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Australian carbon tax – winners and losers*

Sam Meng
Mahinda Siriwardana
Judith McNeill

School of Business, Economics and Public Policy
Faculty of the Professions,
University of New England,

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School of Business, Economics and Public Policy
Faculty of the Professions
University of New England
Armidale NSW 2351
Tel: 02 6773 2432
Fax: 02 6773 3596
Email: beppwps@une.edu.au

AUTHOR CONTACT DETAILS:
Sam Meng, xmeng3@une.edu.au
Institute of Rural Futures
University of New England
Armidale NSW 2351

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Sam Meng
Xmeng3@une.edu.au
Phone: (02) 6773 5142
Institute of Rural Futures
University of New England

Mahinda Siriwardana
asiriwar@une.edu.au
School of Business, Economics and Public Policy
Faculty of the Professions
University of New England

Judith McNeill
jmcneill@une.edu.au
Institute of Rural Futures
University of New England

Tel: 02 6773 2432 • Fax: 02 6773 3596
Email: beppwps@une.edu.au

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ABSTRACT

With the Opposition party and various interest groups objecting to the Australian Government's proposal of a carbon tax, public opinion about pricing carbon is divided. Some of the disagreement may be due to misunderstandings about the effects of the policy. In an effort to clarify some of the issues, this paper reports the simulated effects of a carbon tax of $23 per tonne of carbon dioxide on different economic agents, with and without a compensation policy. We employ a computable general equilibrium (CGE) model with an environmentally-extended Social Accounting Matrix (SAM). According to the simulation results, the carbon tax can cut emissions effectively, but will cause a mild economic contraction. The proposed compensation plan has little impact on emission cuts while significantly mitigating the negative effect of a carbon tax on the economy. At the sectoral level, brown coal electricity, black coal electricity and the brown coal mining sectors are big losers. The effect on various employment occupations is mildly negative, ranging from -0.6% to -1.7%, with production and transport workers worst affected. Regarding household utility projections, low income households suffer more from a carbon tax and benefit more from the proposed compensation policy. However, the commonly used equivalent variation (EV) tends to reverse this conclusion.

Keywords Carbon tax, CGE modelling, macro economy, sectoral effect, distributional effect

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1. Introduction

Although Australia' s greenhouse gas emissions are relatively low – accounting for around 1.5% of global carbon emissions, its emissions per capita are the highest in the world (World Resources Institute, 2010). The high emissions per capita in Australia are partly due to a small population and abundant cheap energy resources, particularly brown and black coal, which have very high emission intensity. The Gillard government has committed to reducing carbon emissions by 80% below 2000 levels by 2050 and announced that it will introduce a carbon tax from July 1st 2012.

The Government's proposal triggered strong resistance from Opposition parties and various interest groups. They claim that a carbon tax will cause a large economic contraction, high unemployment, higher electricity prices and the demise of the coal industry. Certainly, public opinion about a carbon tax is divided. Amid anti- and pro-carbon tax rallies and demonstrations, speculation about the effects of the proposed tax varies widely.

To support the carbon tax proposal, the Australian Treasury has undertaken comprehensive modelling. The Treasury has employed a suite of different models, including two CGE models, one input-output model and a number of micro models for the electricity and road transport sectors (the details about the Treasury modelling will be provided in section 2). The results from this modelling depend on the parameters and assumptions used (as with all models), but given the intricacy and complexity of the modelling, these are not easy to articulate and evaluate. Similarly, the results will depend on the degree of integration and compatibility of the different models, again, matters not assessed easily. Perhaps as a result of this, and certainly because of the way the politics has played out, Australians are sceptical about the modelling results, with the Opposition leader stating openly that the carbon tax proposal is based on a lie[1].

In this paper we adopt a different approach. To single out the effects of a carbon tax, we constructed a single country static CGE model. In companion, an environmentally-extended micro Social Accounting Matrices (SAM) is developed. Based on the simulation results, this paper purports to uncover the short-run implications of a carbon tax policy for

[1] see, for example, "Bad tax based on a lie: Tony Abbott" in *The Australian*, September 15, 2011; "Carbon tax is based on a lie" in *The Telegraph*, August 18, 2011

carbon emission reduction, the macro-economy, different sectors, occupation groups, and household income deciles.

The balance of the paper is organised as follows. Section 2 reviews previous CGE modelling on carbon emissions in Australia. Section 3 describes the model structure and database for the simulations. Section 4 presents and discusses the simulation results with special reference to different economic groups. Section 6 concludes the paper.

2. Previous studies

The effect of a carbon tax is a well researched topic internationally. Notable research includes Beausejour et al. (1992), Hamilton and Cameron (1994), Zhang (1998), Labandeira et al. (2004), Wissema and Dellink (2007), and Devrajan et al. (2011). Due to the space limitations, we review studies with an Australian context. A comprehensive review of international modelling literature is given in Siriwardana et al. (2011).

As early as in 1993, McDougall at the Centre of Policy Studies simulated the effects of a carbon tax using an enhanced ORANI model incorporating a detailed representation of the Australian energy sector. McDougall (1993a) considered the short-run effects of a carbon tax of $25 per tonne of carbon dioxide which was designed to achieve the Toronto target of a 20 per cent reduction in carbon dioxide emissions below the 1988 level by 2005. Following Adams and Dixon (1992), he included seven fossil fuels in the model, namely, black coal, brown coal (lignite), brown coal (briquettes), liquefied petroleum gas, natural gas, petroleum and coal products, and gas. The database is an enhanced ORANI database including 1986-1987 I-O tables by the ABS and energy use and emission data from ABARE. The model is very rigid in that it did not allow flexibility in fuel mix or energy use in production. A very restrictive short-run closure is employed, in which many variables such as the capital stock, money wage rate, exchange rate, and aggregate domestic absorption in real terms (e.g. household consumption, government spending and investment) are assumed fixed (exogenous). The results show that the carbon tax raised output prices, especially for energy-intensive commodities, which results in a loss of competitiveness in trade-exposed industries. GDP fell by 0.9 per cent and employment fell by 1.2 per cent and the real wage rose by 1.9 per cent. Some sectors are badly affected by the carbon tax, with metal production contracting by 6.5 per cent, mining by 5.8 per cent, and electricity, gas and water by 3.4 per cent. To reduce the negative effect of the carbon tax and maintain the employment level unchanged, a lower wage policy is suggested for the government.

McDougall (1993b) used an ORANI-E model to compare the effect of a carbon tax, an energy tax and fuel tax. The database is similar to that for McDougall (1993a), but electricity was disaggregated into six types according to the electricity generation technology used. The model structure had changed substantially to allow substitution between energy inputs, between capital and composite energy, and among electricity generation technologies. The rates of three taxes –tax on carbon emissions, tax on fossil fuel and tax on petroleum products are chosen so that the revenue collected from each tax is equivalent to 0.5 per cent of base case GDP[2]. Based on the simulation results, it is concluded that, while a carbon tax would be the theoretically ideal instrument for carbon dioxide abatement, an energy tax applying to all fossil fuels would also be reasonably effective. However, a tax on petroleum products is much less effective in cutting greenhouse gases and considerably more costly than either an energy or carbon tax.

Based on the Monash Multi-Regional Forecasting (MMRF) model, The Centre of Policy Studies developed the MMRF-Green model to address the carbon emissions issue in Australia. Although MMRF-Green is mainly employed in analysing carbon emissions trading (e.g. Allen consulting group, 2000; Adams, 2007), it is used in the Treasury modelling on carbon taxes, so we briefly discuss it here. MMRF-Green is a dynamic, single country, multi-regional model. There are 52 industry sectors, 56 commodities, and eight States (or 57 sub-States). Each State has a single representative household and a regional government. There is also a federal government. Not to change the CGE core substantially, the substitution effect between energy inputs, between electricity generations, and between transports are realized through the different size of various input saving technological changes for each commodity. This is a clever alternative expression of substitution effect, but it is only workable in a dynamic model and in the long run. In a static simulation when technology is assumed unchanged, all these substitution effects will disappear. There are five emission activities. Four of them cover emissions from combustion of black coal, brown coal, natural gas and petroleum products and the other one covers the emissions from fugitive and non-combustion agricultural sources. The emission data were obtained from the National Greenhouse Gas Inventory (NGGI) summary report by the Australian federal government.

[2] McDougall though this setting would assist comparison of three policies, but with this setting, both the environment effect and economic effect will be different for each tax policy, so it is hard to compare their efficiency (the cost of carbon abatement).

The global trade and environment model (GTEM) developed by ABARE was also used in the Treasury modelling. GTEM is a dynamic multi-country model, derived from the MEGABARE model and the static Global Trade Analysis Project (GTAP) model. The GTEM uses different production functions for electricity, and iron and steel industries. For these two sectors, the output is produced from an intermediate input bundle and a technology bundle using a Leontief function. The intermediate input bundle is a Leontief combination of different kinds of goods, each of which is a CES combination of domestic good and imported good and the latter in turn is a CES combination of imports from different regions. The technology bundle is formed by different kinds of technology using a CRESH (constant ratio of elasticities of substitution, homothetic) function and each technology uses different technology inputs in fixed proportion (Leontief function). The CRESH function is similar to a CES function but it allows different elasticities of substitution between pairs of inputs. For other industries, the producer output is a Leontief combination of the intermediate input bundle and the energy factor bundle. The former is a three-layer CES combination of different goods while the latter is a CES combination of the primary factor bundle and energy bundle. The primary factor bundle includes capital, labour, land and natural resources, and the energy bundle includes coal gas, petroleum products and electricity. Both bundles are formed by CES functions. The data in GTEM are mainly from the GTAP database, but data on carbon emissions from fossil fuel combustion are sourced from the International Energy Agency (IEA) and data on non-combustion emissions is compiled from the United Nations Framework Convention on Climate Change's (UNFCCC) national inventory figures for individual countries, or estimated by ABARE.

To accompany the proposed carbon tax in Australia, the Treasury conducted large-scale carbon price modelling. The Treasury modelling is very ambitious and complex. It consists of a number of models. The GTEM is employed to provide the international economic and emissions context for modelling of the Australian economy. The MMRF is used to project the national, regional and sectoral impact of carbon taxes. With the world carbon price paths being set, the model for the assessment of greenhouse-gas-induced climate change (MAGICC) is used to estimate the greenhouse gas atmospheric concentration levels. The ROAM model by ROAM Consulting and the SKM MMA model by the Sinclair Knight Merz group are used to provide detailed bottom-up information of the Australian electricity generation sector. The Energy sector model (ESM) by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) is used to model the road transport sector. The price revenue incidence simulation model and distribution model (PRISMOD.DIST) are used to examine the distributional implication of carbon pricing for households. The modelling

framework and results are included in the Treasury report: *Strong growth, low pollution – modelling a carbon price* (The Treasury, 2011). Overall, the Treasury modelling results with two starting carbon prices in 2012-13(A$20 and A$30) are very positive: the economy continues to grow strongly and carbon emissions are reduced substantially. It is projected that, without a carbon tax, Australian GNI per person by 2050 is around 60 per cent higher and emissions are 74 per cent higher than today; with a carbon price, the GNI per person is at least 56 per cent higher and the emissions fall by 80 per cent. In the core policy scenario (starting carbon price in 2012-13 at A$20), around 1.6 million jobs are projected to be created to 2020 and a further 4.4 million to 2050; average weekly household expenditure will be higher by around $9.90 in 2012-13, of which electricity accounts for around $3.30 and gas around $1.50. However, the Treasury modelling may have limitations. One is that, since so many models are used, the accuracy of results is subject to the degree of integration among the models and the way they are integrated.

While the GTEM results provide an international setting for the MMRF, the feedback effects of an Australian carbon tax on the world economy is absent in the modelling. In the integration of MMRF with SKM MMA and ROAM, the iteration process provides a good way to achieve consistent results on the supply of, and demand for, electricity generation and road transport, but the price setting is crucial in the integration and it should be endogenously determined by a CGE model (e.g. through MMRF here). In the report, there is no clear description of price setting in the iteration process, but reading between the lines gives us the impression that the electricity prices are determined by the partial equilibrium models SKM MMA and ROAM[3]. Another limitation is that, there are numerous assumptions used in the simulation, the change of key assumptions may alter the simulation results substantially. While the dynamic nature of MMRF demands numerous assumptions about the growth trend of the future economy, a micro model (e.g. ESM, SKM MMA and ROAM) needs very specific assumptions. As acknowledged in the Treasury report (The Treasury, 2011), a large number of assumptions are made about global carbon prices, productivity and technological changes, energy efficiency and options, and household taste changes. Although various sources are used, the assumptions based on the projection into the future 10 to 38 years can only be speculative. Consequently, they are subject to large revisions in the future and so are the modelling results.

[3] In the Treasury report (2011, p148), the description about 'Fuel prices' in the left panel of Table A4 says: 'Electricity price (from SKM MMA and ROAM)'.

3. Model Structure and database

Because the purpose of this study is to assess the effect of a carbon tax policy, instead of forecasting the performance of the whole economy overtime under the tax, the model developed for this study is a static CGE model, based on ORANI-G (Horridge, 2000). The comparative static nature of ORANI-G helps to single out the effect of carbon tax policies while keeping other factors being equal. The model employs standard neoclassical economic assumptions: a perfectly competitive economy with constant returns to scale, cost minimisation for industries and utility maximisation for households, and continuous market clearance. In addition, zero profit conditions are assumed for all industries because of perfect competition in the economy.

The Australian economy is represented by 35 sectors which produce 35 goods and services, one representative investor, ten household groups, one government and nine occupation groups. The final demand includes household, investment, government and exports. With the exception of the production function, we adopted the functions in the multi-households version of ORANI-G.

Overall, the production function is a five-layer nested Leontief-CES function. As in the ORANI model, the top level is a Leontief function describing the demand for intermediate inputs and composite primary factors and the rest is various CES functions at lower levels. However, we have two important modifications to demand functions for electricity generation and energy use.

First, we classify the electricity generation in the economy into five types according to the energy sources used, namely electricity generated from black coal, brown coal, oil, gas and renewable resources. Once generated, the electricity commodity is homogeneous, so there must be a large substitution effect among five types of electricity generation. So we use a CES function to form a composite electricity generation, instead of putting each type of electricity generation in the top level of Leontief function as Adams et al. (2000) did. In this approach, we allow the electricity generation to shift from high carbon-emission generators (e.g. brown coal electricity) to low carbon-emission generators (e.g. gas and renewable electricity).

Second, we argue that energy efficiency is positively related to the investment on energy-saving devices, e.g. well-insulated housing uses less energy for air-conditioning. So we

assume that there are limited substitution effects between energy goods and capital and that the size of substitution effect depends on the cost and the availability of energy-saving technology, which is reflected in the value of the substitution elasticity. Similar treatment of energy inputs has been used by many researchers such as Burniaux et al. (1992), Zhang (1998), Ahammad and Mi (2005), and Devarajan et al. (2009).

Carbon emissions in the model are treated as proportional to the energy inputs used and/or to the level of activity. Based on the carbon emissions accounting published by the Department of Climate Change and Energy Efficiency, we treat carbon emissions in three different ways. First, the stationary fuel combustion emissions are tied with inputs (the amount of fuel used). Based on the emissions data, the input emission intensity – the amount of emissions per dollar of inputs (fuels) – is calculated as a coefficient, and then the model computes stationary emissions by multiplying the amount of input used by the emission intensity. Second, the industry activity emissions are tied with the output of the industry. The output emission intensity coefficient is also pre-calculated from the emission matrix and it is multiplied by the industry output to obtain the activity emissions by the industry. Third, the activity emissions by household sector are tied with the total consumption of the household sector. The total consumption emissions are obtained by the amount of household consumption times the consumption emission intensity coefficient pre-calculated from the emission matrix. All three types of emission intensity are assumed fixed in the model to reflect unchanged technology and household preferences.

Some researchers (e.g. Centre of Policy Studies, 2008) argue that emission intensity may change with different carbon price levels and consequently an equation is designed to show the negative relationship between the change in emission intensity and that in carbon price. We did not adopt this approach for activity emissions, nor for stationary emissions. For activity emissions, this reasoning sounds reasonable for a cost-minimizing firm. However, the sources of activity emissions are quite complex and the level of activity emissions is hard for the government to detect, so the firm may not respond well to a carbon price. For fuel combustion emissions, it is true that firms will use more of low emission inputs in the face of a carbon tax so the emissions should decrease, but the emission intensity could not decrease because of the slow progress of technology in this

area[4]. We further argue that it is not necessary to change emission intensity in our model. One reason is that the substitution effects between high and low emission fuels have already been embedded in the CES function for energy inputs, so it is not necessary to duplicate these substitution effects by changing emission intensity. The other is that the firms' shifting between different energy inputs comes at a cost. For example, using lower emission energy inputs, for example, black coal, may incur higher cost due to its higher price than that of brown coal or additional transportation cost compared with using brown coal nearby. The equipment for coal electricity generation may need substantial alteration so that it can be used as gas electricity generation. This cost has already been taken care of in the elasticity values for the CES function between composite energy and capital.

The functions for final demands are similar to those in the ORANI model (Dixon et al., 1982). For example, the investment demand is a nested Leontief-CES function, the household demand function is a nested LES-CES function. Export demand is dependent on the price of domestic goods, and government demand follows household consumption. However, unlike the assumption of exogenous household either total or supernumerary consumption in ORANI-G, we assume that total consumption is proportional to total income for each household group.

The main data used for the modelling include input-output data, carbon emission data, and various behaviour parameters. We briefly discuss each in turn.

The input-output data used in this study are from Australian Input-output Tables 2004-2005, published by ABS. There are 109 sectors (and commodities) in the original I-O tables. For the purpose of this study, we disaggregate the energy sectors and aggregate other sectors to form 35 sectors (and commodities). Specifically, the disaggregation is as follows: the coal sector is split to black coal and brown coal sectors; the oil and gas sector is separated to the oil sector and gas sector; the petroleum and coal products sector becomes four sectors – auto petrol, kerosene, LPG and other petrol; the electricity supply sector is split to five electricity generation sectors – black coal electricity, brown coal electricity, oil electricity, gas electricity and renewable electricity – and one electricity distributor – the commercial electricity sector. This disaggregation is based on the energy use data published by ABARE. Utilizing the household expenditure survey data by ABS (2004), the household income and consumption data were disaggregated to 10 household

[4] In an earlier working paper of the Centre of Policy Studies, (Adams, et al., 2000) stated, " so far as we know, no advance of this type is likely to be widely adopted with the next 20 years."

groups according to income level and labour supply was disaggregated to 9 occupation groups.

The carbon emissions data are based on the greenhouse gas emission inventory 2005 published by the Department of Climate Change and Energy Efficiency. There are two kinds of emissions: energy emissions and other emissions. The former is mainly stationary energy emissions (emissions from fuel combustion), for which the Australian Greenhouse Emissions Information System provided emission data by sector and by fuel type. We map these data into the 35 sectors (and commodities) in our study. Based on this emission matrix and the absorption (input demand) matrix for industries, we can calculate the emission intensities by industry and by commodity – input emission intensities. The other emissions – the total emissions minus the stationary emissions – are treated as activity emissions and they are assumed directly related to the level of output in each industry. Based on the total output for each industry in the MAKE matrix of the I-O tables, we can calculate the output emission intensities. We assume the activity emissions by households are proportional to household consumption and, using the data on household consumption by commodity in I-O table, we can calculate the consumption emission intensities.

Most of the behavioural parameters in the model are adopted from ORANI-G, e.g. the Armington elasticities, the primary factor substitution elasticity, export demand elasticity, and the elasticity between different types of labour. The changed or new elasticities include the household expenditure elasticity, the substitution elasticities between different electricity generations, between different energy inputs and between composite energy and capital. Since we included in the model 10 household groups and 35 commodities, we need the expenditure elasticities for each household group and for each of the commodities. Cornwell and Creedy (1997) estimated Australian household demand elasticities by 30 household groups and 14 commodities. We adopted these estimates and mapping into the classification in our model. Due to the aggregation and disaggregation as well as the change of household consumption budget share, we found the share weighted average elasticity (Engel aggregation) was not unity. However, the Engel aggregation must be satisfied in a CGE model in order to obtain consistent simulation results. We adjusted (standardised) the elasticity values to satisfy the Engel aggregation.

As stated earlier, the substitution effect between different electricity generations is assumed perfect, so we assign a large value of 50 to their substitution elasticity. The

substitution effects among energy inputs and between composite energy and capital are considered very small, so small elasticity values between 0.1 and 0.6 are commonly used in the literature. In our model, we assume the cost of energy-saving investment is very high given the current technology situation and thus there is a very limited substitution effect between capital and composite energy. Consequently, we assign a value of 0.1 for this substitution elasticity. There are two levels of substitution among energy goods in our model. At the bottom level, the energy inputs have a relatively high similarity, so we assign a value of 0.5 for substitution between black and brown coal, between oil and gas and between various types of petroleum. At the top level, we assume the substitution effect between various types of composite energy inputs is very small, and assign a value of 0.1.

4. Simulation Analysis

The purpose of this study is to gauge the impact of an Australian carbon tax policy on the environment, the economy and various economic agents, so the level of carbon tax is chosen to reflect the proposed government policy, namely, $23 per tonne of carbon dioxide emissions with the exemption of agriculture, road transport, and household sectors. However, the government compensation plan is quite complicated. There are various levels of compensation to a number of industries such as manufactures and exporters. For household, the government proposed reform of tax thresholds and various family tax benefits like clean energy advance, clean energy supplement and single income family supplement. Not to complicate the study, we only impose a simple revenue-neutral compensation for households: all carbon tax revenue is transferred in lump sum equally to all household deciles.

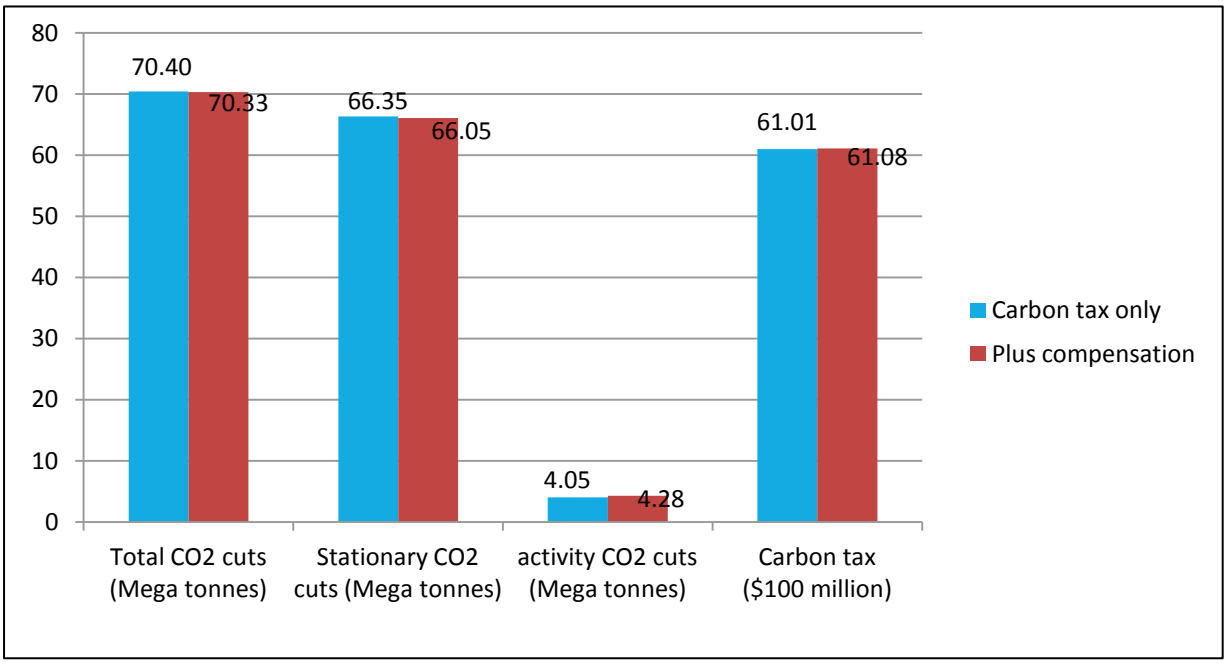
This study simulates and compares two scenarios: carbon tax only and with compensation. This study is mainly concerned with the short run effects, so a short-run macroeconomic closure is assumed, e.g. fixed real wages and capital stocks, free movement of labour but immobile capital between sectors, and government expenditure to follow household consumption. Unless specified, all projections reported in this paper are shown in percentage changes.

4.1 Macroeconomic/environmental Perspective

The simulated macroeconomic and environment effects are reported in terms of emission reduction and carbon tax revenue, GDP and GNP, payment to primary factors, government

income and expenditure, and real household consumption and international trade, as shown in Figures 1 to 5.

Figure 1 Emission reduction and carbon tax revenue



A glance at Figure 1 manifests that a $23 carbon tax is very effective. The total carbon emissions decreased by about 70 mega tonnes. Given Australia's emissions base of 587.1 mega tonnes in 2004-05, this indicates a 12% reduction rate. In the mean time, the government can collect around $6.1 billion in tax revenue, which can improve the government budget in the tax only scenario or relieve consumer's burden in the compensation scenario. A careful observation can reveal more detailed features.

First, the stationary emission cuts are the main contributor to the effectiveness of the carbon tax policy. This looks odd given the emission accounting data. Disaggregating total Australian emissions into stationary emissions and other emissions (or activity emissions), we find the size of activity emissions is bigger: 275.3 mega tonnes for stationary emissions and 311.8 mega tonnes for activity emission. Why does the policy lead to more stationary emission cuts? The features of policy design in our simulation matter much.

One is that, the designed carbon tax policy tried to mimic the proposal of the government by exempting agriculture, transport and household sectors. These three sectors are big contributors to activity emissions – the agricultural sector accounts for 149.4 mega

tonnes, households for 54.6 mega tonnes and road transport for 26.3 mega tonnes. The exclusion of these three sectors makes the activity emission reduction less effective.

The other is that the carbon price for both stationary emissions and activity emissions is the same. Given the smaller base of inputs (e.g. different types of fuels) accounting for stationary emissions compared with the tremendously larger output base for activity emissions, the intensity for stationary emissions should be much bigger than that for activity emissions. With the same carbon price, the higher stationary emission intensity means higher production cost and the industry will respond by reducing production more and thus reducing emissions more. As a result, the policy will work more efficiently on stationary emissions.

Second, in comparing both scenarios, the compensation plan seems to have little impact on carbon emission reduction. It is arguable that, while a carbon tax will reduce carbon emissions by raising the prices of carbon intensive goods like coal and electricity, a compensation policy will offset the carbon reduction through increased demand for carbon intensive goods. Countering this claim, the total emission reduction decreases only very insignificantly from 70.40 mega tonnes in the carbon tax only scenario to 70.33 mega tonnes in compensation scenario. This result may indicate that, under a carbon tax (with or without a compensation policy), consumers will shift their consumption from emission-intensive goods towards more environmental friendly goods. The change of consumers' attitude is further evident when we look into the stationary and activity emissions under two scenarios. It is apparent that the stationary emissions decrease under the compensation scenario while the activity emissions increase. Since we assume the activity emission intensity is fixed in the model, activity emissions have to rise as total output increases in response to the increased household demand under the compensation plan. The decrease in stationary emissions implies that fewer emission-intensive inputs are used and less emission-intensive outputs are produced. These movements of both emissions largely cancelled out each other; hence it is understandable why the total emission reduction is almost the same for both scenarios.

Third, the carbon tax revenue the government can collect moves in the direction opposite to that of emission reduction. As the carbon emission reduction decreases slightly in the compensation scenario, carbon tax revenue increases slightly from $6.101 billion to $6.108 billion. This opposite movement can be easily understood. Given a fixed carbon tax rate, the amount of carbon tax revenue is determined by the base of a carbon tax (or

emissions base). The higher emission cuts means smaller carbon tax base and thus less tax revenue. This result tells us that carbon tax revenue can be another indicator of the effectiveness of carbon tax policy (from the point of view of environment): the more carbon tax revenue the government collects, the less efficient the carbon tax policy will be.

Figure 2 GDP and GNP change

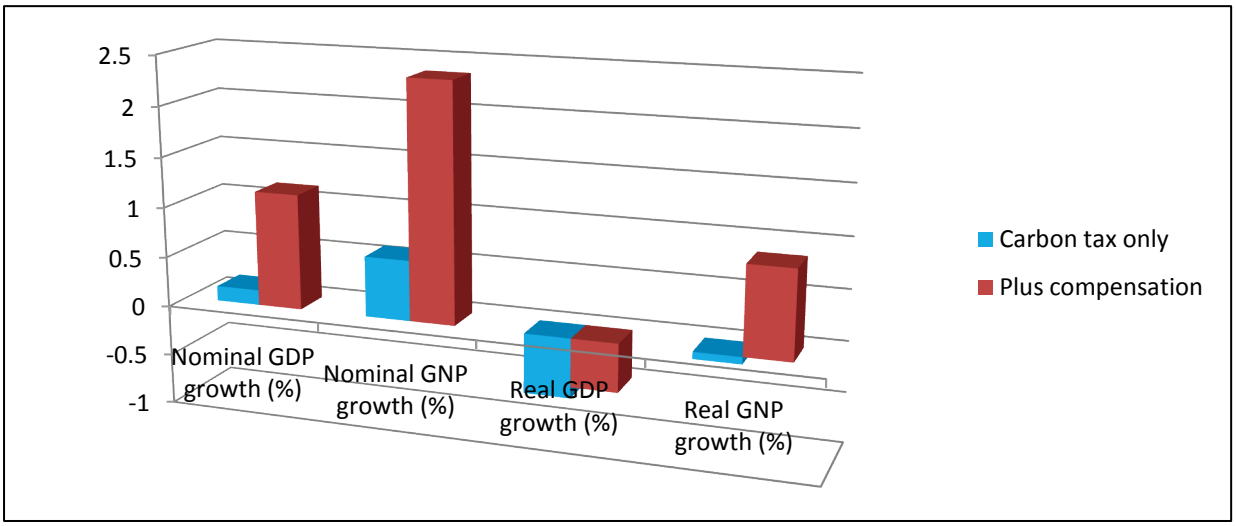
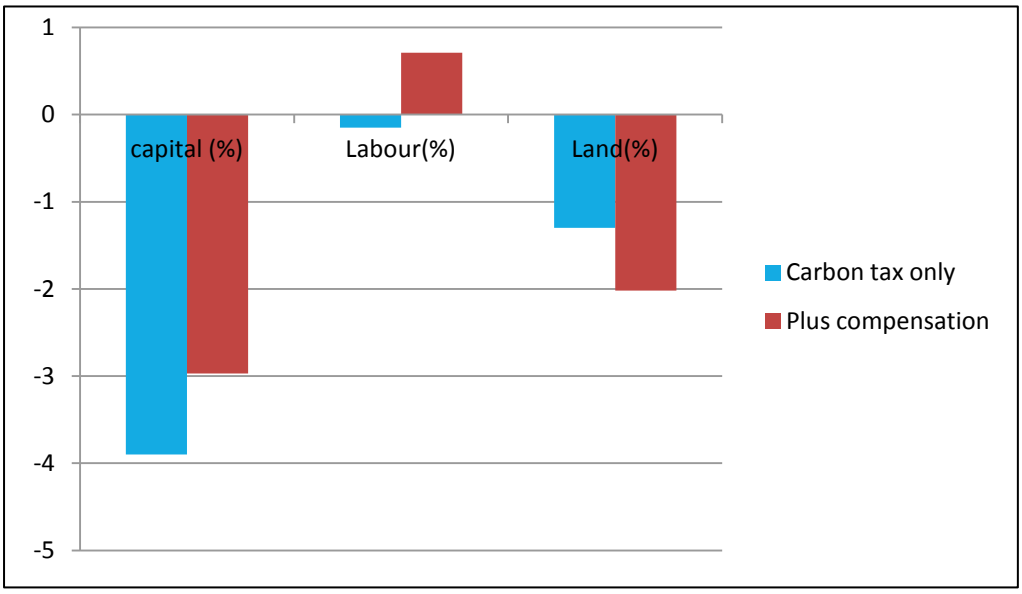


Figure 2 shows the percentage change in Australia's GDP and GNP under the two scenarios. In nominal terms, it is apparent both GDP and GNP are experiencing growth under both scenarios, but GNP growth is much faster than that of GDP. The positive nominal growth of both GDP and GNP can be largely understood by the hike of prices under a new tax. Since the compensation plan will boost household demand and cause much higher inflation, it is reasonable to see much higher growth in the second scenario. While GDP is the total value added of companies in Australia regardless of ownership, GNP excludes the value added by foreign companies in Australia, which are negatively affected by a carbon tax, and includes the value added by Australian owned companies overseas, which are not affected by a carbon tax in Australia; so it is understandable that GNP will be less negatively affected by a Australian carbon tax.

It is not surprising to see the decrease in both GDP and GNP in real terms under the carbon tax only scenario. A new tax will exert a distortion to the economy and cause inefficiency. A carbon tax will increase production costs and industries will respond by scaling down production and thus real GDP and GNP will shrink. Again, GDP will decrease more than GNP. It is of interest to find out that under the compensation scenario, real GNP experiences significant positive growth while the real GDP decreases less compared to the carbon tax only scenario. The significant positive growth of GNP implies that Australian

companies overseas have much better performance under this scenario, which may be the result of increased importation.

Figure 3 Payments to primary factors

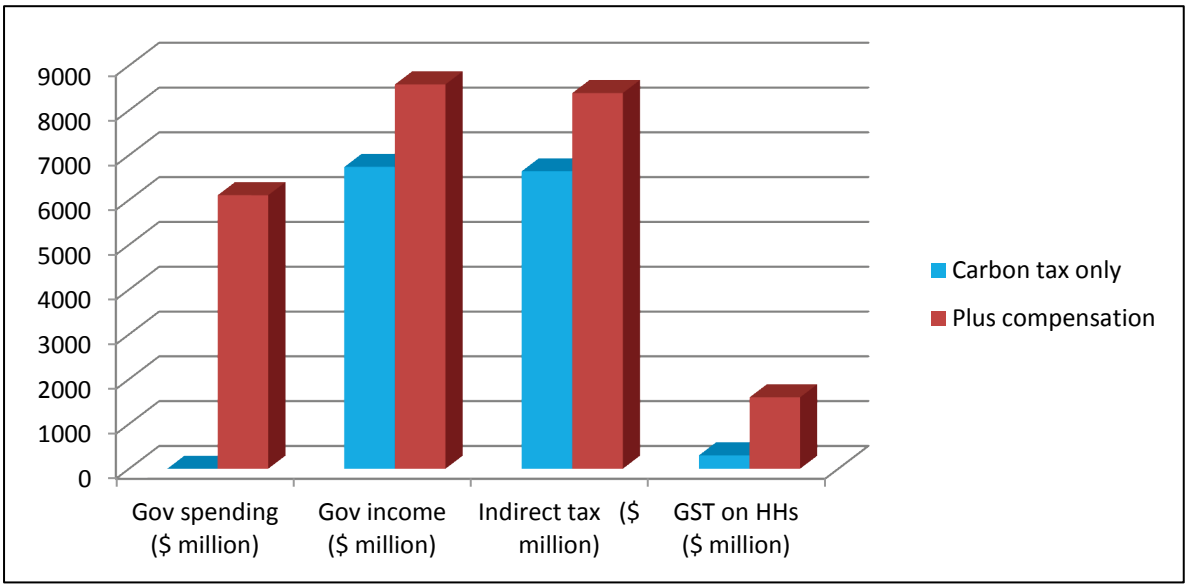


From Figure 3 it is clear that payments to primary factors decrease under both scenarios with the exception of labour under the compensation scenario. For the tax only scenario, payment to capital decreases by around 3.9% while payment to land by around 1.3%. Payment to labour decreases only slightly (around 0.2%). Since total capital and land supply is assumed fixed in the short run, the decrease in payment to capital and land reflects the decrease in their prices. It is reasonable to see their prices to drop due to a decrease in demand for them in the face of economic contraction following the carbon tax policy. Since we adopt the Keynesian assumption of sticky wages in the short run and thus fixed the real wage rate, the decrease in payments to labour reflects both the change in the nominal wage rate and the change in employment. In the model, we fully index the nominal wage rate to CPI so the nominal wage rate should increase in the face of a carbon tax. A small decrease in payments to labour indicates that the decline in employment outweighs the increase in nominal wage rate.

Under the compensation scenario, the payment to labour increases significantly. Since employment decreases under this scenario (as will be seen later), this may result from the much higher nominal wage due to the significantly increased CPI. The payments to capital and land are both negative, but compared with the tax only scenario the payment to capital has improved while the payment to land deteriorates. This may be related to the

consumption behaviour depicted by LES in the model. In LES, as household income grows, they tend to spend more on luxury goods which, by and large, may use more capital to produce. Thus, compared with the tax only scenario, the demand for capital under compensation policy increases and so is the price of and payment to capital. Since land is largely used by the agricultural sector to produce necessities, the demand for land decreases when people are in favour of luxury goods. As a result, the price of land decreases, so does the payment to land.

Figure 4 Government income and expenditure

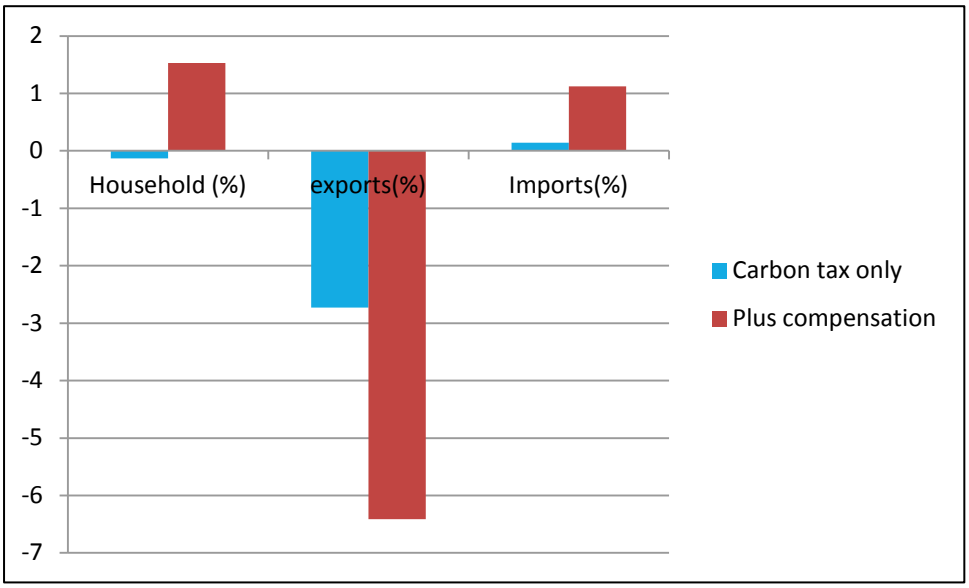


The changes in government income and expenditure are displayed in Figure 4. Looking into the government expenditure side, we find that government spending under the tax only scenario is barely changed but it increases sharply under the compensation scenario. The large government expenditure in the second scenario is underpinned by government transfer of carbon tax revenue to households. The unchanged government expenditure under the tax only scenario may be due to two factors. On one hand, since we assume government real consumption follows household consumption, the former should decrease when the latter decreases as a result of a carbon tax. On the other hand, the increased price level due to introduction of a new tax would inflate government nominal expenditure. When the effects of these two factors are largely cancelled out, the government nominal spending appears quite stable.

The change in government income is interesting. In the carbon tax only scenario, government income is around $6.4 billion, most of which is contributed by carbon tax

revenue. Under the compensation scenario, the government income increases to about $8.3 even if the carbon tax revenue is barely changed (as shown in Figure 1). The changes in indirect tax and GST on households explain the source of government income increase: as households increase consumption under the compensation policy, the government can collect more GST from households and other indirect tax from industries. As a result, even if the government transfers all carbon tax revenue of $6.1 billion to households, it can claim back more than $2.0 billion through indirect taxes.

Figure 5 Real household consumption and international trade



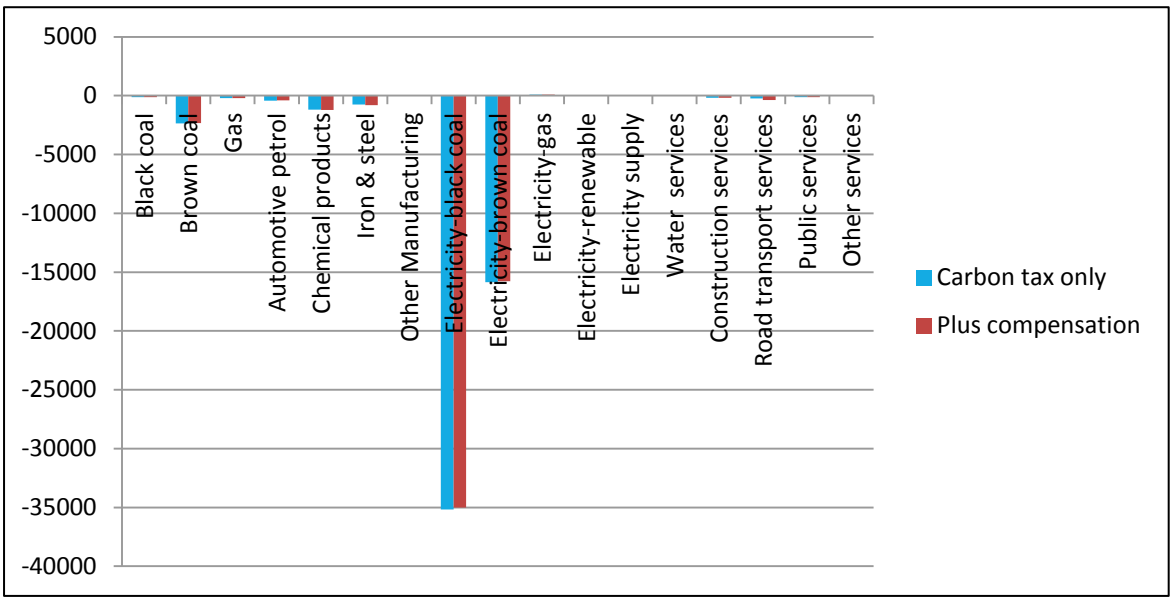
Commodity demand has important implications for the macro-economy. Figure 5 illustrates three important absorptions of commodities under a carbon tax – household consumption, imports and exports. Household consumption decreases marginally under the carbon tax only scenario. One reason for this may be due to the increase in commodity prices. A carbon tax adds extra cost to production of commodities, so commodity prices have to rise as the producers pass on the cost to the consumers. Households would respond by consuming less in the face of a price hike. Moreover, producers will scale down production facing a rising cost and this means households will have less income in the form of reduced payments to primary factors. As income decreases, households have to cut down consumption. The compensation plan witnesses a significant increase in household real consumption. This is quite straightforward. Once households receive a government lump sum transfer, their consumption would rise proportionally to their increased income, given the assumption in the model that marginal propensity to consume is unchanged.

Exporters seem the biggest losers in the face of a carbon tax. Under the tax only scenario, the total volume of exports will reduce by 3.8%. Under the compensation scenario, the situation gets worse for exporters – the decrease in exports becomes 6.4%. This may be due to the price effect. As a carbon tax pushes up commodity prices in Australia, Australian exports become more expensive and less attractive to overseas consumers. As a result, the demand for Australian exports drop. In the compensation scenario, the increased household demand will push the domestic prices to higher levels and then increasingly more expensive Australian exports will drive overseas consumers further away. On the other hand, the importers are benefiting from a carbon tax. As the domestic prices surge, there will be a real appreciation of the Australian dollar given the nominal exchange rate is fixed is our model. A stronger Australian dollar gives local consumers extra purchasing power in consuming imported goods. The increased demand for imports will boost importation. As importation continuously increases while exportation contracts significantly, the Australian current account will deteriorate rapidly.

4.2 Sectoral Perspective

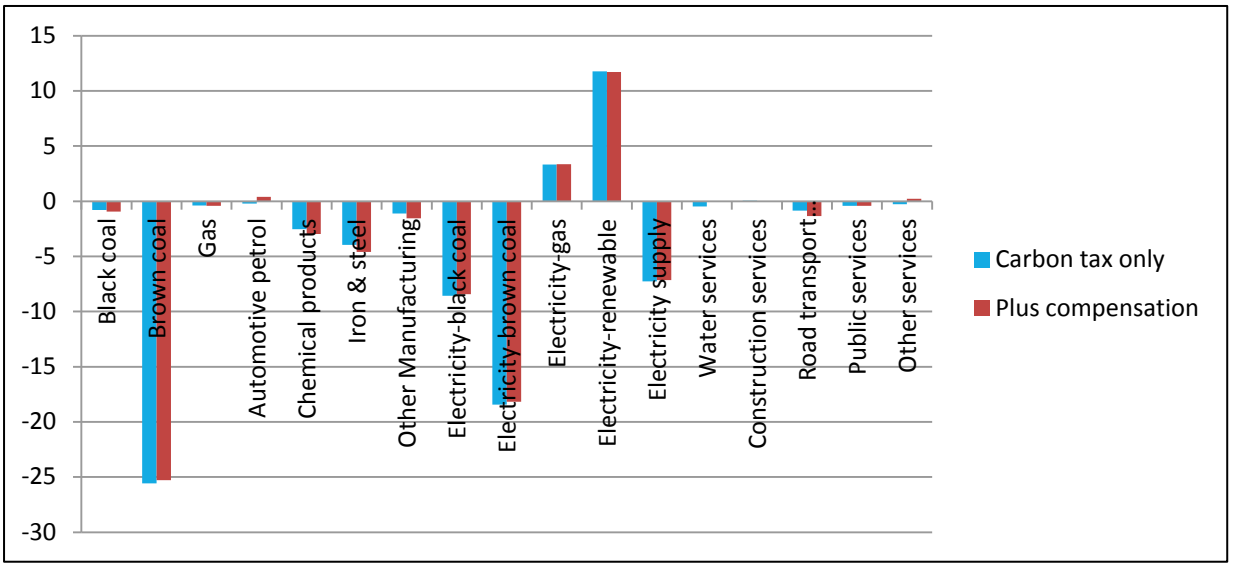
There are a number of indicators for sectoral performance. We only report emissions reduction, output and profitability in this section. Sectoral employment will be addressed in the next section. There are 35 sectors in our model, but we only display 17 sectors here due to length limits on the paper. Of these 17 sectors, 9 are energy sectors, 3 are manufacturing sectors and 5 are service sectors, as shown in Figure 6.

Figure 6 CO2 cuts by sector (kilo tonne)



The first impression of Figure 6 is that the contribution to carbon emissions cuts is mainly coming from brown and black coal electricity generations. Of total emission reduction of around 70 mega tonnes (see Figure 1), these two sectors account for around 53 mega tonnes. Brown coal mining, chemical manufacture, and iron & steel also have significant contributions, but the contribution of the rest is fairly small. These results largely reflect the current emissions state and the responsiveness of each sector to the carbon tax. The biggest emission reduction in the black coal electricity sector is consistent with its No. 1 position in stationary emissions accounting (we disregard the activity emissions here since the activity emission reduction is very small given that the largest activity emission players are exempted from the carbon tax) – out of the total 275.29 mega tonnes of stationary emissions, black coal electricity accounts for almost half (116.18 mega tonnes). Similarly, the second highest emission reduction, the brown coal electricity sector, can be attributed to its emission base of 61.86 mega tonne. When a price is put on carbon emissions, industries seem to respond actively thanks to their profit maximization behaviour. Interestingly, even if the road transport sector is exempted from a carbon tax, it also makes some contribution to total emissions reduction. Apparently, this is induced by the increase fuel prices when a carbon tax is imposed on fuel producing sectors. Although the emission cuts display the response of each sector to a carbon tax, the information revealed in Figure 6 does not take into account the sizes of industries. A more accurate description of responses of industries is provided by percentage changes of sectoral outputs shown in Figure 7.

Figure 7 Percentage change in real output by sector



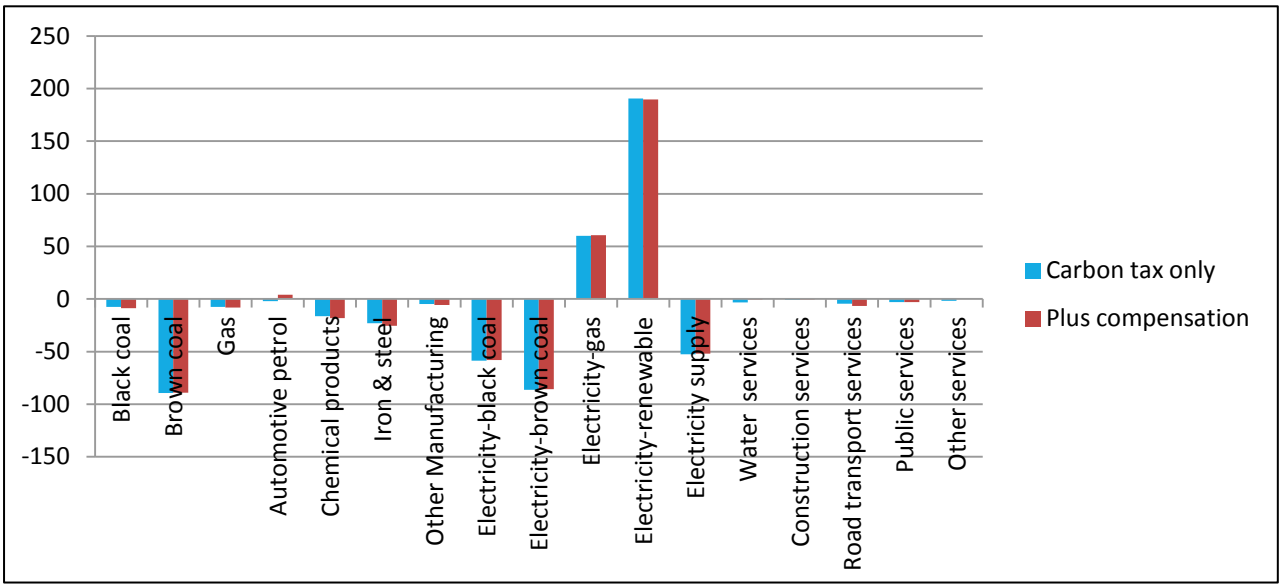
A few features can be gleaned from Figure 7. First, although the emission cuts for the brown coal sector is relatively small (see Figure 6), it experiences the deepest reduction in production. The sharp decrease in real output in the brown coal sector may be attributed to two reasons. One is the increased production cost since it has to pay for its emissions. The other is the dramatically decreased demand for brown coal, which would be the decisive factor. As we see in Figure 7, the major client of the brown coal sector, brown coal electricity, is experiencing a contraction of around 17%.

Second, although the emission cuts of black coal electricity is more than double that of the brown coal electricity sector (see Figure 6), its percentage reduction in real output is only half of that for the latter. The relatively bigger size of the black coal sector is crucial, but the most important factor may be the much higher stationary emission intensity of brown coal. Given the same price for carbon emissions, the high emission intensity of brown coal leads to significantly higher production cost for brown coal electricity generators. The producers' profit maximization leads to the sharp contraction of brown coal electricity generation.

Third, the gas electricity and renewable electricity expand significantly. These sectors apparently benefit from their low emission nature and high substitutability with other forms of electricity generation. As the electricity generated from black and brown coal decreases dramatically in the presence of a carbon tax, the electricity price skyrockets. Since a carbon tax will exert little cost to gas and renewable electricity due to its very low emission intensity, the remarkably increased electricity price provides a substantial profit margin and thus incentives for these two sectors to scale up production. Considering the sharp decline in brown coal mining and coal electricity generations, it is clear that a carbon tax will lead to a change in industry structure – high emission industries will give way to low carbon industries.

Finally, the compensation policy helps to improve the real output for some sectors but aggravates it for others. Manufacturing sectors and the road transport sector contract further while other sectors recover slightly. Interestingly, the automotive petrol sector and other service sectors even experience small positive growth. This result confirms the shift of household consumption when a carbon tax is in place.

Figure 8 Percentage change in profitability by sector



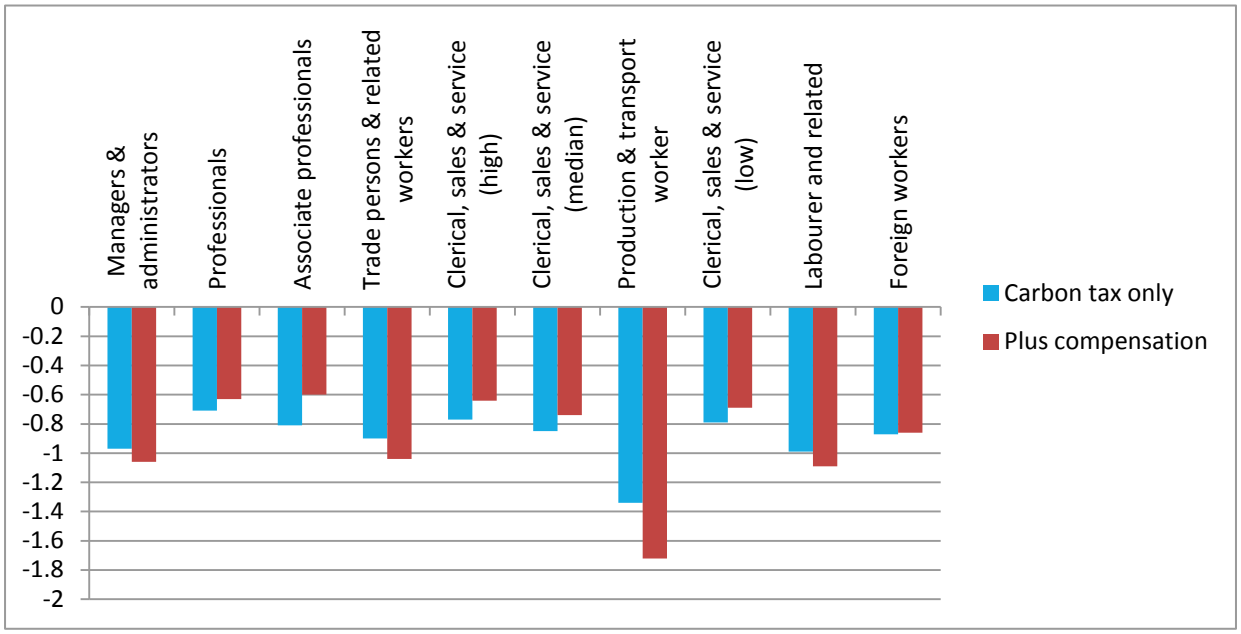
The profitability of each industry shown in Figure 8 has a similar pattern to that of real output, but the magnitude of change is much larger. The similar behaviour of real output and profitability is well explained by the influence of demand and production cost. Generally speaking, an increase in demand will bid up commodity prices, which in turn will increase the profit margin and thus lead to higher profitability. To maximize profit, the firm will respond by increasing output. Similarly, an increase in production cost (e.g. a carbon tax) will reduce firms' profit margin and they will respond by reducing production. The high sensitivity of profitability may relate to the assumption of wage rigidity in the short run. Since real wages will not respond to the change in commodity prices or production cost, the rental price of capital has to respond more, which induces a larger change in industry profitability.

It is of interest to notice that, although the electricity distributor (the electricity supply sector in Figure 8) produces no carbon emissions, its profitability decreases by around 50%. A straightforward reason is that the increased prices of electricity generation eat up its profit margin. However, one may argue that the electricity distributor is able to pass on this increased cost to consumers. The truth is, when the distributor intends to fully pass on the increased cost to consumers by including all costs in the electricity price for end users, the end users will cut down consumption sharply. Given the high fixed cost in electricity distribution, the decrease in sales would lead the average cost per kilowatt electricity to a much higher level than the planned end-user price. The profit maximization solution is to pass on less cost to end users and maintain a sustainable electricity demand.

4.3 Employment Perspective

The employment effects are illustrated by change in employment by occupation and by sector respectively. Domestic employment is put into 9 occupations in our model. The percentage changes of employment for each group are shown in Figure 9.

Figure 9 Percentage change in employment by occupation

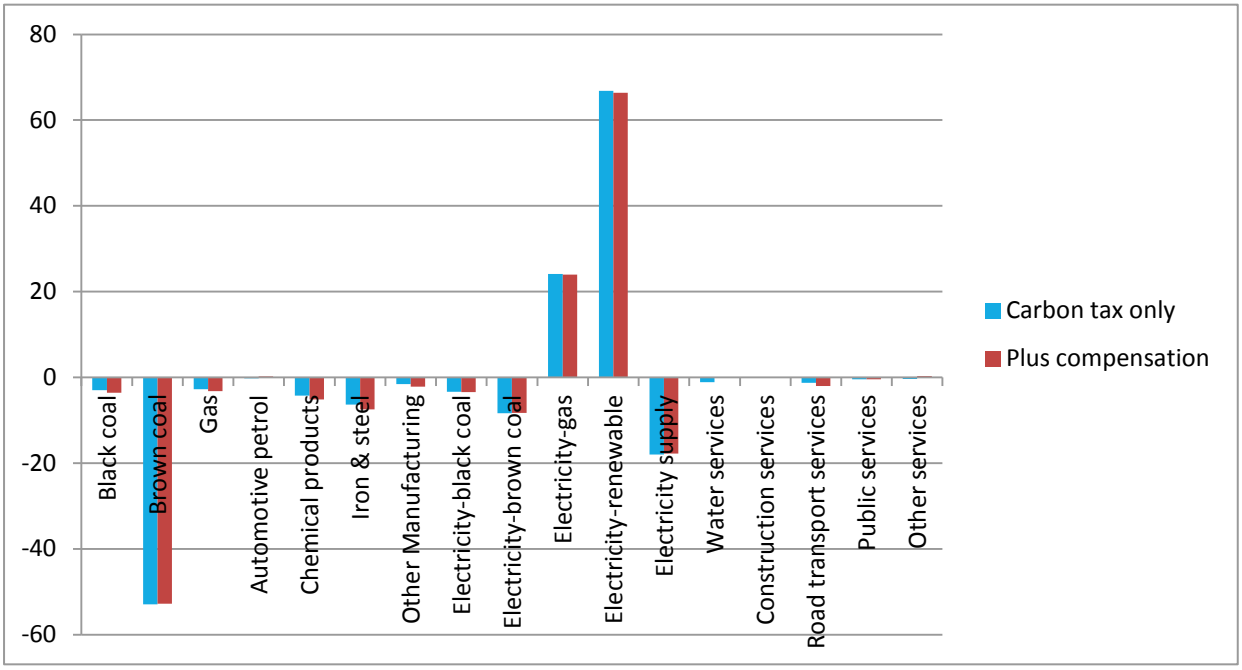


Understandably, the employment effects are negative for all occupation groups under all scenarios due to the contraction of the economy in the presence a carbon tax. However, the employment impact on all occupation groups is relatively small, ranging from -0.6% to -1.7% decrease. Production and transport workers are the worst affected. Apparently, this group is closely related to emission or energy intensive sectors such as electricity, mining, manufacturing and transportation. In the face of a carbon tax, these sectors experience significant contraction and may lay off large number of workers. Similarly, the close link with emission intensive sectors explains the around 1% decrease in employment for the second tier of most affected occupation groups, e.g. managers & administrators, trade persons & related workers, and labourers.

Interestingly, for those worst affected groups, the compensation policy will deteriorate further their employment prospects. This may be the result of consumers' taste changing under a carbon tax. As consumers further substitute away from carbon intensive goods to low carbon commodities under the compensation policy, low carbon sectors expand at the

expense of emission intensive sectors. As a result, occupations more closely associated with emission intensive sectors would be worse off. For the same reasoning, the rest of the groups are less affected and the situation improves under the compensation scenario.

Figure 10 Percentage change in employment by sector



The employment by sector reveals a different aspect of carbon tax impact. For some sectors, the changes in employment are very large. It decreases by 53% for the brown coal industry, increases by around 64% in the renewable electricity industry and 23% in the gas electricity sector. These changes are several times higher than the corresponding changes in sectoral real output. The large change in employment may be explained as follows. As the real wage is rigid in the short run, firms will not incur too much cost by employing more staff during an expansion and have to lay off more workers in order to reduce production costs during a contraction.

Since the large decrease in employment in the brown coal sector will be largely cancelled out by the large employment increase in the gas electricity and renewable electricity sectors, the overall unemployment effect will not be large. However, this is based on the assumption that workers can move freely between sectors and between different regions. In reality, workers may have difficulty doing so. In this case, there would be large structural unemployment when the economy is shifting from high carbon to low carbon production. To reduce structural unemployment, government assistance is much needed.

Comparing with Figure 7, it is interesting to find that, while the electricity supply sector experiences less output reduction than black and brown coal electricity generation sectors, the decrease in employment in the electricity supply sector is larger than that in coal electricity generation sectors. This may reflect the labour intensive nature of electricity distribution. The employment change under the compensation scenario displays a pattern similar to that of change in real output, which confirms the shift of household consumption induced by a carbon tax policy.

4.4 Distributional Perspective

The distributional effect measures the impact of a carbon tax on different household groups. In this study, we disaggregate all households into ten deciles according to their income levels. The simulated distributional effects are analysed through percentage changes in real income, utility per household and equivalent variation (EV).

Figure 11 Percentage change in income by household decile

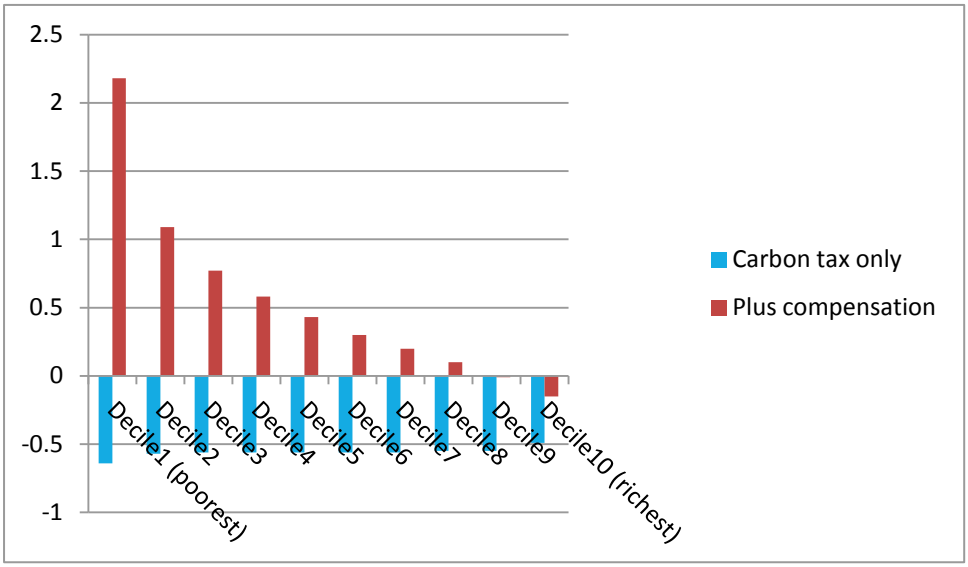


Figure 11 illustrates the percentage changes of household income for both scenarios. Under the carbon tax only scenario, it is apparent that all households are experiencing a decline in income with a higher percentage change for low income households. However, the difference in percentage change is fairly small for all household groups. Given the much larger income base for high income household deciles, it is not difficult to work out that the nominal change in income is much larger for high income households. In short, under a carbon tax all households are losers economically, low income households bear

more burden in terms of percentage change in income and high income households lose more in terms of nominal income change.

With carbon tax revenue equally transferred to each household decile, all deciles are better off compared with a no compensation scenario. The low income households experience a much larger percentage increase in income apparently due to their smaller income base. However, the richest two deciles still experience a decrease in income although only slightly for decile 9. This implies that, for these two deciles, the decrease in income due to the carbon tax is larger than the government compensation received. From this point of view, the low income households are biggest winners from compensation while high income households are losers in both scenarios. But this conclusion may change slightly when we consider changes in household utility.

Figure 12 Percentage change in utility by household decile

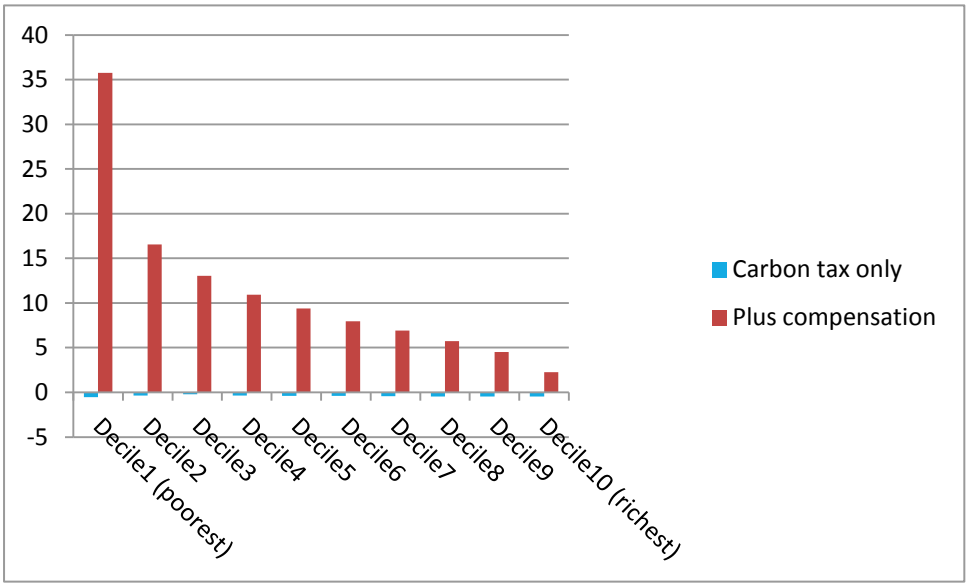


Figure 12 shows the percentage change in utility per household. In comparing with Figure 11, the first impression is that these two graphs have a similar trend – the change is higher for poorer households and smaller for richer households in all scenarios. This similar feature in the two graphs demonstrates the close linkage between household income and household utility – the higher increase in income leads to a higher increase in consumption and generally people will feel happier. In this reasoning, the higher percentage changes in utility for low income household deciles are largely the results of their low utility base stemming from their low income level. However, Figure 12 also displays some other distinguishing features.

First, the percentage change in utility in Figure 12 is much higher than the percentage change in income in Figure 11 (the visually shorter blue bars under the tax only scenario in Figure 12 compared with Figure 11 are due to the change of scale of vertical axis). Household utility is measured by the level of luxury consumption, so the high sensitivity of utility per household may be attributed to the relatively smaller base of luxury consumption compared with total consumption. With the fixed propensity to consume in the model, the percentage change in consumption should be equal to the percentage change in income for each household decile. Since our model features a LES consumption function, the change in consumption is largely realized through the change in supernumerary consumption. Given a much smaller base of supernumerary consumption, this will lead to larger percentage change in supernumerary consumption and thus larger change in household utility.

Second, while Figure 11 shows that the richest two deciles experience income loss under compensation scenario, Figure 12 manifests that their utility has increased. Given the close link between household income and expenditure, the decrease in household income for these two deciles implies a decrease in their consumption level. However, the increase in their utility indicates an increase in their luxury consumption. The increase in luxury consumption in the face of decrease in total consumption may indicate the tendency of these two deciles to switch away from energy intensive necessity consumption towards energy efficient luxury consumption in the wake of a carbon tax.

According to both Figures 11 and 12, the low income household deciles are the biggest losers under the carbon tax only scenario and biggest winners under compensation scenario. But the change in equivalent variation tells a quite different story.

Figure 13 Change in equivalent variation by household decile ($million)

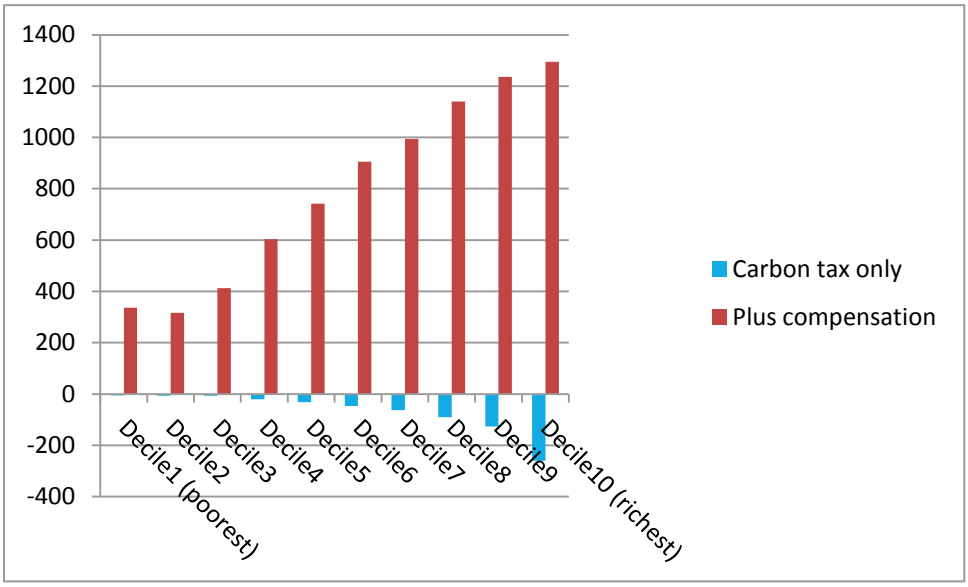


Figure 13 illustrates the change in equivalent variation by household deciles. Equivalent variation is a popular measurement of welfare. It measures the change in utility in terms of real change in dollar value, namely, the amount of income at the initial price level needed to achieve the new level of utility. From Figure 13 it is apparent that the higher the income the household earns, the more it will suffer in the tax only scenario but the more it benefits in the compensation scenario. So, it is the higher income household deciles, who are the biggest losers under a carbon tax and the biggest winners under an indiscriminate compensation plan.

5. Conclusions

To gauge the impact of a carbon tax in Australia, we constructed an environment-extended micro SAM and built a CGE model for Australia. Two scenarios are analysed in the paper. One is a $23 per tonne carbon tax with the exemption of agriculture, land transport and household sectors. The other is, on the top of carbon tax scenario, the tax revenue is fully and equally transferred to household deciles in lump sum. Overall, the simulation results show that a carbon tax of $23 per tonne carbon dioxide can cut emissions effectively, but cause mild economic contraction, and that the proposed compensation plan has little impact on emission cuts while mitigating the negative effects of a carbon tax on the economy.

Specifically, the environment is the biggest winner under both scenarios – around 12% emission reduction can be achieved in the short run. Since the biggest activity emission contributors (e.g agriculture, land transport and household sectors) are exempted from the carbon tax, the total emission cuts are achieved mainly through reductions in stationary emissions. The sectoral analysis shows that black coal electricity and brown coal electricity are the main contributors to emission reductions, accounting for around ½ and ¼ respectively.

Although both the nominal GDP and GNP demonstrate substantial growth, the economy contracts mildly according to real GDP and real GNP under a carbon tax while the real GNP registers significant positive growth under the compensation policy. The return on capital and land decreases substantially, but the return on labour only drops slightly under the tax only scenario and increases significantly under the compensation policy, which may be due to the rigidity of real wages in the short run. The government is a winner in both scenarios. In the absence of compensation, the government's fiscal position improves substantially, but even with compensation, government revenues increase by more than its expenditures. Households are affected negatively, but marginally, while importation benefits slightly under the tax only policy. However, under the compensation policy, they both benefit significantly. Exporters are one of the biggest losers, with an almost 3% drop in real exports in the tax only case and a more than 6% drop in the compensation scenario.

At sectoral level, while brown coal electricity, black coal electricity and brown coal mining sectors are the biggest losers with the highest reduction in real output, profitability and employment, the renewable electricity and gas electricity (and oil electricity, we have not displayed due to the length limits on the paper) are biggest winners, reflecting a dramatic increase in profitability and employment, and substantial increase in real output. Although the large decrease in employment in the brown coal may be cancelled out by the spectacular demand for labour in the renewable electricity and gas electricity sectors, possible structural unemployment requires the attention of the policy makers. The effect on occupational employment is mildly negative, ranging from -0.6% to -1.7%, with the production and transport workers worst affected.

The influence of a carbon tax policy on household income deciles depends on the criteria of judgement used in welfare analysis. If the percentage change of real income or utility per household is used as a criterion, the low income household deciles will be slightly more negatively affected than higher income deciles in the tax only scenario, so a carbon

tax is modestly regressive. In the compensation scenario, the low income deciles benefit more, so the equal lump sum government transfer plan is very progressive. However, if the nominal income or the equivalent variation is used, the higher income deciles appear hardest hit by a carbon tax policy but more greatly benefit from the equal lump sum government transfer.

The limitations of the study largely lie in the underlying features of the model. The model we developed is a static model in which capital is assumed fixed. This assumption may lead to the overstatement of the impact of a carbon tax. However, since inflexibility of capital is indeed the central feature of a short-run situation, overstatement is not a serious problem in the present analysis. Nevertheless, a dynamic model may be essential to avoid any overstatement in a long run simulation.

The other limitation is that, since our model is a single country model, we could not deal with the changing situation in the rest of world, e.g. globally agreed emission reduction targets. To overcome this limitation, it is necessary to develop a multi-country model, or place this model as a sub-model of a multi-country model, or link the current model with a multi-country model like GTAP. However, one should bear in mind that, as the model gets complicated or a number of models are used together, the complexity may increase causing an inefficiency or even inaccuracy in modelling results.

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