[18], because the responsiveness of coal demand and supply to the price is important input to determine the effectiveness of the policy. For example, if production is very responsive, only a small increase in price may lead to strong increase in production. Such responsiveness on both demand and supply-side of the market influences the effects of the taxes, and consumption of coal globally. One way of measuring such responsiveness of production and consumption is through demand and supply elasticities.

4.2.1 Supply elasticities

The responsiveness of quantity supplied to the price is called the price elasticity of supply. It is the percentage change in quantity divided by the percentage change in the price. We can write the elasticity of supply with respect to price as;

$$\varepsilon s = \frac{\%\, change\ Qs}{\%change\ P} = \frac{\Delta Qs/Qs}{\Delta P/P}$$

The period of time influences the size of the coal supply elasticities. In the short run, (say one year) if the coal price goes up, the producers may be able to increase the production by a small amount. Since the coal mine is very capital intensive it takes around 5-7 years to open new mines. Thus, short run elasticities are quite low but in the long run producers are more adjustable to a price change. Therefore, long run elasticity is likely to be larger than short run elasticity. When the price elasticity of supply is low, then the percentage change in quantity is smaller for a given change in the price and the situation would be vice versa with higher price elasticity. Therefore, the size of the elasticity of supply is an important factor in determining the effectiveness of tax policy, especially the leakage rate[19]. This is illustrated in the graphs below (Figures 5 and 6).

[18] Not only the price elasticity of Australian coal, it is important to know the price elasticity of all other competitors and importers

[19] Rises in emissions from non- participating countries

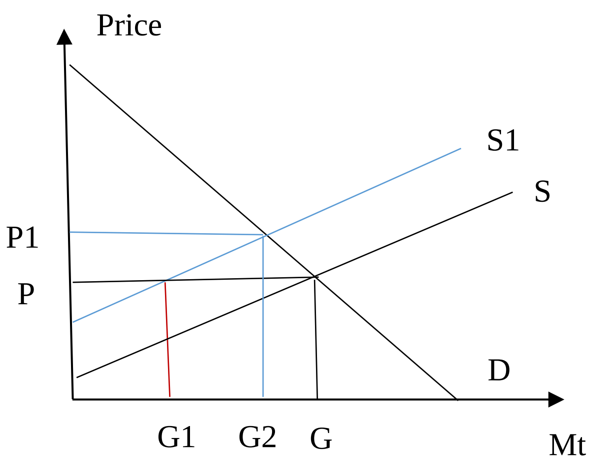


Figure 5: Australia's tax policy and its impact on international coal market with higher price elasticity of Supply of coal

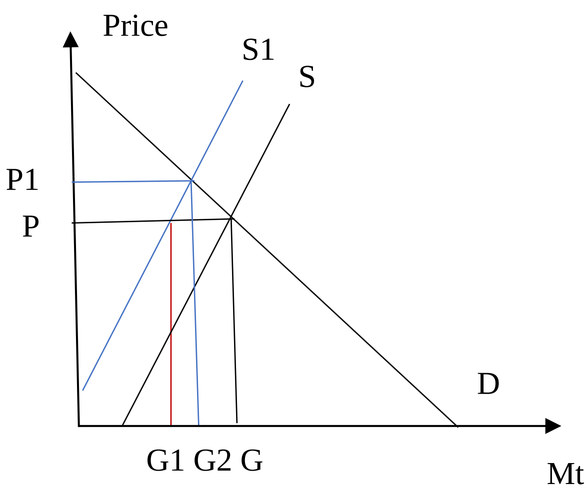


Figure 6: Australia's tax policy and its impact on international coal market with lower price elasticity of Supply of coal

Figure 5, represents the situation of a higher price elasticity of supply[20]. Producers are highly responsive to the price changes. In this scenario, when Australia introduces a tax on coal, it leads to greater reduction in Australia's production and the supply to the international market. At the same time, it also leads to higher leakage rate, meaning that increased production from other countries when Australia reduces its production would be stronger. As shown in the Figure 5, more than half of the reduced production from taxing country is compensated for by other countries (non- taxing countries). On the other hand, in Figure 6, lower price elasticity of supply leads lower reduction in Australia's production and to a lower leakage rate, as the producers are less responsive to the price change.

By comparing both scenarios, net reduction in CO_2 emissions is slightly higher in the scenario with higher price elasticity of supply, the reason being the negative shift in Australian production. Australia's reduction is much bigger (G-G_1) under higher price elasticity of supply. At the same time, the carbon leakage rate is also much stronger, meaning that other producers also increase their production significantly. Therefore, the supply elasticity of coal is found to be is an important factor of the policy effect, with higher elasticity leading to stronger leakage effects.

[20] No changes were made to the price elasticity of demand

4.2.2 Demand elasticities

In contrast to the price elasticity of supply, price elasticity of demand is also an important factor for policy design. The responsiveness of quantity of consumption to the price is called the price elasticity of demand. It is the percentage change in quantity divided by the percentage change in the price. We can write the elasticity of demand with respect to price as;

$$\varepsilon d = \frac{\%\ change\ Qd}{\%change\ P} = \frac{\Delta Qd/Qd}{\Delta P/P}$$

The price elasticity of demand of coal is less elastic or almost inelastic in the short run (Haftendorn & Holz, 2010a). Steam coal demand elasticity depends on various factors such as the power plant mix, the price of alternative fuels (natural gas or crude oil), the price of emission certificates, renewable energy prices and the total electricity demand. Thus, short run elasticity is likely to be lower than long run elasticity. The graphs below illustrate the importance of the size of the elasticity in determining the effectiveness of Australia's tax policy (Figures 7 and 8).

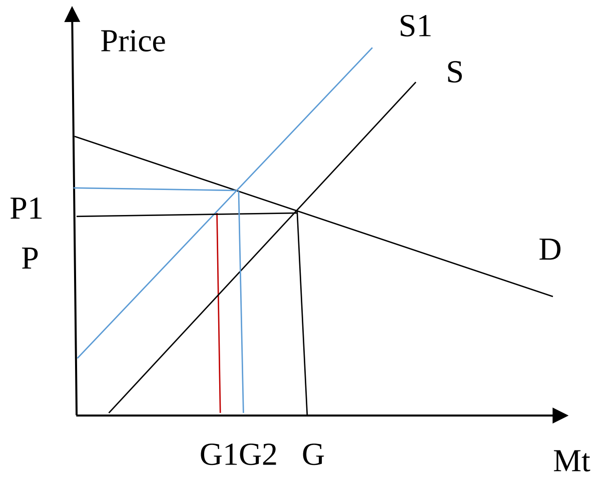


Figure 7: Australia's tax policy and its impact on international coal market with higher price elasticity of demand of coal

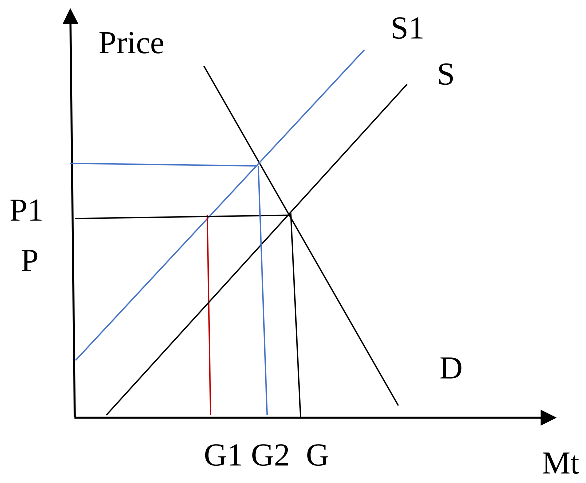


Figure 8: Australia's tax policy and its impact on international coal market with lower price elasticity of demand of coal

In Figure 7, with higher price elasticity of demand, Australia's tax policy leads to lower leakage rate and strong reduction in global CO_2 emissions. The reason is that price increase is much lower in this scenario and the (rebound effect) increased production from other countries is relatively lower. The consumers are highly responsive to the price and, thus they react more than producers when the price change in the global market. By contrast, in Figure 8, lower price elasticity of demand leads to lower reduction in global CO_2 emissions due to high leakage rate. By comparing both scenarios, net reduction in CO_2 emissions is relatively higher with lower leakage rate in the scenario with higher price elasticity of demand.

4.2.3 Supply and demand elasticities

The above sections show how price elasticities a play major role in policy design. We have so far analysed each form of elasticity (supply and demand) while one of them remaining unchanged. In practice, the size of both elasticities may differ among the region or countries and even over periods. The effectiveness of Australia's policy then depends on how all those elasticities assumed for the regions and periods play out.

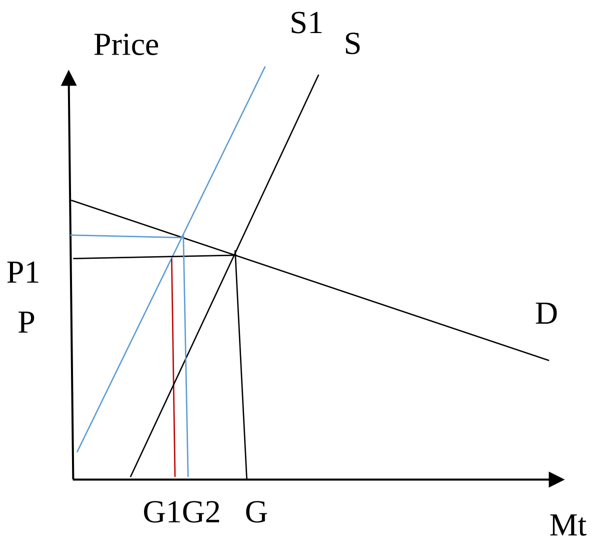


Figure 9: Australia's tax policy and its impact on international coal market with higher price elasticity of demand and lower price elasticity of supply of coal

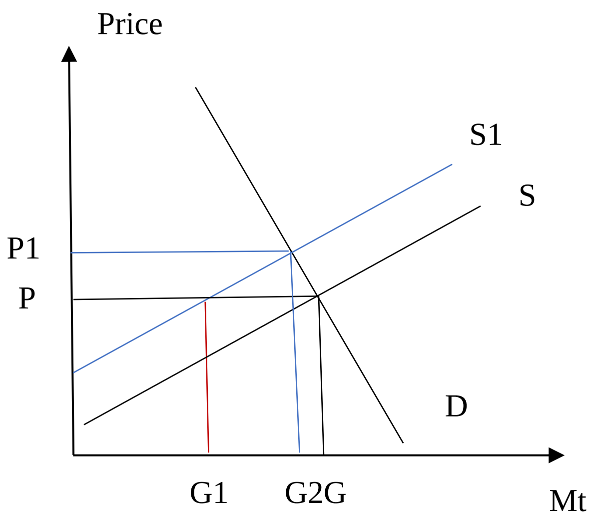


Figure 10: Australia's tax policy and its impact on international coal market with lower price elasticity of demand and higher price elasticity of supply of coal

By comparing the two scenarios, strong net reduction in CO_2 emissions and lower leakage rate took place in the scenario which is shown in Figure 9. The figure shows that the leakage rate is lower due to the lower supply elasticity and higher demand elasticity. The coal producers from other countries are not able to increase their supply in larger amounts when Australia reduces its production. At the same time consumers are highly responsive to the price increase. Thus, they can reduce their consumption to a larger extent when the price change in the global market. By contrast in figure 10, the leakage rate is much higher and net reduction CO_2 emissions is much low. Since the price elasticity of supply is higher, increase in other's production will remain moderately high. In addition, demand elasticity is lower, and the consumers are not flexible to reduce the demand. According to Collier and Venables (2014) international coal market considers price elasticity of demand as high relative to the price elasticity of supply in the long run, closer to the scenario represented in Figure 9. Therefore, a tax on coal production may lead to greater reduction in CO_2 emissions in the long run as per the theory. In the next chapter, I will construct a model and numerically apply it to examine the hypothetical tax on coal production as a supply-side climate policy option to reduce global CO_2 emissions.

Chapter 5 - Numerical Analysis

5.1 Model Description

For numerical analysis, I construct a multi-period equilibrium model for the international steam coal market which is assumed to be competitive (Haftendorn & Holz, 2010b). The model consists of two types of players, net exporting countries and net importing countries of steam coal. The reference year adopted for the analysis is 2014 and the estimated value for the model years in base case are calculated based on New Policy Scenario (IEA, 2016). I then numerically apply the model to get the equilibrium reaction of the market participants when Australia introduces a climate policy to reduce global coal CO_2 emissions.

5.2 Model structure

It is a competitive market with two types of market participants, net exporters (assigned as suppliers) and net importers (assigned as consumers), covering 95% of the world coal production and consumption. Two main criteria have been used to select the countries included in the model, namely, one that the country should be a net exporter or net importer of coal, and two, that only the countries which export or import more than 1million tonne of coal per year. Overall, the model includes 10 major exporting countries and 12 major importing countries, and others being included under 'Rest of World'.

Table 3: Countries included in Model

Net Exporting countries (e)	***Net importing countries (i)***
Indonesia	*China*
Australia	*India*
South Africa	*Korea*
Russia	*Germany*
United States	*United Kingdom*
Colombia	*Turkey*
Kazakhstan	*Malaysia*
Poland	*Philippines*
North Korea	*Thailand*
Mongolia	*Spain*
Rest of the world	*Italy*
	Japan
	Rest of the World

The model runs until 2040 and calculates yearly equilibrium for the coal quantity produced and consumed in the years 2014, 2020, 2025, 2030, 2035 and 2040, which are referred to as the 'model years' There is no link between the periods in the model and different elasticities are assumed for each model years (see appendix A3). The data for 2014 which is the reference year is derived from IEA (Coal information, 2016) and used to project the production and consumption for the remaining model years.

In the IEA projection, different trends are predicted for regional production and consumption through 2040. In the IEA Reference case 2014 (WEO 2016), Australia (0.5%), Russia (0.2%), Indonesia (1.4%), Kazakhstan (0.1%), North Korea (0.6%) and Mongolia (0.6%) increase their production through 2040 under the New Policy Scenario (NPV), whereas Colombia (-0.2%), South Africa (-0.3%), the United States (-2.2%) and Poland (-1.4%) reduce their production on average annually. Rest of the world increases the production by 0.2% on annual average.

On the consumption side, China and India together accounted for around 65% of the world consumption in 2014. However, China continues to grow its coal use through 2020 and then slowly reduces its consumption by 0.5% annually. India will be the second largest consumer through 2040, and it will increase its consumption by 3.6% annually. The highest growth rate is projected in Southeast Asia, at around 4.4% annual growth in consumption. On the other hand, European countries will reduce their consumption by 3% annually, while Japan also reduce its consumptions by 1.4%. The average annual consumption increase worldwide is projected to be 0.2% through 2040.

Although coal market is competitive, coal prices are slightly different for countries and regions. The reasons for these differences is that the coal price is determined by not only the cost of production, but also transportation cost and the prevailing tax policies in the respective countries. So, longer distance for the transport, higher the price. In the reference case year of 2014, the observed lowest price was USD50/t and the highest price was USD66/t among all 22 countries that are included in the model[21]. In this model, I have used the weighted average global price of USD60/t to keep the analysis simple.

The price elasticity of demand and supply used here are based on extensive literature review. The existing empirical studies in elasticities for coal market have concentrated mostly on demand-side, especially for short run. The studies on supply elasticity are limited. Both elasticity estimations vary quite a lot, because the analyses differ in terms regional coverage,

[21] Except Japan, USD79/t observed in Japan

time frame and methodological approach. In general, empirically estimated elasticities for coal fall within the range from -0.05 < Ed < -0.57 for demand[22] elasticity and 0.3 < Es < 0.5 for supply elasticity in the short run (Dahl, 1993), (Dahl, 2006), (Burke. J & Liao, 2015), (Haftendorn & Holz, 2010b). In the long run, supply elasticities are estimated to be up to 2.0 and demand elasticities are at the level below -1.2 (Trüby & Paulus, 2012). As a more realistic result, different elasticities are assumed for all importing countries, demand elasticities (-0.1 < Ed < -0.6[23]) and exporting countries, supply elasticities (0.3 < Es < 0.8) for the different model years[24] (see appendix A3). This assumption is based on the above-mentioned literature review.

5.3 Model Solution

By considering a unilateral climate policy that aims to reduce global emissions through a production tax on coal, I simplify the model with two types of players *e* and *i* to refer to exporter and importer respectively. *XD* and *XS* denote consumption and production, and coal is traded in the international market at price P_g. Market equilibrium requires that global production equal to global consumption in each period. In the next section I will model taxes explicitly.

The exogenous variables (reference price, reference demand and supply) and the parameters (demand and supply elasticities) are used to derive the constant of demand ($AD^{i,tt}$) and constant of supply ($AS^{e,tt}$) for every region and every period in the equations (1) and (2).

$$AD^{i,tt} = \frac{XD_0^{i,tt}}{P_0^{\varepsilon^{i,tt}}} \qquad (1)$$

$$AS^{e,tt} = \frac{XS_0^{e,tt}}{P_0^{\delta^{e,tt}}} \qquad (2)$$

where, $XD_0^{i,tt}$ represent reference demand in the regoin i, in the time *tt and* $P_0^{\varepsilon^{i,tt}}$ is the reference price in region i, in time tt, *and* ε is the price elasticity of demand.

$XS_0^{e,tt}$ is reference supply in the region e, in time tt, $P_0^{\delta^{e,tt}}$ is the reference price in the region e, in time tt, and δ is the price elasticity of supply.

[22] Kolstad and Abbey assume demand elasticity -0.6 for all region
[23] Range between short run to long run
[24] Different elasticity data is available only for demand elasticity. For supply elasticity all regions are assigned same elasticity but differ for the periods.

The Price is set equal to USD60/t in all year when calibrating constant demand and supply. The 'Base case' demand and supply in every model year for each participant are driven from constants $AD^{i,tt}$ and $AS^{e,tt}$, given in the equations (3) and (4).

$$XD^{i,tt} = AD^{i,tt} . \; P_g^{\varepsilon^{i,tt}} \qquad (3)$$

$$XS^{e,tt} = AS^{e,tt} . \; P_g^{\delta^{e,tt}} \qquad (4)$$

Where, $XD^{i,tt}$ denotes consumption in region i, in time tt, and $XS^{e,tt}$ denotes the production in region e, in time tt. $P_g^{\varepsilon^{i,tt}}$ is the price for coal in region i, in the time *tt*. $P_g^{\delta^{e,tt}}$ is the price for coal in region e, in the time *tt*. The market equilibrium is derived from the aggregate demand and supply for every model year, as in equation (5).

$$\sum_i \sum_{tt} x_{i,tt}^s = \sum_i \sum_{tt} x_{i,tt}^D \qquad (5)$$

Now, I have the 'base case' result (price, quantity of demand and supply) for every model year and for each participant. This should reproduce the projection from the IEA. Next, I introduce the tax scenarios, and run the model and find out deviations in the production and consumption of the world. The taxes are set hypothetically and the tax base year is 2020. Three different production tax scenarios are constructed and tested[25]. Under the unilateral tax policy of Australia, estimated production from each participant, is given in equation (6). The production under the coalition tax scenario is derived from the equation (7). Finally, run the market equilibrium for each scenario, given in equation (5).

$$XS^{e,tt} = AS^{e,tt} . \left(P_g - taus_{tt}\right)^{\delta^{e,tt}} \qquad (6)$$

$$XS^{e,tt} = AS^{e,tt} . \; \left(P_g - t_{e,tt}\right)^{\delta^{e,tt}} \qquad (7)$$

where, $taus_{tt}$ refers to the production tax in Australia, in time tt. $t_{e,tt}$ refers to the coalition tax in region e, in the time tt.

Finally, I calculate the reduction in CO_2 emissions which is due the tax policy. Typically, the carbon content of coal is not the same for each type of coal. Steam coal has around 70% of carbon and this may vary slightly among different region or countries. Generally, CO_2 emission factors are expressed in terms of the energy content of coal as tons of CO_2 per million Btu

[25] Tax scenario explanations are given in page 27, under the section scenario definition

(British Thermal Units). The emission factors are estimated based on standard global average conversion factors compiled based on average carbon content. The IEA[26] (IEA, 2016a) uses simplest (Tier 1) methodology to estimate CO_2 emissions from fuel combustion. Generally, the Tier 1 estimation of CO_2 emissions from fuel combustion for a given fuel can be summarised as flows;

CO_2 emissions from fuel combustion

CO_2 = Fuel consumption * Emission factor

where,

Fuel consumption = amount of fuel combusted

Emission factor = default emission factors

EIA[27] (1994) calculate an approximate estimation of CO_2 emission for coal. According to the study, one tonne of coal will generate about 2.62 tonne of CO_2 when the coal is completely burned.

Tonne of CO_2 = (Tonne of coal) x (2.62 tonne of CO_2 per tonne of coal)

Thus, 2.62 tonne of CO_2 = 1 tonne of coal

In this model, the above conversion is used to estimate the amount of CO_2 emissions reduced because of the climate policy. However, the model does not include emissions on extraction. The numerical analysis is implemented in GAMS. The model GAMS files are attached in appendix C.

5.4 Scenario Definition

The model's 'base case' is constructed based on New Policy Scenario (NPS) of World Energy Outlook (IEA,2016). NPS is a scenario of moderate climate policy, by assuming that countries will implement the current climate policy proposals. For example, because of EU's climate policies, it is expected that the production and consumption of coal will decline through 2040 in that region. On the other hand, South and Southeast Asian countries continue to grow their

[26] IEA estimates change under the 2006 IPCC Guidelines

[27] https://www.eia.gov/coal/production/quarterly/co2_article/co2.html

coal use. Therefore, global emissions are increasing with the production and consumption of steam coal being projected to increase through 2040 (IEA, 2016).

Three production tax scenarios are constructed which could cause deviation in the production and consumption of the world, and the results are then compared to the base case;

- Tax-Australia: The unilateral tax on coal production levied by Australia. The tax base year for this is 2020 and the initial tax level in this year is takes as 10USD/t coal (or 3.80USD/tCO_2). The tax rate then increases by 5USD/t of coal in each model year, and in 2040 the tax rate is taken to be 30USD/t of coal (see appendix C)
- Alternative Tax scenario: Taking the Tax-Australia scenario above, I additionally test a faster tax growth rate, in which the initial tax is 20USD/t of coal (or $7.63/t$CO_2$) in 2020. The tax rate then increases by 10USD/t of coal in each model year, 30USD/t in 2025, 40USD/t in 2030, 50USD/t in 205 and in 2040 the tax rate is 60USD/t of coal (see appendix C).
- Tax- coalition; implying that the production tax on coal levied by all major exporting countries, namely Australia, Indonesia, South Africa, Russia, United States, Colombia, Kazakhstan, Poland, North Korea and Mongolia. All countries impose equal tax and the tax growth rate is the same as in Tax-Australia. (see appendix C)

Further to this, I run the model to test the sensitivity of the price elasticities to all those above-mentioned scenarios. In this analysis, two different price elasticity scenarios are examined (see appendix A3).

- Higher price elasticity of supply: - double the size of supply elasticity while demand elasticity remains as in default elasticity scenario.
- Higher price elasticity of demand: - double the size of demand elasticity while supply elasticity remains as in default elasticity scenario.

The results from the sensitivity analysis are then compared with the default elasticity scenario, which is the scenario basically used in all three tax scenarios and the base case estimations.

Chapter 6 - Results and Discussion

As mentioned in the previous chapter, levying a tax on coal production by a major exporting country leads to different partial effects. First, coal extraction (and supply to the international market) from the tax setting country is reduced due to additional costs incurred by the production tax. Second, production in all other countries increases: Net exporting countries increase their production to compensate for the lower international supply, and the net importers increase their domestic production. Since the supply reduced from the tax implementing country, the coal price rise in the global market. Third, with the global coal price increases, the global consumption is reduced and thus, global coal use emissions are reduced. Increased supply in other countries is a second order effect, which is smaller than the first order effect of reduced production in the tax setting country. Hence, the net effect on emission is a reduction.

The following sections present the result and discussion concerning the impact of a production tax on coal, and compares the changes in the pattern of production, consumption and price with the base case. The results between different scenarios are also compared, especially, the reduction in global CO_2 emissions and the carbon leakage rate.

6.1 Scenario 1: A unilateral Australian production tax on Coal

As explained in section 5.4, the tax on Australian steam coal production starts from 2020[28]. The tax rate in this year will be about 10USD per tonne of coal or equivalent to a carbon tax of 3.8USD/tCO_2. A tax rate increase over time by 5USD/t of coal every five years (or the model years) is assumed until 2040. Thus, in 2040, the tax will be around 30USD/t of coal (or carbon tax 11.45USD/tCO_2).

The model result shows that the tax policy of Australia affects global coal production and consumption. Figure 11 shows how Australian and world production and consumptions are affected by this tax policy. In the base case, Australian coal production increases over time from 248Mt in 2014 to 282Mt in 2040. However, when Australia introduces tax on coal production, the production decreases from the base case level. The production of every model is lower than the base case. For instance, in 2020, Australia reduces its coal production by 17Mt compared to the base case. When the tax rate increases over time, the reduction in coal

[28] Tax base year

production is stronger. In 2040, after tax, Australia produces 166Mt of coal, which is 115Mt less compared to the base case, where Australian production was 282Mt.

Figure 11 also shows the reaction to the Australian tax from other global producers. In 2020, when the tax is introduced, the production in all other countries increases to compensate for Australia's reductions (see appendix B1). Globally, the production increased by 13Mt of coal in 2020 and by 70Mt of coal in 2040 compared to the base case. Indonesia, the United States, South Africa and Russia increase their level of production significantly among all other exporters.

Figure 11: Impact on coal production in Australia and rest of the world after tax-Australia, in Mt

The global consumption pattern is changed when Australia introduce the tax in 2020. First, the countries that rely on imports generally suffer to meet their demand. As shown in Figure 12, major importing countries such as China and India reduce their consumption by a small amount, in 2020, by 2Mt and 1Mt respectively. However, the consumption is reduced more strongly in 2040, by 21Mt in China and 11Mt in India. The greater reduction in consumption is observed in China. The consumption in Australia also reduced due to the unilateral tax policy. In total, the world consumption is reduced by 45Mt of coal in 2040 compared to the base case.

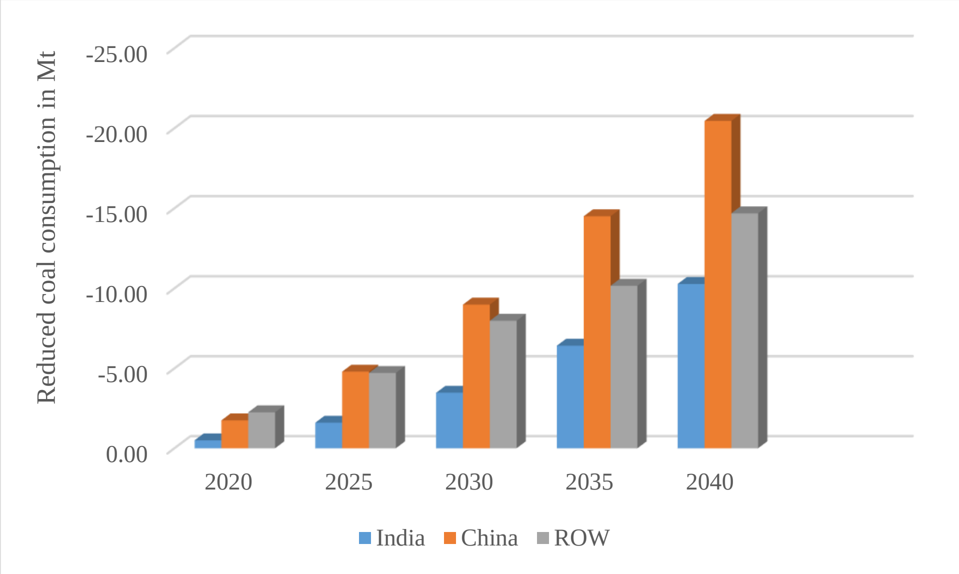


Figure 12: Impact on consumption of China, India and Rest of the World after tax-Australia, in Mt

Table 4 below summarises the net reduction in consumption and global CO_2 emissions of Australia's tax policy. In line with the base case, global CO_2 emissions are reduced in every model year. In 2020, global emissions of CO_2 are reduced by around 12Mt and the reduction level increases over time. In 2040, the global CO_2 emission reduction is ten times higher than in 2020 (119Mt of CO_2).

Table 4: Changes in world coal production and the impact on global CO_2 emissions after tax-Australia, in Mt

Year	**Difference in production of Australia – 'base case' and 'after tax'**		**Difference in production of ROW- 'base case' and 'after tax'**		**Net Reduction**	
	Reduced Coal production in Mt	***Equivalent to CO_2 in Mt***	***Increased coal production in Mt***	***Equivalent to CO_2 Mt***	***Reduced consumption in Mt***	***Net CO_2 in Mt***
2020	-17	-45	13	33	-4	-12
2025	-34	-89	23	60	-11	-29
2030	-56	-146	35	93	-20	-53
2035	-83	-218	52	136	-31	-82
2040	-115	-302	70	183	-45	-119

Changes to the global coal price are very minimal in this tax scenario from the base case; with a less than 1% increase observed until 2030, then in 2035 it increases by 1.5% and there is around a 2% increase in 2040 (see appendix B1). The main reason for the slower increase is that only Australia imposes tax and the tax rate is very low in this scenario. Thus, the impact on global prices is very minimal. Figure 13 shows it clearly in 2020 the price increases by less than 0.50USD/t when the tax rate is 10USD/t. However, in 2040 its increase by about 1USD/t, and the tax rate in this year is 30USD/t. Thus the evidence suggests that only higher tax rates influence global coal prices significantly.

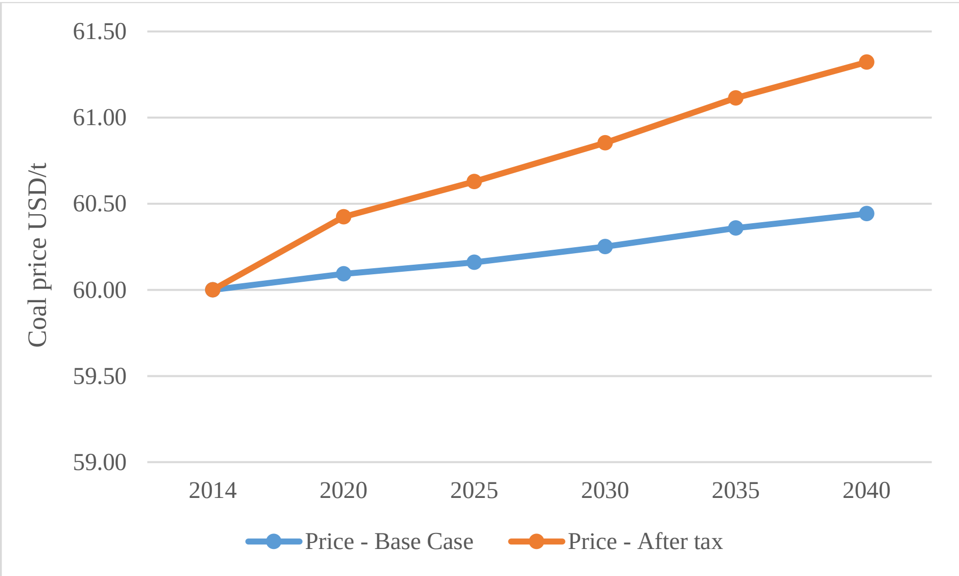


Figure 13: Changes in global coal price after tax-Australia, in USD/t

The leakage rate is relatively high under this tax level, with the estimated average leakage rate being 63%. The supply elasticity is greater than the demand elasticity in this model, which resulted in a higher leakage rate (over 50%). Since the supply elasticity is relatively high, the production is very responsive to the price. Thus, the production in non- regulating countries reacts more than the consumption. On the other hand, demand elasticities are lower in the short run, which leads to slower reduction in the demand, meaning that consumers are not ready to reduce their demand on a large scale. Nevertheless, the leakage rate reduces over time from 74% (in 2020) to 61% (in 2040). The reason for the reduction is the percentage change in the demand elasticity in the long run compared to supply elasticity[29].

[29] But still demand elasticities are lower than supply elasticity

In summary, the unilateral introduction of production tax on Australian coal significantly changes the global pattern of production and consumption. This leads to an average reduction in global CO_2 emissions of 59Mt of CO_2 per model year. However, the leakage rate is moderately high.

6.2 Alternative Policy Scenario: Fast increasing tax rate

As an alternative to the default tax scenario, I have analysed another tax scenario in which the tax rate is higher with a faster growth rate. For instance, in the default tax scenario, the tax rate increases in each model year by 5USD/t coal (slow increase) and starts from 10USD/t. In the alternative tax scenario, the tax rate increases by 10USD/t coal and the initial tax level is 20USD/t of coal (or equivalent to a carbon tax of 7.6USD/tCO_2) in 2020. In 2040 the tax rate is 60USD/t of coal (or equivalent to a carbon tax of 22.9USD/tCO_2).

The result, presented in Figure 14 shows that increasing the tax rate leads to a stronger reduction in Australian coal production. In 2020, the production was 255Mt of coal in the base case and it was reduced by 36Mt to 219Mt of coal after tax. The coal production further reduced in each model years and had a stronger reduction in 2040. It reduced from 281Mt (in base case) to 21Mt after tax in 2040, an almost 260Mt reduction of coal compared to the base case.

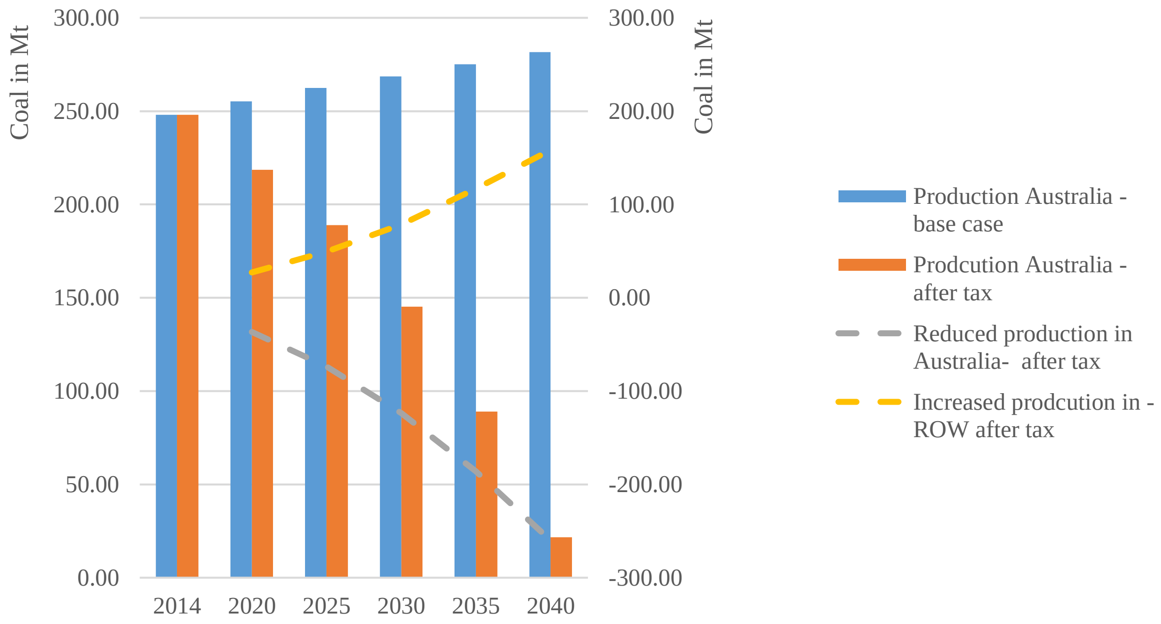


Figure 14: Impact on coal production in Australia and rest of the world after tax-Australia (faster tax growth), in Mt

The production in all other countries increases to compensate for Australia's reductions (see appendix B2). Globally, the production increased by 27Mt of coal in 2020 and by 158Mt of coal in 2040. Indonesia has the highest increase (18Mt) compared to other competitors, who increased by less than 10Mt of coal in 2040. On the consumption side, China has the largest reduction in consumption (46Mt) followed by India (23Mt) and the rest of the world reduced by 28Mt of coal in 2040 compared to the base case. The reason for the relatively higher reduction in consumption is the increased global coal price due to higher tax. This leads to a net reduction in CO_2 of 25Mt in 2020 and 267Mt in 2040 in this scenario.

The leakage rate under this scenario is the same as at the default tax rate level, with an average leakage rate of 63%. Since the price elasticity of demand and supply are assumed to be the same as in the default scenario, the leakage rate remains similar. However, there is a moderate increase in the global coal price compared to the default tax rate due to the higher tax rate and greater reduction from Australia. The global coal price increases by around 1% in 2020 and by around 3.5% in 2040 from the base case. This increase is slightly higher than the default tax rate.

6.2.1 Default tax (lower tax) Vs Fast increasing tax rate (higher tax)

Figure 15 shows that the reduction in global CO_2 emissions is much stronger when the tax rate is high and increasing more quickly. Compared to the default tax rate scenario, a significant reduction observed in the faster growth tax scenario for every model year. The net reduction in CO_2 is 25Mt in 2020 and 267Mt in 2040 in the fast-increasing tax scenario whereas with the lower tax rate, CO_2 emission is reduced by 12Mt in 2020 and 119Mt in 2040. Thus, a unilateral climate policy should consider a reasonable higher rate of tax for a greater reduction in CO_2 emissions.

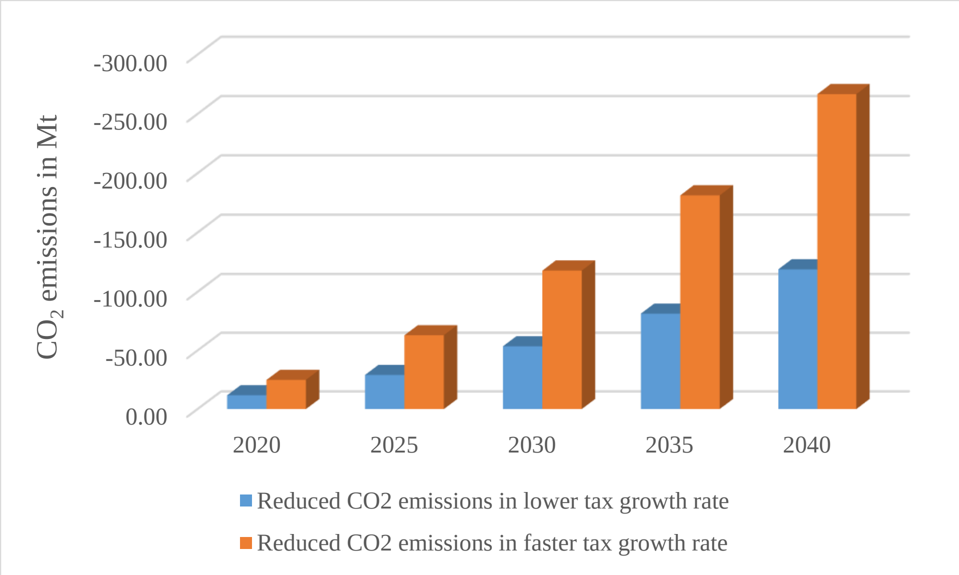


Figure 15: CO_2 reduction in slow increase and faster increase tax growth rates, after tax-Australia, in Mt

6.3 Scenario 3: Tax coalition, a jointly set production tax on coal by major exporting countries

A joint tax on production of coal by all major exporting countries - Indonesia, Australia, the United States, Russia, South Africa, Colombia, Kazakhstan, Poland, North Korea and Mongolia - leads to stronger CO_2 emission reduction compared to Australia's unilateral policy action. The tax rate in this scenario is the same as in the unilateral tax scenario, the default tax rate.

In this scenario, after tax, coal production is reduced significantly in all major exporting (tax setting) countries from the base case, while local production increases in other importing countries (or non-regulating countries) to meet the domestic needs. The coal production reduced in the tax implementing countries by 108Mt of coal (equivalent to 287Mt CO_2) and the coal production increased by around 72Mt of coal (equivalent to 187Mt CO_2) in non-regulating countries in 2020 (see appendix B3). Table 5 presents the net reduction in global CO_2 emissions after joint tax by major exporting countries. Indonesia (570Mt CO_2) and the United States (321Mt CO_2) had the largest reductions in CO_2 emissions, while Australia's reduction (242Mt CO_2) is relatively low compared to its unilateral case (302Mt CO_2) in 2040.

The result shows that, for a given tax level, the Tax-Coalition always lead to higher emission reductions than the unilateral case. As in Tax-Australia, the rebound effect is mainly driven by the increase in production by the competitors and domestic markets. However, with the coalition case, the rebound effect is less severe, and the global consumption is reduced to a larger extent than in the unilateral case. Therefore, global CO_2 emissions are reduced by 420Mt on average compared to 59 Mt of CO_2 in the unilateral case.

The average global coal price increase in the year 2020 is around 4%, and 10% in 2040 compared to the base case, which is also higher than the price effect with the unilateral tax policy. Since more countries impose tax and cut-back their production, the price increases are much higher in the international market. As many countries reduce their production, the leakage rate is reduced in this scenario compared to the unilateral case. The average leakage rate is around 56%. The leakage rate continues to decrease when all countries jointly implement the tax on coal production, from 66% in 2020 to 55% in 2040.

Table 5: A joint production tax and the impact on CO_2 emissions, in Mt

Exporter / Year	***2020***	***2025***	***2030***	***2035***	***2040***
Indonesia	-69	-144	-251	-391	-570
Australia	-33	-67	-114	-171	-242
South Africa	-33	-64	-104	-151	-205
Russia	-25	-49	-82	-122	-171
United States	-89	-155	-223	-280	-321
Colombia	-11	-21	-34	-50	-69
Kazakhstan	-12	-23	-38	-57	-79
Poland	-7	-13	-20	-27	-34
North Korea	-4	-8	-14	-22	-31
Mongolia	-1	-3	-5	-7	-11
Total Reduction	**-284**	**-550**	**-887**	**-1279**	**-1733**
Rest of the World	187	323	490	704	929
Net Reduction	-97	-227	-397	-575	-804

6.4 Sensitivity Analysis;

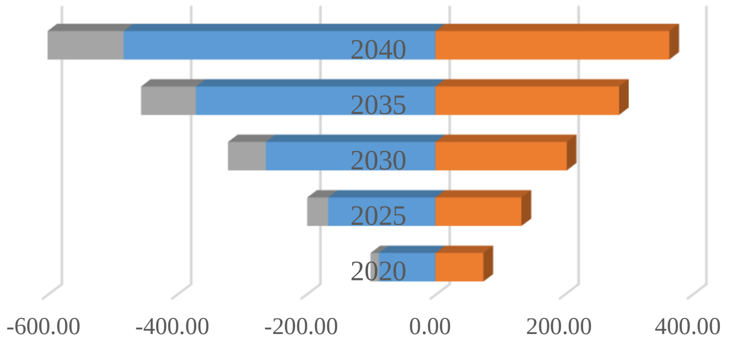
6.4.1 Price elasticity of Supply

The results from the previous sections show that the leakage rates are relatively high unless we have the tax-coalition. The leakage is mainly driven by how price responds to supply and demand: i.e. the price elasticities. Thus, a sensitivity analysis with price elasticity is conducted in this model to ascertain how the elasticities influences the effectiveness of the tax policy. In this analysis, the price elasticity of supply is assumed to be high and increases over time (0.6 in 2014 and 1.8 in 2040 for all producers), while elasticity of demand remains the same as in the default scenario (-0.1 in 2014 and -0.5 in 2040). In the default scenario, the predetermined price elasticity of supply is in the range between 0.3 in 2014 and 0.8 in 2040 (see appendix A3).

A (unilateral) tax[30] levied on the entire production by Australia under the scenario reduces Australian coal production by 33Mt of coal in 2020 and 184Mt of coal in 2040 compared to the base case (see appendix B4). The reductions are slightly higher than the scenario that we discussed in 6.1 (in the default tax rate, lower price elasticity of supply). After the tax, the global coal price increases by less than 1% in 2020 and by around 1.5% in 2040 compared to the base case. This price effect is similar to the default scenario.

The international export competitors increase their production. Mainly, Indonesia (16Mt), the United States (9Mt), South Africa (6Mt) and Russia (5Mt) increase their production to replace Australia's exports in the international market. In total, the coal production increased by 139Mt of coal to replace the reduction of around 184Mt of coal from Australia in 2040. As a result, the global coal use CO_2 emissions reduced by 13Mt CO_2 in 2020 and 118Mt CO_2 in 2040, as shown in Figure 16. The average CO_2 emission reduction is around 61Mt of CO_2 after tax. It is important to note that net reduction in CO_2 with a higher price elasticity of supply is slightly higher than lower price elasticity of supply in the model years until 2035. However, in 2040 net reduction in CO_2 is higher by 1Mt of CO_2 with lower price elasticity of supply; with the lower price elasticity CO_2 emissions are reduced by 119Mt in 2040, whereas the reduction is 118Mt with the higher price elasticity of supply. We can see this clearly when we apply it to the faster increasing tax rate scenario in the next section.

[30] The default lower tax growth rate



	2020	2025	2030	2035	2040
Reduced (production) CO2 emissions by Australia	-87.28	-165.65	-262.15	-370.39	-482.07
Increased (production) CO2 emissions by others	74.28	133.25	203.65	285.52	364.24
Net reduction in CO2 emissions	-13.00	-32.40	-58.49	-84.87	-117.83

CO_2 emissions in Mt

Figure 16: Production tax by Australia and the impact on CO_2 emission, with higher price elasticity of supply, in Mt

The result indicates that high price elasticity of supply leads to moderately high reductions in the production of the tax setting country (Australia). However, it increases the production significantly in non-taxing countries. The producers are very responsive to the price than consumers. Thus, they react more than the consumers in this scenario. Therefore, the difference in the net reduction in coal production (thus CO_2 reduction) is very minimal compared to the scenario with a lower price elasticity of supply. This is because of higher leakage rate at this elasticity level. The estimated average leakage rate at this tax level is 78% which is much higher compared with the lower supply elasticity rate, where the average leakage rate is 63%. It is important to note that the leakage rate in 2020, immediately after tax is introduced, is about 85%.

For the sensitivity analysis, I also ran the model and combined higher price elasticity of supply and faster tax growth rate (see appendix B5). Then I compared the result with the alternative tax scenario with default elasticities. Figure 17 shows that the net reductions in CO_2 emissions in both tax scenarios are very similar until 2030, after which, surprisingly, the higher tax rate in the scenario with higher elasticity of supply leads to lower reduction in emissions than the alternative policy scenario where the elasticity of supply is lower. When the price elasticity of supply is relatively high, levying higher unilateral tax leads to a greater reduction in the tax setting country. However, the benefit of the tax policy is highly eroded by a severe rebound effect in this scenario. For instance, Australia reduced its production by 281Mt of coal compared to the base case in 2040, where the base case production was 282Mt of coal. The higher tax is not able to reduce Australia's production further when Australia's production is already close to 1Mt. Other producers increase their production by 213Mt of coal. Thus, the net reduction is 68Mt. Since the supply elasticity is highly price responsive in this scenario, non-participating countries benefit from the Australia's unilateral tax policy.

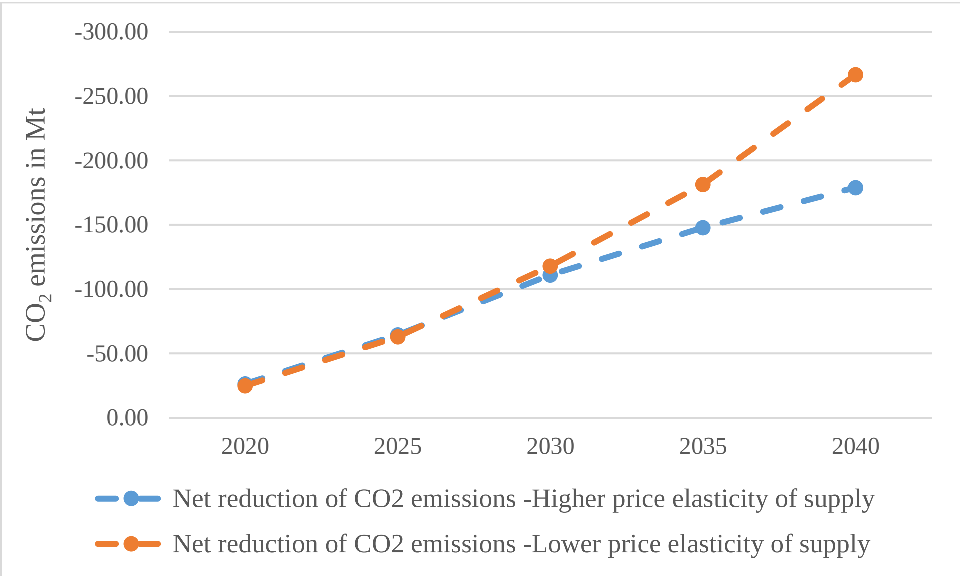


Figure 17: The impact on global CO_2 emissions in higher tax growth rate - with different price elasticity of supply, in Mt

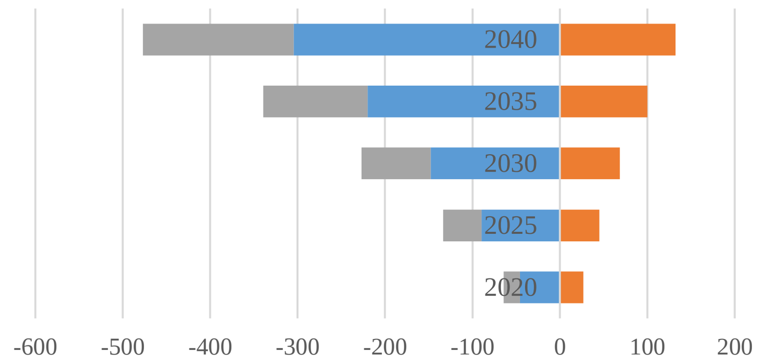
In summary, a unilateral tax policy is highly sensitive to the supply and demand elasticity of coal. If the supply is highly price elastic, then it leads to higher leakage rate (nearly 85%). Another important thing to consider is that imposing a higher (over 50USD/t) tax on coal would be favourable for non- tax setting countries when price elasticity of supply (about 1.4) is much higher than the demand elasticity (about -0.6).

6.4.2 Price elasticity of Demand

In this analysis, the price elasticity of demand is assumed to be high and increases over time (-0.2 in 2014 and -1.0 in 2040 for all consumers, but differing between regions)[31]. In the default scenario, the predetermined price elasticity of demand is in the range between -0.1 in 2014 and -0.5 in 2040 (see appendix A3)

[31] The supply elasticity is remaining as in the default scenario

A (unilateral) tax[32] levied on the entire production by Australia under this scenario reduces the Australian coal production by 18Mt of coal in 2020 and 116Mt of coal in 2040 compared to the base case (see appendix B6). The reductions are relatively similar to the default scenario with lower price elasticity of demand. This scenario showed a very minimal increase in global coal price with a less than 1% increase being observed until 2035, then it increased to slightly over 1% in 2040 compared to the base case. Thus, the coal production in the rest of the world increased at a lower rate. The production increase by 10Mt of coal in 2020 and 60Mt of coal in 2040 compensated for the reduction from Australia. As a result, a significant amount of coal demand in the market is left uncompensated, and so the consumption is reduced globally. This leads to global coal use CO_2 emissions reducing by 19Mt CO_2 in 2020 and 172Mt CO_2 in 2040, shown in Figure 18.



	2020	2025	2030	2035	2040
Reduced CO2 emissions due to reduced Australian coal production	-46	-90	-148	-220	-305
Increased CO2 emissions due to increased coal production by others	27	45	69	100	132
Net reduction in CO2 emissions	-19	-44	-79	-120	-172

CO_2 emissions in Mt

Figure 18: Production tax by Australia and the impact on CO_2 emission, with higher price elasticity of demand

The result indicates that high price elasticity of demand leads to greater reduction in global CO_2 emissions. The main reason for this is that the consumers are highly responsive to the price increase and more flexible in reducing their demand when the price goes up. Thus, the consumer reacts more than the producers in non-taxing countries. The production from the non-taxing countries is slower. Therefore, the net reduction in CO_2 emissions is higher compared to the

[32] The default lower tax growth rate

default scenario with lower price elasticity of demand and the scenario with higher price elasticity of supply. In 2040 greater reduction in global CO_2 emissions took place in this scenario (see appendix B6). Since the demand elasticity is higher, consumers are highly responsive to the price change. Any smaller increase in price leads to a greater reduction in demand. At the same time, when supply elasticity is lower, producers of non- taxing countries are not able to rapidly increase their production when Australia reduces its production. Thus, a relatively lower leakage rate is observed in this scenario. The estimated average leakage rate at this tax level is 46% which is much lower compared with other scenarios in this model. The leakage rate in 2020 is 56% immediately after tax is introduced, and reduced to about 43% in 2040. As the demand elasticity increases over time, the leakage rate is reduced.

I ran the model combining higher price elasticity of demand and faster tax growth rate to analyse the sensitivity of price elasticity of demand. The result (see appendix B7) from the analysis shows that net reduction in CO_2 emission is relatively higher in the scenario with higher price elasticity of demand compared with lower price elasticity of demand with higher growth rate of tax. The difference between the two scenarios increases over time and in 2040 it is around 123Mt of CO_2, shown in Figure 19. When the tax rate increases more quickly, the reduction in CO_2 also increases with higher price elasticity of demand.

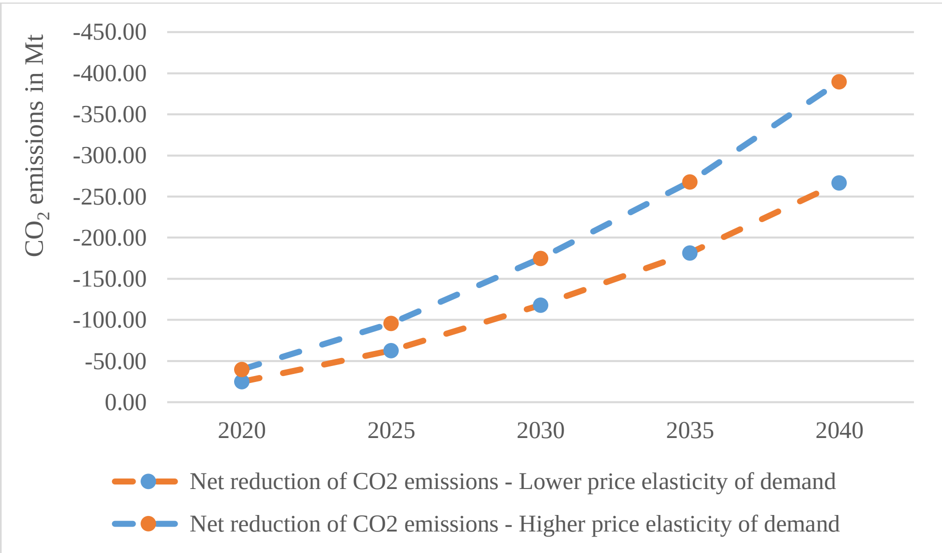


Figure 19: The impact on global CO_2 emissions in higher tax growth rate with different price elasticity of demand, tax-Australia, in Mt

The leakage rate is much lower in this scenario, between 59% and 46% and the average leakage rate is 43%. Due to the lower leakage rate, global CO_2 emissions are reduced significantly. The global coal price increase is slightly higher compared to the default tax rate; 1.2% in 2020 and 2.6% in 2040 from the base case.

6.4.3 Sensitivity Analysis in tax coalition

From the analysis in sections 6.3, it is shown that there is a much greater reduction in global CO_2 in a tax-coalition than with a unilateral policy. In this section, I have analysed how this coalition- tax[33] is sensitive to the price elasticity.

6.4.3.1 Higher price elasticity of supply: Table 6 summarises the reduction in CO_2 emissions of tax-coalition. On average global CO_2 emission reduction is 455Mt of CO_2 in this scenario, which is 35Mt CO_2 higher than the default scenario with lower price elasticity of supply (see appendix B8). The average global coal price increase is in the year 2020, around 5%, and in 2040 it is about 11% compared to the base case. The leakage rate is also stronger at this tax level. The average leakage rate is around 72%. However, it is relatively lower compared to the unilateral case with higher price elasticity of supply, where the leakage rate is 85%. Since more countries impose tax and reduce their production, tax coalition leads to effective CO_2 emission reduction and reduction of the leakage rate, when there is a higher price elasticity of supply. In other words, if there is a higher price elasticity of supply, then it is beneficial to have a coalition tax on coal production.

Table 6: A joint production tax and the impact on CO_2 emissions (Mt)

With higher price elasticity of supply

Exporter / Year	***2020***	***2025***	***2030***	***2035***	***2040***
Indonesia	-128	-262	-446	-676	-947
Australia	-62	-123	-202	-296	-402
South Africa	-61	-117	-185	-260	-340
Russia	-46	-90	-146	-212	-284
United States	-166	-283	-396	-484	-532
Colombia	-20	-38	-61	-86	-115
Kazakhstan	-22	-42	-68	-98	-131
Poland	-14	-24	-35	-46	-56
North Korea	-8	-15	-26	-38	-52
Mongolia	-3	-6	-9	-13	-19
Total Reduction	**-529**	**-1000**	**-1574**	**-2208**	**-2878**
Rest of the World	421	744	1130	1586	2036
Net reduction	**-108**	**-256**	**-444**	**-623**	**-842**

[33] No changes to the tax level

6.4.3.2 Higher price elasticity of demand: The coal production in non-regulating countries increases by less than 50% of the reduced production in tax-implementing countries. As a result, the coal use CO_2 emissions are reduced by 627Mt CO_2 on average, which is higher than any other scenario. Table 7 below summarises the net reduction in CO_2. The average global coal price increase is around 3% increase in 2020, and in 2040 it increases by 7% compared to the base case. At the same time, this tax level shows the lowest leakage rate. The average leakage rate is around 39%. The leakage rate continues to decrease when all countries jointly implement the tax on coal production, from 49% in 2020 to 37% in 2040.

Table 7: A joint production tax and the impact of production and CO_2 emission (Mt) – Higher price elasticity of demand

Exporter/ Year	***2020***	***2025***	***2030***	***2035***	***2040***
Indonesia	-74	-156	-272	-423	-614
Australia	-36	-73	-123	-185	-260
South Africa	-36	-70	-113	-163	-220
Russian Federation	-27	-54	-89	-132	-184
United States	-96	-168	-242	-302	-345
Colombia	-12	-23	-37	-54	-74
Kazakhstan	-13	-25	-41	-61	-85
Poland	-8	-15	-22	-29	-36
North Korea	-5	-9	-16	-24	-33
Mongolia	-2	-3	-6	-8	-12
Total Reductions	**-307**	**-596**	**-960**	**-1381**	**-1865**
Rest of the World	151	248	367	525	684
Net Reduction	-156	-348	-593	-856	-1181

Figure 20 shows the comparison of elasticities when countries jointly implement the tax. The reduction in CO_2 emissions is much higher and steadily increases over time with higher price elasticity of demand. By contrast, higher price elasticity of supply leads to lower reduction in CO_2 emissions due to higher leakage rate.

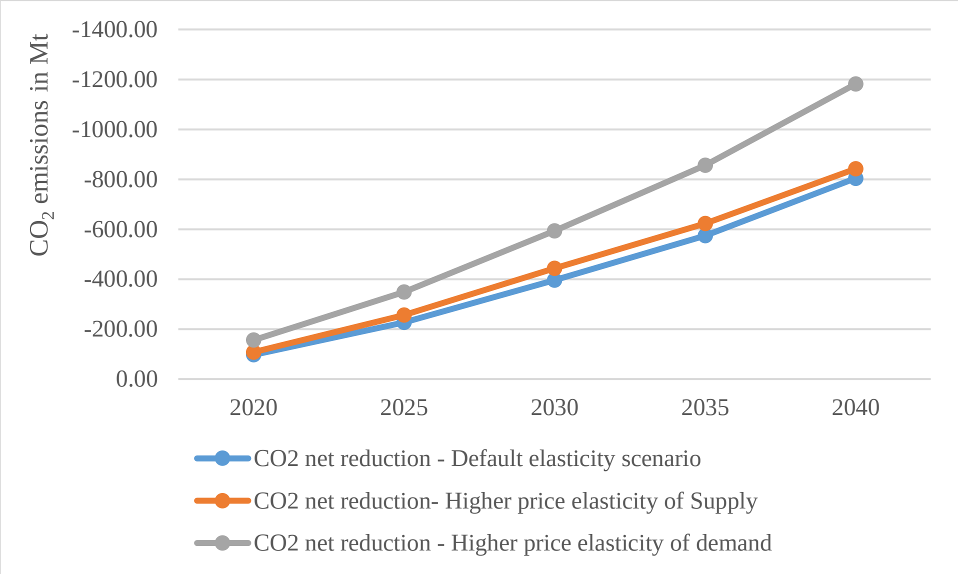


Figure 20: The impact on global CO_2 emissions in tax-coalition with different price elasticity of supply and demand, in Mt

In summary, the net reduction in global CO_2 emissions is much higher with very lower leakage rate in the scenario with price elasticity of demand is higher than price elasticity of supply. This scenario is shown an effective reduction of global CO_2 emission compared with all other scenarios, refer Table 8 for comparison of the scenarios. Table 8 (see appendix A2) summaries the key results on production, price, global CO_2 emissions reduction and the leakage rate across all different scenarios.

6.5 Main findings and Policy suggestions

The model result suggests that levying a carbon tax on coal production leads to CO_2 emissions reduction in any scenario. Without any doubt, tax can be a supply-side climate policy option. However, there are certain important factors that need to be considered while designing such a policy to reduce CO_2 emissions.

The elasticities of demand and supply are the main factors to be considered in the policy design. If the demand elasticity is higher than supply elasticity, then the production tax leads to greater reduction in emissions. However, if supply elasticity is higher than demand elasticity, then the leakage rate is much higher, and emission rises in non-taxing countries are high. Therefore, the emission reduction by unilateral policy would be highly eroded by non-taxing countries. In that case, it is recommended to draw up a climate policy with as many participants as possible to obtain a better outcome.

The tax rate should be endogenously determined by considering other factors in the economy; for example, discount rate, time and elasticity of supply and demand of coal. The optimal tax rates influence the effectiveness of the policy. In this model, tax rates are hypothetically assumed, which leads to large differences in CO_2 emission reduction in each model year. Since the supply elasticity influences the effectiveness of the tax rate, the tax rate should be given with the consideration of the elasticities. When we have really high supply elasticity, for example if supply elasticity is 3 times higher than demand elasticity, imposing higher tax may slow down the net effect on emissions. The main reason for this is that suppliers are highly flexible in adjusting their production to the price increase. Thus, the non-taxing countries increase their production rapidly to compensate for the reduced supply from the tax-setting country. As a result, net effect in emission is not stronger.

Levying a production tax on coal unilaterally may burden not only the producers, but also the consumers of the tax-setting country, because the producers lose their profits, while consumers suffer from increased local coal prices. Policy advisers should consider the options to balance the burden through the market and maximise the producers' and consumers' surpluses. In the case of Australia, we need to find the answer to how the Australian producers will be compensated for their profit loss due to the higher tax rate and it also needs to be investigated whether this is politically feasible.

Further research needs to be done on the cost of collecting tax and the tax revenue for the Government of a unilateral production tax on coal.

Chapter 7 - Conclusion

It is clear that reducing emissions from coal consumption is necessary to avoid an increase in global temperatures. In this research, I have examined restriction (through tax) on coal supply to the international market as a supply-side policy option to reduce global coal consumption. To do this, I have investigated the hypothesis of levying production tax on coal by large coal exporting country/ countries reduce global CO_2 emissions. The production tax reduces the supply from the tax-setting country to the international market. The lower supply causes global coal prices to increase. As a result, global patterns in production and consumption change which affects global CO_2 emissions. For this, I have constructed an equilibrium model for the international steam coal market and tested the tax policy scenarios (unilateral and coalition) with different growth rates. Further to this, I have analysed how the tax policy is sensitive to the different assumptions on demand and supply elasticities.

The results indicate that the unilateral tax policy of Australia leads to reduced global coal consumption and global CO_2 emissions. When Australia imposes tax on coal production, coal extraction in Australia declines, but non-taxing countries increase their production to compensate for Australia's reduction. However, the increased production from others is smaller than Australia's reduction. Global consumption drops and thus global CO_2 emissions are reduced. Overall, undoubtedly, Australian's tax policy supports the reduction of global CO_2 emissions. However, emission reduction under the unilateral policy is insufficient to provide significant support to the 2^oC target.

The result from the alternative policy scenario concludes that, in the unilateral climate policy, the tax rate influences the level of reduction in global consumption and CO_2 emissions. The higher rate of tax leads to a greater reduction in Australia's production, and therefore a significant price increase in the global market. Global consumption is reduced significantly. Thus, there is a greater global CO_2 emission reduction. Therefore, the initial tax rate should be at least 11USD/t to enable greater reduction in CO_2 emissions and an effective tax policy.

The results suggest that a coalition of the largest exporters is necessary to significantly lower CO_2 emissions. The tax-coalition leads to higher emissions reduction than unilateral policy, as more countries jointly impose tax and cut back their production. Thus, the carbon leakage rate is lower under the coalition. The increased production from the net importing or non- regulating countries is less severe under the coalition tax than the unilateral policy. Therefore, global CO_2 emissions are reduced to a greater extent. A global agreement on tax coalition is important for the reduction of CO_2 emissions.

The results from the sensitivity analysis suggest that if the price elasticity of supply is higher relative to the price elasticity of demand, this leads to less impact on emissions reduction under the unilateral tax policy, owing to a much higher leakage rate. The non-regulating countries increase their production significantly under this scenario. The consumers react less than producers. Thus, net reduction in CO_2 emissions is less. On the other hand, if the price elasticity of demand is high relative to the price elasticity of supply, then the leakage rate is much lower and thus emissions reductions are higher. The consumers reduce their demand to a greater extent, this there is a greater reduction in global CO_2 emissions.

Normally, the international coal market is considered to have a slightly higher price elasticity of supply than demand. In the short run, demand is almost inelastic and supply is less elastic, and in the long run price elasticity of supply is slightly higher than price elasticity of demand. In that case, tax coalition is beneficial and reduces global CO_2 emissions more significantly than unilateral policy, because unilateral policies by any country are greatly undermined by increased production from other countries. Therefore, it is recommended that tax coalition on coal production is a better option to reduce global emissions from coal than unilateral climate policies. In the absence of global coordination, a unilateral policy would reduce CO_2 emissions through tax on coal production by a major exporting country.

7.2 Limitations of the Study

The research has certain limitations that should be considered for the qualification of this research. The important points are discussed below.

The study does not directly include the long-term investment and capacity expansion of coal mines. For instance, the competing countries may invest to expand their production capacity in the long-term to increase production when Australia reduces its production. The importing countries also take the chance to invest in the capacity to increase local production. In that case, Australia’s reduction is largely compensated by increased production from the competitors and net importers in the long term. However, I have indirectly included this by differentiating the scale of elasticity in the short run and long run. The higher supply elasticities show that the countries can conduct investment and expand their capacity to increase production in the long run.

The substitution effect with other fossil fuels is not taken into account. A relative price increase through tax may increase the consumption of other fossil fuels such as natural gas and crude oil. The effect of CO_2 emissions reductions from lower coal consumption is then partly compensated for by higher emissions from other sources. However, coal is the most carbon-intensive fossil fuel compared with natural gas and crude oil.

Any changes in a country's climate policies may affect the 'base case' projections and thus net emission reduction in the long-term. The research is built on the projection under the New Policy Scenario by assuming that countries will implement certain climate policies in the future. When a country (or countries) adopts a new policy, or withdraws from the current policy, this would then change the projection and affect the results.

The tax rate is not optimally decided in this model. It is set hypothetically to reduce any complexity. I have not modelled the tax by considering discount rate or other economic factors that endogenously determine the tax rate. Therefore, the tax is exogenously given. However, different growth rates of tax are tested in the model.

It is often argued by Australian politicians that Australian coal is cleaner and the quality is better than that from other countries. However, I could not find any scientific data on quality variations in coal from other countries. Thus, equal weight is given to coal regardless of the country it comes from. Further to this, this research only includes the emissions from consumption of coal and the emissions from extraction are not included in the research.

There is a large amount of empirical literature available on direct price elasticities of demand. By contrast very limited literature is available for price elasticity of supply, especially for the long run. However, estimates for both elasticities vary quite a lot. This has meant there have been difficulties in the research with regard to coming to a suitable conclusion about elasticities. I chose the range between 0.3 to 0.8 for price elasticity of supply and -0.1 to -0.6 for price elasticity of demand as the default scenario. In practice, this may differ and thus affect the results.

References

Arroyo-Curras, T., Bauer, N., Kriegler, E., Jana Schwanitz, V., Luderer, G., Abounmahboub, T., Giannousakis, A., & Hillaire, J. (2015). Carbon leakage in a fragmented climate regime: The dynamic response of global energy markets *Technological Forecasting and Social Change, 90 Part A*, 192-203.

Asheim, G. B. (2012). A Distributional Argument for Supply-Side Climate Policies *Environmental and Resource Economics, 56*(2), 239-254.

Babiker, M. H. (2005). Climate change policy, market structure, and carbon leakage *Journal of International Economics, 65*(2), 421-445.

Bohm, P. (1993). Incomplete International cooperation to Reduce CO2 Emissions: Alternative Policies *Journal of Environmental Economics and Management, 24*(3), 258-271.

Burke. J, P., & Liao, H. (2015). Is the price elasticity of demand for coal in China increasing *China Economic Review, 36*, 309-332.

Burniaux, J.-M., & Olivera Martins, J. (2012). Carbon leakages: a general equilibrium view *Economic Theory, 49*(2), 473-495.

Collier, P., & Venables, A. J. (2014). Closing coal: economic and moral incentives *Oxford Review of Economic Policy, 30*(31), 492-512.

Dahl, C. (1993). A Survey of Energy Demand Elasticities in Support of the Development of the NEMS. *Tech. Rep. Colorado Scholl of Mines*.

Dahl, C. (2006). Survey of Econometric Energy Demand Elasticities, Progress Report

Dahl, C., & Ko. J. (1998). The effect of deregulation on US fossil fuel substitution in the generation of electricity *Energy Policy, 28*, 981-988.

DIW Berlin. (2017). Leaving coal unburned: Options for demand-side and supply-side policies. Retrieved from https://www.diw.de/de/diw_01.c.522192.de/presse/diw_roundup/leaving_coal_unburned_options_for_demand_side_and_supply_side_policies.html

Fæhn, T., Hagem, C., Lindholt, L., Mæland, S., & Rosendahl, K. E. (2013). Climate policies in a fossil fuel producing country- Demand versus supply side policies. *Discussion Papers, 747*.

Felder, S., & Rutherford, T. F. (1993). Unilateral CO2 Reduction and Carbon Leakage: The consequences of international Trade in Oil and Basic Materials *Journal of Environmental Economics and Management, 25*(2), 162-176.

Graham P, Thorpe S, & Hogan L. (1999). Non-competitive market behavior in the international coking coal market *Energy Economics (Guildford), 21*(3), 195-212.

Haftendorn, C., & Holz, F. (2010a). Modeling and analysis of the international steam coal trade *The Energy Journal, 31*(4), 205-229.

Haftendorn, C., Holz, F., & von Hirschhausen, C. (2010b). COALMOD-World: A Model to Assess International Coal Markets until 2030. *Discussion Papers, DIW Berlin, 1067*.

Hagem, C., & Storrøsten, H. B. (2016). Supply Versus demand-side policies in the presence of carbon leakage and the green paradox. *Discussion Papers, Statistics Norway Research department, No. 836*.

Harstad, B. (2012). Buy Coal! A Case for Supply-Side Environmental Policy *Journal of Political Economy, 120*(1), 77-115.

Hoel, M. (1994). Efficient Climate Policy in the Presence of Free Riders *Journal of Environmental Economics and Management, 27*(3), 259-274.

Hoel, M. (2012). Supply side climate policy and the green Paradox. *CESifo working paper Series, 4094*.

IEA. (2015). Coal Information 2015.

IEA. (2015). World Energy Outlook.

IEA. (2016a). CO2 emissions from fuel combustion - Highlights, International Energy Agency

IEA. (2016b). Coal Information 2016.

IEA. (2016c). World Energy Outlook

IEA. (2017). Key World Energy Statistics

Ko, J., & Dahl, C. (2001). Inter-fuel substitution in Us electricity generation. *Applied Economics, 33*, 1833-1843.

Lazarus, M., Erickson, P., & Tempest, K. (2015). Supply-side climate policy: the road less taken *SEI Working Paper No. 2015-13*.

Lewis, R. (2015, October 27). Ending coal exports may increase global emission: Malcolm Turnbull. *The Australian*

Maria, C. D., & Van der Werf, E. (2008). Carbon leakage revisited: unilateral climate policy with directed technical change *Environmental and Resource Economics, 39*(2), 55-74.

Martin, A. (2014). Commodity exports and transboundary atmospheric impacts: regulating coal in an era of climate change *Environmental Politics, 23*(4), 590-609.

McGlade, C., & Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. *Nature*, *517*, 187. doi:10.1038/nature14016

Mendelevitch, R. (2016). Testing Supply-Side Climate policies for the Global Steam Coal Market - Can They Curb Coal Consumption? *Discussion Papers, 1604*.

Pa, B. (1993). Incomplete international cooperation to reduce CO2 emissions: Alternative policies. *Journal of Environmental Economics and Management*, *24*, 258-271.

Richter, P., Mendelevitch, R., & Jotzo, F. (2015). Market Power Rents and Climate Change Mitigation: A Rational for Coal Taxes? *Discussion Papers, 1471*.

Sinn, H.-W. (2015). Introductory comment - The Green Paradox: A Supply-Side View of the Climate Problem. *Review of Environmental Economics and Policy, 9*(2), 239-245.

Steckel, J. C., Edenhofer, O., & Jakob, M. (2015). Drivers for the renaissance of coal. *Proceedings of the National Academy of Sciences, 112*(29), E3775.

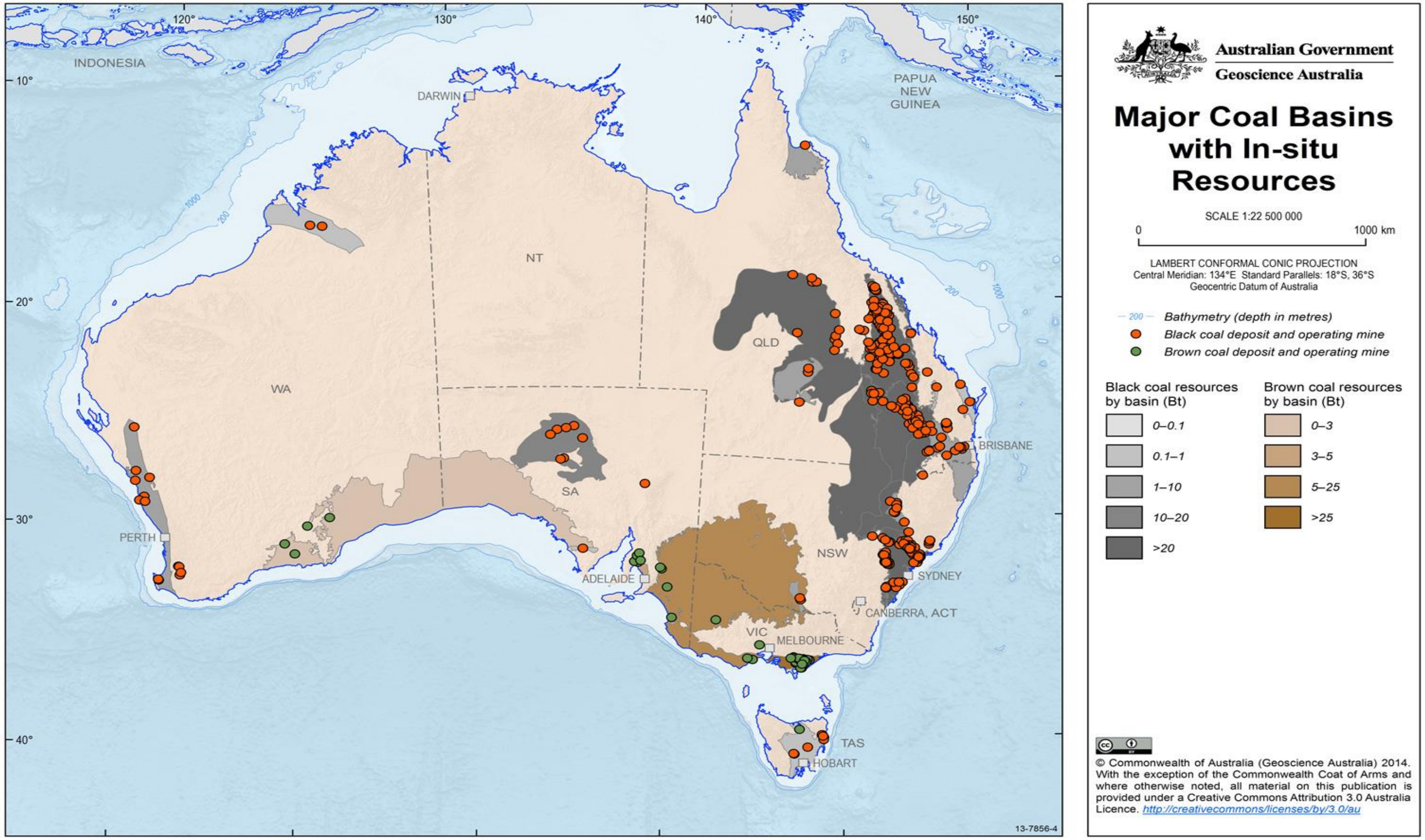
Tong, A. (2015). Letter from His Excellency Anote Tong, President of the Republic of Kiribati [Press release]. Retrieved from http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/08/HEs-letter.pdf

Trüby, J. (2013). Strategic Behavior in International Metallurgical Coal Market. *Energy Economics, 36*, 147-157.

Trüby, J., & Paulus, M. (2012). Market Structure Scenarios in International Steam Coal Trade. *The Energy Journal, 33*(3), 91-123.

UN Climate Change. (30 Jan 2018). Paris Agreement Triggers Divestment from Coal-Study [Press release]. Retrieved from https://unfccc.int/news/paris-agreement-triggers-divestment-from-coal-study

Appendix A1: Major Coal Basins in Australia



Source: Mineral Council of Australia, 2018

Appendix: A2

Table 8: Comparison of key statistics across scenarios for production, global CO_2 emission and leakage rate

Scenario	Average Reduction in Australia's Production (Mt)	Average reduction in tax setting countries production (Mt)	Average increase in non-taxing countries production (Mt)	Average net global CO_2 emission reduction (Mt)	Average Price Change (%)	Average leakage rate CO2-based (%)
Tax – Australia						
Lower tax rate	61	-	39	59	0.010	0.63
Higher tax rate	136	-	86	131	0.022	0.63
Tax- Coalition	48	361	201	420	0.077	0.56
Sensitivity Analysis						
Tax – Australia						
Higher price elasticity of Supply						
+ Lower tax rate	104	-	81	61	0.011	0.78
+ Higher tax rate	183	-	143	106	0.019	0.78
Higher price elasticity of Demand						
+ Lower tax rate	62	-	28	87	0.007	0.46
+ Higher tax rate	138	-	64	194	0.017	0.46
Tax – Coalition						
Higher price elasticity of Supply	83	625	452	454	0.085	0.74
Higher price elasticity of Demand	52	390	151	627	0.058	0.39

Appendix: A3

A1: Price elasticity of supply and price elasticity of demand in default scenario

Supply elasticities						
Country	**2014**	**2020**	**2025**	**2030**	**2035**	**2040**
Indonesia	0.3	0.4	0.5	0.6	0.7	0.8
Australia	0.3	0.4	0.5	0.6	0.7	0.8
South Africa	0.3	0.4	0.5	0.6	0.7	0.8
Russian Federation	0.3	0.4	0.5	0.6	0.7	0.8
United States	0.3	0.4	0.5	0.6	0.7	0.8
Colombia	0.3	0.4	0.5	0.6	0.7	0.8
Kazakhstan	0.3	0.4	0.5	0.6	0.7	0.8
Poland	0.3	0.4	0.5	0.6	0.7	0.8
North Korea	0.3	0.4	0.5	0.6	0.7	0.8
Mongolia	0.3	0.4	0.5	0.6	0.7	0.8
Rest of the world	0.3	0.4	0.5	0.6	0.7	0.8

Demand elasticities						
Country	**2014**	**2020**	**2025**	**2030**	**2035**	**2040**
China	-0.1	-0.1	-0.2	-0.3	-0.4	-0.5
India	-0.1	-0.1	-0.2	-0.3	-0.4	-0.5
Korea	-0.2	-0.2	-0.3	-0.4	-0.4	-0.5
Germany	-0.3	-0.3	-0.4	-0.4	-0.5	-0.6
United Kingdom	-0.3	-0.3	-0.4	-0.4	-0.5	-0.6
Turkey	-0.2	-0.2	-0.3	-0.4	-0.5	-0.6
Malaysia	-0.2	-0.2	-0.3	-0.4	-0.4	-0.5
Philippines	-0.2	-0.2	-0.3	-0.4	-0.4	-0.5
Thailand	-0.2	-0.2	-0.3	-0.4	-0.4	-0.5
Spain	-0.2	-0.3	-0.4	-0.4	-0.5	-0.6
Italy	-0.2	-0.3	-0.4	-0.4	-0.5	-0.6
Japan	-0.2	-0.3	-0.4	-0.4	-0.5	-0.6
Rest of the world	-0.2	-0.2	-0.3	-0.4	-0.4	-0.5

A2: Higher price elasticity of supply

Country	2014	2020	2025	2030	2035	2040
Indonesia	0.6	0.8	1.0	1.2	1.4	1.6
Australia	0.6	0.8	1.0	1.2	1.4	1.6
South Africa	0.6	0.8	1.0	1.2	1.4	1.6
Russian Federation	0.6	0.8	1.0	1.2	1.4	1.6
United States	0.6	0.8	1.0	1.2	1.4	1.6
Colombia	0.6	0.8	1.0	1.2	1.4	1.6
Kazakhstan	0.6	0.8	1.0	1.2	1.4	1.6
Poland	0.6	0.8	1.0	1.2	1.4	1.6
North Korea	0.6	0.8	1.0	1.2	1.4	1.6
Mongolia	0.6	0.8	1.0	1.2	1.4	1.6
Rest of the world	0.6	0.8	1.0	1.2	1.4	1.6

A2: Higher price elasticity of demand

Country	2014	2020	2025	2030	2035	2040
China	-0.2	-0.2	-0.4	-0.6	-0.8	-1.0
India	-0.2	-0.2	-0.4	-0.6	-0.8	-1.0
Korea	-0.4	-0.4	-0.6	-0.8	-0.8	-1.0
Germany	-0.6	-0.6	-0.8	-0.8	-1.0	-1.2
United Kingdom	-0.6	-0.6	-0.8	-0.8	-1.0	-1.2
Turkey	-0.4	-0.4	-0.6	-0.8	-1.0	-1.2
Malaysia	-0.4	-0.4	-0.6	-0.8	-0.8	-1.0
Philippines	-0.4	-0.4	-0.6	-0.8	-0.8	-1.0
Thailand	-0.4	-0.4	-0.6	-0.8	-0.8	-1.0
Spain	-0.4	-0.6	-0.8	-0.8	-1.0	-1.2
Italy	-0.4	-0.6	-0.8	-0.8	-1.0	-1.2
Japan	-0.4	-0.6	-0.8	-0.8	-1.0	-1.2
Rest of the world	-0.4	-0.4	-0.6	-0.8	-0.8	-1.0

Appendix B

B.1 Scenario 1: A Unilateral Australian production tax on coal and the impact on Australian, global production of coal and CO_2 emissions in the Base case and Tax- Australia, in Mt

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.32	255.16	252.16	190.12	680.42	83.05	90.06	56.03	32.02	11.01	3898.40	6073.74	60.09
2025	559.75	262.35	249.33	192.26	603.80	82.11	90.12	52.07	33.04	12.02	3994.32	6131.17	60.16
2030	593.48	268.67	245.61	194.49	527.32	81.20	90.23	47.12	34.09	12.03	4090.21	6184.43	60.25
2035	628.62	275.15	242.01	196.82	449.88	80.33	91.38	43.18	35.15	12.05	4182.44	6237.00	60.36
2040	663.89	281.65	238.40	199.17	373.18	80.47	91.54	39.23	36.21	13.08	4270.00	6286.80	60.44
		Coal Production (Mt) - Tax Australia											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	526.48	237.87	252.71	190.54	681.92	83.23	90.25	56.16	32.09	11.03	3906.98	6069.25	60.42
2025	561.92	228.48	250.30	193.00	606.15	82.43	90.47	52.27	33.17	12.06	4009.82	6120.07	60.63
2030	597.04	212.80	247.08	195.65	530.47	81.69	90.77	47.40	34.29	12.10	4114.71	6164.00	60.85
2035	634.11	192.05	244.12	198.54	453.80	81.04	92.18	43.56	35.45	12.16	4218.93	6205.92	61.11
2040	671.60	166.46	241.17	201.48	377.52	81.41	92.60	39.69	36.63	13.23	4319.62	6241.39	61.32
		Changes in production Mt (Reduced / Increased production)										**Total Increase**	**% Change in price**

2020	1.16	**-17.29**	0.55	0.42	1.50	0.18	0.20	0.12	0.07	0.02	8.58	**12.80**	**0.005**
2025	2.17	**-33.87**	0.97	0.75	2.34	0.32	0.35	0.20	0.13	0.05	15.50	**22.77**	**0.008**
2030	3.56	**-55.87**	1.47	1.16	3.16	0.49	0.54	0.28	0.20	0.07	24.50	**35.44**	**0.010**
2035	5.49	**-83.10**	2.11	1.72	3.93	0.70	0.80	0.38	0.31	0.11	36.50	**52.02**	**0.012**
2040	7.71	**-115.19**	2.77	2.31	4.34	0.94	1.06	0.46	0.42	0.15	49.62	**69.78**	**0.014**
		CO2 Emissions (Mt)										**Total* Increase**	
2020	3.03	**-45.30**	1.45	1.10	3.92	0.48	0.52	0.32	0.18	0.06	22.47	**33.54**	
2025	5.69	**-88.75**	2.53	1.95	6.14	0.83	0.92	0.53	0.34	0.12	40.60	**59.66**	
2030	9.31	**-146.37**	3.85	3.05	8.28	1.27	1.42	0.74	0.53	0.19	64.19	**92.84**	
2035	14.37	**-217.72**	5.53	4.50	10.28	1.84	2.09	0.99	0.80	0.28	95.62	**136.30**	
2040	20.21	**-301.80**	7.26	6.06	11.36	2.45	2.79	1.19	1.10	0.40	130.00	**182.83**	
		Global net reduction of CO2 Emissions (Mt)											**Leakage Rate**
2020												**-11.76**	**-0.74**
2025												**-29.09**	**-0.67**
2030												**-53.53**	**-0.63**
2035												**-81.42**	**-0.63**
2040												**-118.96**	**-0.61**
Average												**-58.95**	**-0.63**

B.2 Scenario 2: A Unilateral Australian production tax on coal and the impact on Australian, global production of coal and CO_2 emissions in the Base case and Tax- Australia, in Mt

Faster growth tax rate

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.32	255.16	252.16	190.12	680.42	83.05	90.06	56.03	32.02	11.01	3898.40	6073.74	60.09
2025	559.75	262.35	249.33	192.26	603.80	82.11	90.12	52.07	33.04	12.02	3994.32	6131.17	60.16
2030	593.48	268.67	245.61	194.49	527.32	81.20	90.23	47.12	34.09	12.03	4090.21	6184.43	60.25
2035	628.62	275.15	242.01	196.82	449.88	80.33	91.38	43.18	35.15	12.05	4182.44	6237.00	60.36
2040	663.89	281.65	238.40	199.17	373.18	80.47	91.54	39.23	36.21	13.08	4270.00	6286.80	60.44
		Coal Production (Mt) – Tax Australia											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	527.77	218.54	253.33	191.00	683.59	83.44	90.48	56.30	32.17	11.06	3916.58	6064.25	60.80
2025	564.46	188.87	251.43	193.88	608.89	82.80	90.88	52.51	33.32	12.12	4027.98	6107.14	61.18
2030	601.36	145.14	248.87	197.07	534.31	82.28	91.42	47.74	34.54	12.19	4144.49	6139.42	61.59
2035	640.94	89.10	246.75	200.68	458.69	81.91	93.17	44.03	35.84	12.29	4264.40	6167.79	62.06
2040	681.38	21.60	244.68	204.42	383.02	82.59	93.95	40.26	37.17	13.42	4382.53	6185.03	62.44
		Changes in production Mt (Reduced / Increased production)										***Total Increase***	***% Change in Price***
2020	2.45	-36.62	1.18	0.89	3.17	0.70	0.42	0.26	0.15	0.05	18.17	27.13	**0.012**

2025	4.72	-73.48	2.10	1.62	5.09	1.02	0.76	0.44	0.28	0.10	33.66	49.45	**0.017**
2030	7.88	-123.53	3.26	2.58	7.00	1.34	1.20	0.63	0.45	0.16	54.29	78.52	**0.022**
2035	12.32	-186.04	4.74	3.86	8.82	1.70	1.79	0.85	0.69	0.24	81.96	116.84	**0.028**
2040	17.50	-260.05	6.28	5.25	9.84	2.00	2.41	1.03	0.95	0.34	112.54	158.27	**0.033**
		CO2 Emissions (Mt) (Reduced/ increased)										**Total Increase**	
2020	6.42	-95.95	3.08	2.32	8.31	1.01	1.10	0.68	0.39	0.13	47.62	**71.07**	
2025	12.36	-192.53	5.50	4.24	13.33	1.81	1.99	1.15	0.73	0.27	88.18	**129.57**	
2030	20.64	-323.65	8.54	6.76	18.34	2.82	3.14	1.64	1.19	0.42	142.23	**205.72**	
2035	32.28	-487.44	12.43	10.11	23.10	4.12	4.69	2.22	1.80	0.62	214.75	**306.11**	
2040	45.84	-681.32	16.46	13.75	25.77	5.56	6.32	2.71	2.50	0.90	294.85	**414.67**	
		Global net reduction of CO2 Emissions (Mt)											**Leakage Rate**
2020												**-24.87**	**-0.74**
2025												**-62.96**	**-0.67**
2030												**-117.94**	**-0.64**
2035												**-181.32**	**-0.63**
2040												**-266.65**	**-0.61**
Average												**-130.75**	**-0.63**

B.3 Scenario 3: Coalition production tax on coal and the impact on global coal production and CO_2 emissions in the Base case and Tax- Coalition, in Mt

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.32	255.16	252.16	190.12	680.42	83.05	90.06	56.03	32.02	11.01	3898.40	6073.74	60.09
2025	559.75	262.35	249.33	192.26	603.80	82.11	90.12	52.07	33.04	12.02	3994.32	6131.17	60.16
2030	593.48	268.67	245.61	194.49	527.32	81.20	90.23	47.12	34.09	12.03	4090.21	6184.43	60.25
2035	628.62	275.15	242.01	196.82	449.88	80.33	91.38	43.18	35.15	12.05	4182.44	6237.00	60.36
2040	663.89	281.65	238.40	199.17	373.18	80.47	91.54	39.23	36.21	13.08	4270.00	6286.80	60.44
		Coal Production (Mt) - Tax Coalition											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	499.14	242.44	239.59	180.64	646.51	78.91	85.57	53.24	30.42	10.46	3969.84	6036.77	62.88
2025	504.80	236.60	224.86	173.38	544.53	74.05	81.27	46.96	29.80	10.84	4117.54	6044.63	63.93
2030	497.57	225.25	205.92	163.06	442.10	68.08	75.64	39.50	28.58	10.09	4277.30	6033.09	64.91
2035	479.32	209.80	184.53	150.07	343.02	61.25	69.68	32.92	26.80	9.19	4451.11	6017.69	65.97
2040	446.17	189.28	160.22	133.85	250.80	54.08	61.52	26.36	24.34	8.79	4624.53	5979.94	66.78
		Changes in production Mt (Reduced / Increased production)										**Total Reduction**	**% Changes in Price**
2020	-26.18	-12.72	-12.57	-9.47	-33.91	-4.14	-4.49	-2.79	-1.60	-0.55	71.44	-108.41	**0.04**
2025	-54.95	-25.75	-24.47	-18.87	-59.27	-8.06	-8.85	-5.11	-3.24	-1.18	123.22	-209.76	**0.06**
2030	-95.91	-43.42	-39.69	-31.43	-85.22	-13.12	-14.58	-7.61	-5.51	-1.94	187.09	-338.44	**0.08**

2035	-149.30	-65.35	-57.48	-46.75	-106.85	-19.08	-21.70	-10.26	-8.35	-2.86	268.68	-487.98	**0.09**
2040	-217.72	-92.36	-78.18	-65.31	-122.38	-26.39	-30.02	-12.87	-11.88	-4.29	354.53	-661.39	**0.10**
		CO_2 Emissions (Mt) (Reduced/ increased)										**Total Reduction**	
2020	-68.59	-33.31	-32.92	-24.82	-88.84	-10.84	-11.76	-7.32	-4.18	-1.44	187.16	-284.02	
2025	-143.96	-67.47	-64.12	-49.45	-155.29	-21.12	-23.18	-13.39	-8.50	-3.09	322.82	-549.56	
2030	-251.28	-113.76	-103.99	-82.35	-223.27	-34.38	-38.20	-19.95	-14.43	-5.09	490.18	-886.70	
2035	-391.18	-171.22	-150.60	-122.48	-279.95	-49.99	-56.86	-26.87	-21.87	-7.50	703.93	-1278.52	
2040	-570.41	-241.99	-204.83	-171.12	-320.64	-69.14	-78.65	-33.71	-31.11	-11.24	928.88	-1732.85	
		Global net reduction of CO_2 Emissions (Mt)											**Leakage rate**
2020												**-96.86**	**-0.66**
2025												**-226.74**	**-0.59**
2030												**-396.52**	**-0.55**
2035												**-574.58**	**-0.55**
2040												**-803.97**	**-0.54**
Average												**-419.73**	**-0.56**

B.4 Scenario 1: A Unilateral Australian production tax on coal and the impact on Australian, global production of coal and CO_2 emissions in the Base case and Tax- Australia, in Mt

<u>Higher price elasticity of supply with slower growth rate of tax</u>

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.37	255.18	252.18	190.13	680.48	83.06	90.06	56.04	32.02	11.01	3898.75	6074.28	60.05
2025	559.89	262.42	249.40	192.30	603.96	82.13	90.14	52.08	33.05	12.02	3995.33	6132.72	60.10
2030	593.80	268.82	245.75	194.59	527.60	81.25	90.27	47.14	34.10	12.04	4092.42	6187.79	60.15
2035	629.21	275.40	242.23	197.00	450.30	80.41	91.47	43.22	35.18	12.06	4186.34	6242.82	60.22
2040	664.82	282.04	238.73	199.45	373.71	80.58	91.66	39.28	36.26	13.09	4275.99	6295.62	60.27
		Coal Production (Mt) – Tax- Australia											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	527.93	221.87	253.41	191.06	683.79	83.46	90.50	56.31	32.18	11.06	3917.74	6069.32	60.42
2025	564.74	199.19	251.56	193.97	609.19	82.84	90.92	52.53	33.34	12.12	4029.95	6120.35	60.62
2030	601.60	168.76	248.97	197.15	534.53	82.31	91.46	47.76	34.55	12.19	4146.17	6165.46	60.81
2035	640.70	134.03	246.66	200.60	458.52	81.88	93.14	44.01	35.82	12.28	4262.79	6210.43	61.00
2040	680.19	98.05	244.25	204.06	382.35	82.45	93.78	40.19	37.10	13.40	4374.84	6250.65	61.14
		Changes in production Mt (Reduced / Increased production)										**Total Increase**	**% Change in price**
2020	2.56	-33.31	1.23	0.93	3.32	0.40	0.44	0.27	0.16	0.05	18.99	**28.35**	**0.006**

2025	4.85	-63.23	2.16	1.67	5.23	0.71	0.78	0.45	0.29	0.10	34.61	**50.86**	**0.009**
2030	7.80	-100.06	3.23	2.56	6.93	1.07	1.19	0.62	0.45	0.16	53.74	**77.73**	**0.011**
2035	11.49	-141.37	4.42	3.60	8.22	1.47	1.67	0.79	0.64	0.22	76.45	**108.98**	**0.013**
2040	15.37	-184.00	5.52	4.61	8.64	1.86	2.12	0.91	0.84	0.30	98.85	**139.02**	**0.014**
		CO2 Emissions (Mt)										**Total Increase**	
2020	6.71	-87.28	3.22	2.43	8.69	1.06	1.15	0.72	0.41	0.14	49.76	**74.28**	
2025	12.71	-165.65	5.66	4.37	13.71	1.86	2.05	1.18	0.75	0.27	90.69	**133.25**	
2030	20.43	-262.15	8.46	6.70	18.15	2.80	3.11	1.62	1.17	0.41	140.81	**203.65**	
2035	30.11	-370.39	11.59	9.43	21.55	3.85	4.38	2.07	1.68	0.58	200.30	**285.52**	
2040	40.27	-482.07	14.46	12.08	22.64	4.88	5.55	2.38	2.20	0.79	258.99	**364.24**	
		Global net reduction of CO2 Emissions (Mt)											**Leakage Rate**
2020												**-13.00**	**-0.85**
2025												**-32.40**	**-0.80**
2030												**-58.49**	**-0.78**
2035												**-84.87**	**-0.77**
2040												**-117.83**	**-0.76**
Average												**-61.32**	**-0.78**

B.5 Scenario 2: A Unilateral Australian production tax on coal and the impact on Australian, global production of coal and CO_2 emissions in the Base case and Tax- Australia, in Mt

<u>Higher price elasticity of supply with higher growth rate of tax</u>

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.37	255.18	252.18	190.13	680.48	83.06	90.06	56.04	32.02	11.01	3898.75	6074.28	60.05
2025	559.89	262.42	249.40	192.30	603.96	82.13	90.14	52.08	33.05	12.02	3995.33	6132.72	60.10
2030	593.80	268.82	245.75	194.59	527.60	81.25	90.27	47.14	34.10	12.04	4092.42	6187.79	60.15
2035	629.21	275.40	242.23	197.00	450.30	80.41	91.47	43.22	35.18	12.06	4186.34	6242.82	60.22
2040	664.82	282.04	238.73	199.45	373.71	80.58	91.66	39.28	36.26	13.09	4275.99	6295.62	60.27
		Coal Production (Mt) – Tax Australia											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	530.59	187.30	254.68	192.02	687.24	83.88	90.96	56.60	32.34	11.12	3937.47	6064.19	60.80
2025	569.60	135.97	253.72	195.64	614.43	83.55	91.71	52.99	33.63	12.23	4064.63	6108.09	61.14
2030	608.71	77.81	251.92	199.48	540.85	83.29	92.54	48.33	34.96	12.34	4195.19	6145.42	61.41
2035	649.40	27.43	250.01	203.33	464.75	82.99	94.40	44.61	36.31	12.45	4320.71	6186.38	61.59
2040	688.35	0.85	247.18	206.51	386.94	83.44	94.91	40.68	37.55	13.56	4427.35	6227.29	61.60
		Changes in production Mt (Reduced / Increased production)										**Total Increase**	**% Change in price**
2020	5.22	**-67.88**	2.50	1.89	6.76	0.82	0.89	0.56	0.32	0.11	38.72	**57.79**	**0.012**

2025	9.71	**-126.45**	4.33	3.34	10.48	1.42	1.56	0.90	0.57	0.21	69.30	**101.82**	**0.017**
2030	14.91	**-191.00**	6.17	4.89	13.25	2.04	2.27	1.18	0.86	0.30	102.77	**148.63**	**0.021**
2035	20.20	**-247.97**	7.77	6.32	14.45	2.58	2.94	1.39	1.13	0.39	134.37	**191.53**	**0.023**
2040	23.53	**-281.20**	8.45	7.06	13.23	2.85	3.24	1.39	1.28	0.46	151.36	**212.87**	**0.022**
		CO2 Emissions (Mt)										**Total Increase**	
2020	13.67	-177.84	6.56	4.95	17.71	2.16	2.34	1.46	0.83	0.29	101.45	**151.41**	
2025	25.44	-331.29	11.33	8.74	27.45	3.73	4.10	2.37	1.50	0.55	181.56	**266.77**	
2030	39.07	-500.43	16.17	12.80	34.71	5.35	5.94	3.10	2.24	0.79	269.25	**389.42**	
2035	52.91	-649.69	20.37	16.57	37.87	6.76	7.69	3.63	2.96	1.01	352.04	**501.82**	
2040	61.66	-736.74	22.14	18.50	34.66	7.47	8.50	3.64	3.36	1.21	396.57	**557.72**	
		Global net reduction of CO2 Emissions (Mt)											**Leakage Rate**
2020												**-26.43**	**-0.85**
2025												**-64.53**	**-0.81**
2030												**-111.00**	**-0.78**
2035												**-147.87**	**-0.77**
2040												**-179.01**	**-0.76**
Average												**-105.77**	**-0.78**

B.6 Scenario 1: A Unilateral Australian production tax on coal and the impact on Australian, global production of coal and CO_2 emissions in the Base case and Tax- Australia, in Mt

<u>Higher price elasticity of demand with slower growth rate of tax</u>

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.26	255.13	252.12	190.09	680.33	83.04	90.04	56.03	32.02	11.01	3897.92	6072.99	60.07
2025	559.57	262.27	249.25	192.19	603.61	82.08	90.09	52.05	33.03	12.01	3993.04	6129.20	60.12
2030	593.09	268.49	245.45	194.36	526.97	81.15	90.17	47.09	34.06	12.02	4087.52	6180.37	60.18
2035	627.92	274.84	241.74	196.60	449.37	80.25	91.28	43.13	35.11	12.04	4177.77	6230.04	60.26
2040	662.80	281.19	238.01	198.84	372.58	80.34	91.39	39.17	36.15	13.06	4263.03	6276.54	60.32
		Coal Production (Mt) – Tax Australia											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	526.18	237.71	252.57	190.43	681.53	83.19	90.20	56.13	32.07	11.02	3904.78	6065.81	60.34
2025	561.22	228.10	249.99	192.76	605.39	82.32	90.36	52.21	33.13	12.05	4004.81	6112.33	60.48
2030	595.72	212.10	246.54	195.22	529.30	81.51	90.57	47.30	34.21	12.08	4105.63	6150.17	60.63
2035	631.95	190.94	243.29	197.86	452.26	80.76	91.86	43.41	35.33	12.11	4204.58	6184.37	60.82
2040	668.39	164.90	240.01	200.52	375.72	81.02	92.16	39.50	36.46	13.17	4298.96	6210.78	60.95
		Changes in production Mt (Reduced / Increased production)										**Total Increase**	**% Change in price**
2020	0.92	-17.42	0.44	0.33	1.20	0.15	0.16	0.10	0.06	0.02	6.86	**10.24**	0.004
2025	1.65	-34.17	0.73	0.57	1.78	0.24	0.27	0.15	0.10	0.04	11.77	**17.30**	0.006
2030	2.63	-56.39	1.09	0.86	2.33	0.36	0.40	0.21	0.15	0.05	18.11	**26.19**	0.007

2035	4.03	-83.90	1.55	1.26	2.88	0.52	0.59	0.28	0.23	0.08	26.82	**38.23**	0.009
2040	5.59	-116.29	2.01	1.68	3.14	0.68	0.77	0.33	0.30	0.11	35.93	**50.53**	0.011
		CO2 Emissions (Mt)										**Total Increase**	
2020	2.42	**-45.64**	1.16	0.88	3.14	0.38	0.42	0.26	0.15	0.05	17.98	**26.83**	
2025	4.32	**-89.52**	1.93	1.48	4.66	0.63	0.70	0.40	0.26	0.09	30.85	**45.32**	
2030	6.88	**-147.74**	2.85	2.26	6.12	0.94	1.05	0.55	0.40	0.14	47.44	**68.62**	
2035	10.56	**-219.81**	4.07	3.31	7.56	1.35	1.54	0.73	0.59	0.20	70.26	**100.16**	
2040	14.64	**-304.68**	5.26	4.39	8.23	1.77	2.02	0.86	0.80	0.29	94.14	**132.40**	
		Global net reduction of CO2 Emissions (Mt)											**Leakage Rate**
2020												**-18.81**	**-0.59**
2025												**-44.20**	**-0.51**
2030												**-79.12**	**-0.46**
2035												**-119.66**	**-0.46**
2040												**-172.28**	**-0.43**
Average												**-86.81**	**-0.46**

B.7 Scenario 2: A Unilateral Australian production tax on coal and the impact on Australian, global production of coal and CO_2 emissions in the Base case and Tax- Australia, in Mt

<u>Higher price elasticity of demand with higher growth rate of tax</u>

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.26	255.13	252.12	190.09	680.33	83.04	90.04	56.03	32.02	11.01	3897.92	6072.99	60.07
2025	559.57	262.27	249.25	192.19	603.61	82.08	90.09	52.05	33.03	12.01	3993.04	6129.20	60.12
2030	593.09	268.49	245.45	194.36	526.97	81.15	90.17	47.09	34.06	12.02	4087.52	6180.37	60.18
2035	627.92	274.84	241.74	196.60	449.37	80.25	91.28	43.13	35.11	12.04	4177.77	6230.04	60.26
2040	662.80	281.19	238.01	198.84	372.58	80.34	91.39	39.17	36.15	13.06	4263.03	6276.54	60.32
		Coal Production (Mt) - Tax Australia											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	527.22	218.20	253.07	190.80	682.88	83.35	90.38	56.24	32.14	11.05	3912.47	6057.78	60.64
2025	563.16	188.01	250.85	193.43	607.48	82.61	90.67	52.39	33.25	12.09	4018.67	6092.60	60.90
2030	598.94	143.47	247.87	196.27	532.16	81.95	91.05	47.55	34.40	12.14	4127.80	6113.59	61.18
2035	637.02	86.28	245.24	199.45	455.89	81.41	92.60	43.76	35.62	12.21	4238.32	6127.80	61.51
2040	675.59	16.76	242.60	202.68	379.76	81.89	93.15	39.92	36.85	13.31	4345.29	6127.80	61.78
		Changes in production Mt (Reduced / Increased production)										**Total Increase**	**% Change in price**
2020	1.96	-36.93	0.94	0.71	2.54	0.31	0.34	0.21	0.12	0.04	14.56	**21.72**	**0.009**

2025	3.59	-74.26	1.60	1.23	3.87	0.53	0.58	0.33	0.21	0.08	25.63	**37.66**	**0.013**
2030	5.84	-125.03	2.42	1.91	5.19	0.80	0.89	0.46	0.34	0.12	40.27	**58.25**	**0.016**
2035	9.10	-188.56	3.50	2.85	6.51	1.16	1.32	0.63	0.51	0.17	60.55	**86.32**	**0.021**
2040	12.79	-264.42	4.59	3.84	7.19	1.55	1.76	0.76	0.70	0.25	82.26	**115.69**	**0.024**
		CO2 Emissions (Mt)										**Total Increase**	
2020	5.14	**-96.76**	2.47	1.86	6.66	0.81	0.88	0.55	0.31	0.11	38.14	**56.92**	
2025	9.41	**-194.55**	4.19	3.23	10.15	1.38	1.52	0.88	0.56	0.20	67.15	**98.67**	
2030	15.31	**-327.57**	6.34	5.02	13.60	2.09	2.33	1.22	0.88	0.31	105.52	**152.61**	
2035	23.85	**-494.02**	9.18	7.47	17.07	3.05	3.47	1.64	1.33	0.46	158.65	**226.15**	
2040	33.51	**-692.79**	12.03	10.05	18.84	4.06	4.62	1.98	1.83	0.66	215.53	**303.11**	
		Global net reduction of CO2 Emissions (Mt)											**Leakage Rate**
2020												**-39.84**	**-0.59**
2025												**-95.88**	**-0.51**
2030												**-174.96**	**-0.46**
2035												**-267.87**	**-0.46**
2040												**-389.68**	**-0.43**
Average												**-193.65**	**-0.46**

***-** Total includes all other countries except Australia

B.8 Scenario 3: Coalition production tax on coal and the impact on global coal production and CO_2 emissions in the Base case and Tax- Coalition, in Mt

<u>Higher price elasticity of supply</u>

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.37	255.18	252.18	190.13	680.48	83.06	90.06	56.04	32.02	11.01	3898.75	6074.28	60.05
2025	559.89	262.42	249.40	192.30	603.96	82.13	90.14	52.08	33.05	12.02	3995.33	6132.72	60.10
2030	593.80	268.82	245.75	194.59	527.60	81.25	90.27	47.14	34.10	12.04	4092.42	6187.79	60.15
2035	629.21	275.40	242.23	197.00	450.30	80.41	91.47	43.22	35.18	12.06	4186.34	6242.82	60.22
2040	664.82	282.04	238.73	199.45	373.71	80.58	91.66	39.28	36.26	13.09	4275.99	6295.62	60.27
		Coal Production (Mt) - Tax Coalition											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	476.59	231.49	228.76	172.48	617.30	75.35	81.70	50.84	29.05	9.99	4059.60	6033.14	63.17
2025	459.92	215.56	204.87	157.97	496.13	67.47	74.05	42.78	27.15	9.87	4279.24	6035.02	64.37
2030	423.55	191.74	175.29	138.80	376.33	57.95	64.39	33.63	24.33	8.59	4523.80	6018.40	65.39
2035	371.31	162.52	142.95	116.26	265.73	47.45	53.98	25.51	20.76	7.12	4791.55	6005.14	66.32
2040	303.26	128.66	108.90	90.98	170.47	36.76	41.81	17.92	16.54	5.97	5053.07	5974.34	66.90
		Changes in production Mt (Reduced / Increased production)										**Total Reduction**	**% Change in price**

2020	-48.78	-23.69	-23.41	-17.65	-63.18	-7.71	-8.36	-5.20	-2.97	-1.02	160.86	**-202.00**	0.05
2025	-99.96	-46.85	-44.53	-34.33	-107.83	-14.66	-16.09	-9.30	-5.90	-2.15	283.91	**-381.62**	0.07
2030	-170.25	-77.07	-70.46	-55.79	-151.27	-23.29	-25.88	-13.52	-9.78	-3.45	431.37	**-600.76**	0.09
2035	-257.89	-112.88	-99.29	-80.75	-184.56	-32.96	-37.49	-17.71	-14.42	-4.94	605.22	**-842.89**	0.10
2040	-361.56	-153.39	-129.83	-108.47	-203.24	-43.83	-49.85	-21.36	-19.72	-7.12	777.09	**-1098.37**	0.11
		CO2 Emissions (Mt)										**Total Increase**	
2020	-127.81	-62.08	-61.35	-46.25	-165.54	-20.21	-21.91	-13.63	-7.79	-2.68	421.44	**-529.24**	
2025	-261.91	-122.75	-116.66	-89.96	-282.52	-38.42	-42.17	-24.36	-15.46	-5.62	743.85	**-999.83**	
2030	-446.05	-201.93	-184.60	-146.17	-396.32	-61.03	-67.81	-35.41	-25.62	-9.04	1130.20	**-1573.99**	
2035	-675.68	-295.75	-260.13	-211.56	-483.56	-86.35	-98.22	-46.41	-37.78	-12.95	1585.67	**-2208.38**	
2040	-947.28	-401.88	-340.16	-284.19	-532.49	-114.82	-130.61	-55.98	-51.67	-18.66	2035.97	**-2877.73**	
													Leakage Rate
		Global net reduction of CO2 Emissions (Mt)											
2020												**-107.80**	**-0.80**
2025												**-255.99**	**-0.74**
2030												**-443.79**	**-0.72**
2035												**-622.72**	**-0.72**
2040												**-841.76**	**-0.71**
Average												**-454.41**	**-0.72**

B.9 Scenario 3: Coalition production tax on coal and the impact on global coal production and CO_2 emissions in the Base case and Tax- Coalition, in Mt

<u>Higher price elasticity of demand</u>

		Coal Production (Mt) - Base case											
Model Year	Indonesia	Australia	South Africa	Russian Federation	United States	Colombia	Kazakhstan	Poland	North Korea	Mongolia	Rest of the World	Total	Price
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	525.26	255.13	252.12	190.09	680.33	83.04	90.04	56.03	32.02	11.01	3897.92	6072.99	60.07
2025	559.57	262.27	249.25	192.19	603.61	82.08	90.09	52.05	33.03	12.01	3993.04	6129.20	60.12
2030	593.09	268.49	245.45	194.36	526.97	81.15	90.17	47.09	34.06	12.02	4087.52	6180.37	60.18
2035	627.92	274.84	241.74	196.60	449.37	80.25	91.28	43.13	35.11	12.04	4177.77	6230.04	60.26
2040	662.80	281.19	238.01	198.84	372.58	80.34	91.39	39.17	36.15	13.06	4263.03	6276.54	60.32
		Coal Production (Mt) - Tax Coalition											
2014	484.00	248.00	257.00	188.00	773.00	84.00	89.00	61.00	31.00	11.00	3781.00	6007.00	60.00
2020	496.99	241.40	238.56	179.86	643.72	78.57	85.20	53.01	30.29	10.41	3955.45	6013.47	62.32
2025	500.00	234.35	222.72	171.74	539.36	73.35	80.50	46.51	29.52	10.73	4087.62	5996.40	63.00
2030	489.21	221.46	202.46	160.31	434.67	66.94	74.37	38.84	28.10	9.92	4227.63	5953.90	63.66
2035	466.64	204.25	179.65	146.10	333.95	59.63	67.83	32.05	26.09	8.95	4378.15	5903.30	64.43
2040	428.51	181.79	153.87	128.55	240.87	51.94	59.08	25.32	23.37	8.44	4523.94	5825.71	64.97
		Changes in production Mt (Reduced / Increased production)										**Total Increase**	**% Change in price**
2020	-28.27	-13.73	-13.57	-10.23	-36.61	-4.47	-4.85	-3.02	-1.72	-0.59	57.53	**-117.05**	0.04

2025	-59.56	-27.92	-26.53	-20.46	-64.25	-8.74	-9.59	-5.54	-3.52	-1.28	94.59	**-227.38**	0.05
2030	-103.89	-47.03	-42.99	-34.04	-92.30	-14.21	-15.79	-8.25	-5.97	-2.11	140.11	**-366.58**	0.06
2035	-161.28	-70.59	-62.09	-50.50	-115.42	-20.61	-23.44	-11.08	-9.02	-3.09	200.39	**-527.12**	0.07
2040	-234.29	-99.40	-84.13	-70.29	-131.70	-28.40	-32.30	-13.84	-12.78	-4.61	260.92	**-711.75**	0.08
		CO2 Emissions (Mt)										**Total Reduction**	
2020	-74.06	**-35.97**	-35.55	-26.80	-95.92	-11.71	-12.70	-7.90	-4.51	-1.55	150.73	**-306.67**	
2025	-156.05	**-73.14**	-69.51	-53.60	-168.34	-22.89	-25.12	-14.52	-9.21	-3.35	247.81	**-595.74**	
2030	-272.18	**-123.22**	-112.64	-89.19	-241.84	-37.24	-41.38	-21.61	-15.63	-5.52	367.08	**-960.44**	
2035	-422.56	**-184.95**	-162.68	-132.30	-302.40	-54.00	-61.43	-29.03	-23.63	-8.10	525.02	**-1381.07**	
2040	-613.85	**-260.42**	-220.43	-184.15	-345.06	-74.41	-84.64	-36.27	-33.48	-12.09	683.61	**-1864.79**	
		Global net reduction of CO2 Emissions (Mt)											**Leakage Rate**
2020												**-155.94**	**-0.49**
2025												**-347.93**	**-0.42**
2030												**-593.37**	**-0.38**
2035												**-856.05**	**-0.38**
2040												**-1181.18**	**-0.37**
Average												**-629.89**	**-0.39**

```
$title
Appendix C
An International Steam Coal Trade Model

$onText
The Coal market models interrrelated coal markets.
Price will equlibriate supply and demand.
Tax will be itroduced to control over quantities traded.

Shanthiny Kathiresu, NMBU, 2018

$offText

set
   tt total time horizon   /2014,2020,2025,2030,2035,2040/
   e  exporting countries  /indonesia,australia,SAfrica,RFederation,UStates,colo»
mbia,kazakshtan,poland,Nkorea,mongolia,ROW/
   i  importing countries  /china,india,korea,germany,UK,turkey,malaysia,philipi»
nes,thailands,spain,italy,japan,ROW/
   ;

parameters
ad             constant determining initial demand
epsilond       demand elasticity
av             constant determining initial supply
epsilonv       Supply elasticity
p_e            initial price before carbon tax in dollars
t              Carbon tax
xd_0(i)        Initial Demand of coal in metric ton
xtv_0(e)       Initial Supply of coal in metric ton
;


p_e = 60;
t = 0
;

Table epsilonv(e,tt) supply elasiticity data
                   2014   2020    2025   2030   2035   2040
  indonesia        0.3    0.4     0.5    0.6    0.7    0.8
  australia        0.3    0.4     0.5    0.6    0.7    0.8
  SAfrica          0.3    0.4     0.5    0.6    0.7    0.8
  RFederation      0.3    0.4     0.5    0.6    0.7    0.8
  UStates          0.3    0.4     0.5    0.6    0.7    0.8
  colombia         0.3    0.4     0.5    0.6    0.7    0.8
  kazakshtan       0.3    0.4     0.5    0.6    0.7    0.8
  poland           0.3    0.4     0.5    0.6    0.7    0.8
  Nkorea           0.3    0.4     0.5    0.6    0.7    0.8
  Mongolia         0.3    0.4     0.5    0.6    0.7    0.8
  ROW              0.3    0.4     0.5    0.6    0.7    0.8
  ;

Table epsilond(i,tt) demand elasticity data
                 2014   2020    2025   2030   2035   2040
 china           -0.1   -0.1    -0.2   -0.3   -0.4   -0.5
 india           -0.1   -0.1    -0.2   -0.3   -0.4   -0.5
 korea           -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
```

```
germany          -0.3   -0.3    -0.4   -0.4   -0.5   -0.6
UK               -0.3   -0.3    -0.4   -0.4   -0.5   -0.6
turkey           -0.2   -0.2    -0.3   -0.4   -0.5   -0.6
malaysia         -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
philipines       -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
thailands        -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
spain            -0.2   -0.3    -0.4   -0.4   -0.5   -0.6
italy            -0.2   -0.3    -0.4   -0.4   -0.5   -0.6
japan            -0.2   -0.2    -0.3   -0.4   -0.5   -0.6
ROW              -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
;

Table ssdat(e,tt) supply data
                   2014   2020    2025   2030   2035   2040
 indonesia         484    525     559    592    626    660
 australia         248    255     262    268    274    280
 SAfrica           257    252     249    245    241    237
 RFederation       188    190     192    194    196    198
 UStates           773    680     603    526    448    371
 colombia          84     83      82     81     80     80
 kazakshtan        89     90      90     90     91     91
 poland            61     56      52     47     43     39
 Nkorea            31     32      33     34     35     36
 Mongolia          11     11      12     12     12     13
 ROW               3781   3896    3989   4080   4165   4245
 ;

Table dddat(i,tt) demand data
                 2014   2020    2025   2030   2035   2040
china            3279   3181    3099   3017   2935   2853
india            740    900     1033   1166   1299   1433
korea            100    87      77     66     56     45
germany          47     39      31     24     17     10
UK               42     34      28     22     16     9
turkey           26     21      17     14     10     6
malaysia         24     30      36     41     46     51
philipines       20     25      30     34     38     43
thailands        17     21      25     29     33     36
spain            22     18      15     11     8      5
italy            17     14      11     9      6      4
japan            137    125     116    106    97     87
ROW              1536   1580    1617   1654   1691   1728
;

ad(i,tt)= dddat(i,tt)/(p_i**epsilond(i,tt));


av(e,tt)= ssdat(e,tt)/(p_e**epsilonv(e,tt));

display ad, av;

variables
XD(i,tt)      demand of coal in Mt
XT(e,tt)      Supply of coal in Mt
TXD(tt)       total demand of coal in Mt
TXT(tt)       total supply of coal in Mt
PK(tt)        Consumer price per Mt
```

```
PV(tt)        Producer price per Mt
OPT           Artificial objective
;

Positive Variables XD, XT,TXD,TXT, PK, PV;

PK.LO(tt) = 0.01 ;
PV.LO(tt) = 0.01 ;


equations
XDD(i,tt)       demand of coal in Mt
XTT(e,tt)       supply of coal in Mt
TXDD(tt)        Total demand of coal in Mt
TXTT(tt)        Total supply of coal in Mt
MARKET(tt)      market equlibruim
OPTI            Artificial objective
;

XDD(i,tt)..   XD(i,tt)=E=ad(i,tt)*(PK(tt)**epsilond(i,tt));

XTT(e,tt)..   XT(e,tt)=E=av(e,tt)*(PK(tt)**epsilonv(e,tt));


TXDD(tt)..   TXD(tt)=E= sum(i,XD(i,tt));
TXTT(tt)..   TXT(tt)=E= sum(e,XT(e,tt));

MARKET(tt).. TXD(tt)=E=TXT(tt);

OPTI.. OPT =E= 0;

model cmm  / all / ;
solve cmm using NLP maximizing OPT;

```

```
set
   tt total time horizon   /2014,2020,2025,2030,2035,2040/
   e  exporting countries  /indonesia,australia,SAfrica,RFederation,UStates,colo»
mbia,kazakshtan,poland,Nkorea,mongolia,ROW/
   i  importing countries  /china,india,korea,germany,UK,turkey,malaysia,philipi»
nes,thailands,spain,italy,japan,ROW/
   ;

parameters
ad             constant determining initial demand
epsilond       demand elasticity
av             constant determining initial supply
epsilonv       Supply elasticity
p_e            initial price before carbon tax in dollars
t              Carbon tax
xd_0(i)        Initial Demand of coal in metric ton
xtv_0(e)       Initial Supply of coal in metric ton
;

p_e = 60;
t = 0;

Table epsilonv(e,tt) supply elasiticity data

                    2014   2020    2025   2030   2035   2040
  indonesia         0.3    0.4     0.5    0.6    0.7    0.8
  australia         0.3    0.4     0.5    0.6    0.7    0.8
  SAfrica           0.3    0.4     0.5    0.6    0.7    0.8
  RFederation       0.3    0.4     0.5    0.6    0.7    0.8
  UStates           0.3    0.4     0.5    0.6    0.7    0.8
  colombia          0.3    0.4     0.5    0.6    0.7    0.8
  kazakshtan        0.3    0.4     0.5    0.6    0.7    0.8
  poland            0.3    0.4     0.5    0.6    0.7    0.8
  Nkorea            0.3    0.4     0.5    0.6    0.7    0.8
  Mongolia          0.3    0.4     0.5    0.6    0.7    0.8
  ROW               0.3    0.4     0.5    0.6    0.7    0.8
  ;

Table epsilond(i,tt) demand elasticity data
                   2014   2020    2025   2030   2035   2040
 china             -0.1   -0.1    -0.2   -0.3   -0.4   -0.5
 india             -0.1   -0.1    -0.2   -0.3   -0.4   -0.5
 korea             -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
 germany           -0.3   -0.3    -0.4   -0.4   -0.5   -0.6
 UK                -0.3   -0.3    -0.4   -0.4   -0.5   -0.6
 turkey            -0.2   -0.2    -0.3   -0.4   -0.5   -0.6
 malaysia          -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
 philipines        -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
 thailands         -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
 spain             -0.2   -0.3    -0.4   -0.4   -0.5   -0.6
 italy             -0.2   -0.3    -0.4   -0.4   -0.5   -0.6
 japan             -0.2   -0.2    -0.3   -0.4   -0.5   -0.6
 ROW               -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
;

Table ttdat(e,tt) tax data
                  2014   2020  2025   2030   2035   2040
```

```
  indonesia        0    0       0       0     0      0
  australia        0    10      15      20    25     30
  SAfrica          0    0       0       0     0      0
  RFederation      0    0       0       0     0      0
  UStates          0    0       0       0     0      0
  colombia         0    0       0       0     0      0
  kazakshtan       0    0       0       0     0      0
  poland           0    0       0       0     0      0
  Nkorea           0    0       0       0     0      0
  Mongolia         0    0       0       0     0      0
  ROW              0    0       0       0     0      0
 ;

Table ssdat(e,tt) supply data
                   2014   2020    2025   2030   2035   2040
  indonesia        484    525     559    592    626    660
  australia        248    255     262    268    274    280
  SAfrica          257    252     249    245    241    237
  RFederation      188    190     192    194    196    198
  UStates          773    680     603    526    448    371
  colombia         84     83      82     81     80     80
  kazakshtan       89     90      90     90     91     91
  poland           61     56      52     47     43     39
  Nkorea           31     32      33     34     35     36
  Mongolia         11     11      12     12     12     13
  ROW              3781   3896    3989   4080   4165   4245
  ;

Table dddat(i,tt) demand data
                 2014   2020    2025   2030   2035   2040
 china           3279   3181    3099   3017   2935   2853
 india           740    900     1033   1166   1299   1433
 korea           100    87      77     66     56     45
 germany         47     39      31     24     17     10
 UK              42     34      28     22     16     9
 turkey          26     21      17     14     10     6
 malaysia        24     30      36     41     46     51
 philipines      20     25      30     34     38     43
 thailands       17     21      25     29     33     36
 spain           22     18      15     11     8      5
 italy           17     14      11     9      6      4
 japan           137    125     116    106    97     87
 ROW             1536   1580    1617   1654   1691   1728
;

ad(i,tt)= dddat(i,tt)/(p_i**epsilond(i,tt));


av(e,tt)= ssdat(e,tt)/(p_e**epsilonv(e,tt));

display ad, av;

variables
XD(i,tt)      demand of coal in Mt
XT(e,tt)      Supply of coal in Mt
TXD(tt)       total demand of coal in Mt
TXT(tt)       total supply of coal in Mt
```

```
PK(tt)        Consumer price per Mt
PV(tt)        Producer price per Mt
OPT           Artificial objective
;

Positive Variables XD, XT,TXD,TXT, PK, PV;

PK.LO(tt) = 30 ;


equations
XDD(i,tt)      demand of coal in Mt
XTT(e,tt)      supply of coal in Mt
TXDD(tt)       Total demand of coal in Mt
TXTT(tt)       Total supply of coal in Mt
MARKET(tt)     market equlibruim
OPTI           Artificial objective
;

XDD(i,tt)..   XD(i,tt)=E=ad(i,tt)*(PK(tt)**epsilond(i,tt));

XTT(e,tt)..   XT(e,tt)=E=av(e,tt)*((PK(tt)-ttdat(e,tt))**epsilonv(e,tt));


TXDD(tt)..   TXD(tt)=E= sum(i,XD(i,tt));
TXTT(tt)..   TXT(tt)=E= sum(e,XT(e,tt));

MARKET(tt).. TXD(tt)=E=TXT(tt);

OPTI.. OPT =E= 0;

model cmm  / all / ;
solve cmm using NLP maximizing OPT;
```

```
set
   tt total time horizon   /2014,2020,2025,2030,2035,2040/
   e  exporting countries  /indonesia,australia,SAfrica,RFederation,UStates,colo»
mbia,kazakshtan,poland,Nkorea,mongolia,ROW/
   i  importing countries  /china,india,korea,germany,UK,turkey,malaysia,philipi»
nes,thailands,spain,italy,japan,ROW/
   ;

parameters
ad             constant determining initial demand
epsilond       demand elasticity
av             constant determining initial supply
epsilonv       Supply elasticity
p_e            initial price before carbon tax in dollars
t              Carbon tax
xd_0(i)        Initial Demand of coal in metric ton
xtv_0(e)       Initial Supply of coal in metric ton
;

p_e = 60;
t = 0;

Table epsilonv(e,tt) supply elasiticity data

                     2014   2020    2025   2030   2035   2040
  indonesia          0.3    0.4     0.5    0.6    0.7    0.8
  australia          0.3    0.4     0.5    0.6    0.7    0.8
  SAfrica            0.3    0.4     0.5    0.6    0.7    0.8
  RFederation        0.3    0.4     0.5    0.6    0.7    0.8
  UStates            0.3    0.4     0.5    0.6    0.7    0.8
  colombia           0.3    0.4     0.5    0.6    0.7    0.8
  kazakshtan         0.3    0.4     0.5    0.6    0.7    0.8
  poland             0.3    0.4     0.5    0.6    0.7    0.8
  Nkorea             0.3    0.4     0.5    0.6    0.7    0.8
  Mongolia           0.3    0.4     0.5    0.6    0.7    0.8
  ROW                0.3    0.4     0.5    0.6    0.7    0.8
  ;

Table epsilond(i,tt) demand elasticity data
                    2014   2020    2025   2030   2035   2040
 china              -0.1   -0.1    -0.2   -0.3   -0.4   -0.5
 india              -0.1   -0.1    -0.2   -0.3   -0.4   -0.5
 korea              -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
 germany            -0.3   -0.3    -0.4   -0.4   -0.5   -0.6
 UK                 -0.3   -0.3    -0.4   -0.4   -0.5   -0.6
 turkey             -0.2   -0.2    -0.3   -0.4   -0.5   -0.6
 malaysia           -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
 philipines         -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
 thailands          -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
 spain              -0.2   -0.3    -0.4   -0.4   -0.5   -0.6
 italy              -0.2   -0.3    -0.4   -0.4   -0.5   -0.6
 japan              -0.2   -0.2    -0.3   -0.4   -0.5   -0.6
 ROW                -0.2   -0.2    -0.3   -0.4   -0.4   -0.5
;

Table ttdat(e,tt) tax data
                   2014   2020  2025   2030   2035   2040
```

```
  indonesia        0    10      15     20     25     30
  australia        0    10      15     20     25     30
  SAfrica          0    10      15     20     25     30
  RFederation      0    10      15     20     25     30
  UStates          0    10      15     20     25     30
  colombia         0    10      15     20     25     30
  kazakshtan       0    10      15     20     25     30
  poland           0    10      15     20     25     30
  Nkorea           0    10      15     20     25     30
  Mongolia         0    10      15     20     25     30
  ROW              0    0       0      0      0      0
 ;

Table ssdat(e,tt) supply data
                   2014   2020    2025   2030   2035   2040
  indonesia        484    525     559    592    626    660
  australia        248    255     262    268    274    280
  SAfrica          257    252     249    245    241    237
  RFederation      188    190     192    194    196    198
  UStates          773    680     603    526    448    371
  colombia         84     83      82     81     80     80
  kazakshtan       89     90      90     90     91     91
  poland           61     56      52     47     43     39
  Nkorea           31     32      33     34     35     36
  Mongolia         11     11      12     12     12     13
  ROW              3781   3896    3989   4080   4165   4245
  ;

Table dddat(i,tt) demand data
                  2014   2020    2025   2030   2035   2040
 china            3279   3181    3099   3017   2935   2853
 india            740    900     1033   1166   1299   1433
 korea            100    87      77     66     56     45
 germany          47     39      31     24     17     10
 UK               42     34      28     22     16     9
 turkey           26     21      17     14     10     6
 malaysia         24     30      36     41     46     51
 philipines       20     25      30     34     38     43
 thailands        17     21      25     29     33     36
 spain            22     18      15     11     8      5
 italy            17     14      11     9      6      4
 japan            137    125     116    106    97     87
 ROW              1536   1580    1617   1654   1691   1728
;

ad(i,tt)= dddat(i,tt)/(p_i**epsilond(i,tt));


av(e,tt)= ssdat(e,tt)/(p_e**epsilonv(e,tt));

display ad, av;

variables
XD(i,tt)      demand of coal in Mt
XT(e,tt)      Supply of coal in Mt
TXD(tt)       total demand of coal in Mt
TXT(tt)       total supply of coal in Mt
```

```
PK(tt)         Consumer price per Mt
PV(tt)         Producer price per Mt
OPT            Artificial objective
;

Positive Variables XD, XT,TXD,TXT, PK, PV;

PK.LO(tt) = 30 ;


equations
XDD(i,tt)       demand of coal in Mt
XTT(e,tt)       supply of coal in Mt
TXDD(tt)        Total demand of coal in Mt
TXTT(tt)        Total supply of coal in Mt
MARKET(tt)      market equlibruim
OPTI            Artificial objective
;

XDD(i,tt)..   XD(i,tt)=E=ad(i,tt)*(PK(tt)**epsilond(i,tt));

XTT(e,tt)..   XT(e,tt)=E=av(e,tt)*((PK(tt)-ttdat(e,tt))**epsilonv(e,tt));


TXDD(tt)..   TXD(tt)=E= sum(i,XD(i,tt));
TXTT(tt)..   TXT(tt)=E= sum(e,XT(e,tt));

MARKET(tt).. TXD(tt)=E=TXT(tt);

OPTI.. OPT =E= 0;

model cmm  / all / ;
solve cmm using NLP maximizing OPT;
```

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