Carbon pricing and revenues recycling in China

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Abstract:

This paper examines the impact of carbon pricing and the ways of using the revenues in China. We use a dynamic CGE model to simulate a carbon pricing scheme between 2015 and 2030. 7 revenue recycling schemes are tested, namely 1) lump-sum transfer to households, 2) cutting consumption tax rate, 3) cutting investment tax rate, 4) cutting export tax rate, 5) cutting intermediate tax rate, 6) cutting labour tax rate and 7) cutting capital tax rate. The budget deficit to GDP ratio is fixed at the base-case level in all scenarios. We examine the economic efficiency using three indicators, including real GDP, real GNP and the erosion of the tax base. The weak form of the double dividend is evident in all non-lump sum revenue recycling schemes, tested by all three economic efficiency indicators in all policy years, with few exception. The strong form is less certain and varies. Nevertheless, the deviations in emission intensity of GDP are similar across the revenue recycling schemes.

JEL code: C68, H23, Q54

Key words: carbon pricing, double dividend, CGE, China

1. Introduction

China intends to build a nation-wide carbon pricing scheme. This study investigates the impact of carbon pricing in China, with an emphasis on the revenues-recycling policies.

While carbon pricing is generally regarded as the most cost-effective way of reducing carbon dioxide emissions, the prospect of a 'double dividend' presents more incentives for pricing carbon. A carbon price adds a new form of distortion to the economy, where there are pre-existing taxes and distortions. However the revenues generated from carbon pricing can be used to cut the pre-existing taxes, thereby leading to an efficiency dividend as well as an environmental dividend.

There is no theoretical agreement as to whether a double dividend condition would exist for sure. The empirical modelling exercises have shown no general agreement either. Section 2 reviews the double dividend literature. Section 3 illustrates the CGE model used in this study. Section 4 describes the simulation design. Section 5 presents and interprets the simulation results. The final section concludes.

2. Literature review

There are two forms of the double dividend condition – the strong form and the weak form (Goulder, 1995). The strong form holds when replacing a pre-existing tax with an environmental tax, in a budget neutral fashion, improves the efficiency of the tax system. The weak form holds when the same tax swap leads to a higher efficiency than recycling the environmental tax revenues in a lump-sum fashion. Hence for the strong form to hold the weak form must also hold, but when the weak form holds the strong form may not. Nevertheless, both forms represent opportunities for realising the revenue benefits of carbon pricing schemes.

There is no uniform agreement as to either form would exist. Partial equilibrium models generally confirm the existence of the strong form (Lee and Misiolek, 1986). But partial equilibrium models could not capture the 'second-round' tax-interaction effects, which are found to be negative by general equilibrium models. Bovenberg and Mooij (1994) was the first study to construct a stylistic general equilibrium model to test the double dividend hypothesis. Theirs demonstrates that when the uncompensated labor supply curve is upward-sloping, due to the erosion of the tax base[1], the reduction in labor tax is insufficient to prevent real after-tax labor wage from falling. A lower wage discourages labor supply as more people would voluntarily stay unemployed, hence employment falls and the strong form of the double dividend fails.

The Bovenberg and Mooij (1994) model has a few limitations. First, the model only has one factor of production in the form of labor. Adding capital into the frame would reveal 'second round' tax-shifting effects (Goulder, 1995). The tax-shifting effects exist when there are multiple types of pre-existing taxes. If the environmental tax shifts the incidence of the tax towards the less distortionary pre-existing taxes, the tax-shifting effect could be welfare-improving and even lead to a strong double dividend (Mooij, 2000). However if the tax shifting effects work in the opposite direction, it might even compromise the weak double dividend condition (Metcalf et al., 2004).

Another limitation with the model is that it does not give representation to the producers. From a producer's perspective, a fall in the real wage would allow producers to shift from capital to labor thus increasing labor employment. Hence altering assumptions regarding labor

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[1] The environment-damaging activities may form part of the pre-existing tax base. An environmental tax reduces these activities thus reduces the tax base for pre-existing taxes. This means the rate of the pre-existing tax needs to increase to maintain budget neutrality. Hence the erosion of the tax base limits the extent to which the environmental tax revenues can be used to reduce the rate of the pre-existing taxes.

and capital may lead to vastly different conclusions about the double dividend condition (Bovenberg and van der Ploeg, 1996).

More sophisticated theoretical models have been constructed to examine the double dividend hypothesis under a variety of specific circumstances: political economy (Bovenberg, 1999) market imperfection (Bayındır-Upmann, 2004), endogenous growth (Fullerton and Kim, 2008, Nakada, 2010), and labour income uncertainty. No general conclusion can be drawn regarding the existence of the double dividend condition from these studies. These exercise emphasize the conclusion that whether the double dividend condition exists depends largely on the underlying assumptions.

Apart from the underlying assumptions, the structure of the tax system may also be deterministic to the existence of a double dividend condition. The higher the pre-existing tax rate, the narrower the tax base and the more price-elastic the tax base is, the more distortionary the pre-existing tax is likely to be (Bruce and Ellis, 1993).

Numerical models that contain information about such details have been used. Takeda (2007) pays particular attention to the pre-existing tax structure. The author uses a GAM-based dynamic model for Japan. Revenues are recycled in the forms of 1) labor income tax cut; 2) capital income tax cut, 3) consumption tax cut, 4) labor tax cut, 5) capital tax cut and 6) lump-sum transfer. By using life-time utility as the measure of welfare, only cutting capital tax leads to a strong double dividend condition. A weak double dividend condition however is found in all non-lump-sum transfer mechanisms. The author shown that the capital tax has a higher marginal excess burden than the other forms of taxes, hence scenario 5) generates strong positive tax-shifting effects that stimulate capital use in the short and medium run. The sensitivity tests suggest that the results hold within a plausible region.

Garbaccio et al. (1999) uses a recursive-dynamic CGE model for China. Revenues are recycled by reducing all other taxes by a uniform factor, under budget neutrality, and GDP is used as the indicator for welfare. The simulation identifies the strong form of the double dividend condition in the long-run. But the authors are careful in pointing out that the results are contingent on the assumption that labour supply is price-inelastic, which has helped to sustain employment and thus GDP.

Although both Takeda (2007) and Garbaccio et al. (1999) identified the existence of a double dividend condition, their simulations may indeed be showing opposite outcomes. The former study used life-time utility as the measure of welfare whereas the latter used GDP. Takeda (2007) does not report GDP, but the simulation shows lower levels of both capital stock and labor supply in the long-run under all revenues recycling scenarios. Using life-time utility may have downplayed the significance of the fall in production factors in the later years. In fact, GDP in the long run might even be negative in Takeda (2007).

Other than the underlying assumptions and the structure of the tax system, many numerical simulations have also shown the significance of the macro-economic structure to the existence of the double dividend condition. Relatedly, choosing a suitable pre-existing tax to be replaced by an environmental tax could lead to double dividend conditions.

McKitrick (1997) uses a static model for Canada, with capital as a fixed production factor. Five, revenues recycling scenarios were simulated: 1) lump-sum; 2) goods and services tax reduction; 3) corporate income tax reduction; 4) personal income tax reduction; and 5) payroll (equally on employer and employee) tax reduction. Consumers' utility was used as the measure for welfare. The simulation shows that only the 5th scenario delivers a double dividend condition, the 4th scenario leads to a weak double dividend condition, while the other scenarios do not lead to significant welfare changes. The strong form of the double dividend comes as a result of an increase in the demand for labor employment as both real wage and employment increases.

He & Li (2009) uses a static model for China. Although their simulation was based on SO_2 control rather than CO_2 control, the fundamental mechanism of tax swapping is similar. Revenues are recycled by 1) reducing service sector's production tax and 2) reducing enterprises' income tax. By using the indicators of GDP, consumption, household income and employment, the double dividend condition is found under the former mechanism but not under the later. This result reflects the fact that the service sector is relatively less carbon intensive and more labour intensive, therefore a carbon tax hits this sector less, and reducing tax rate in this sector stimulates more employment.

Heerden et al. (2006) uses a static model for South Africa. The revenues of environmental taxes are recycled through 1) a direct tax break on both labor and capital, 2) an indirect tax break to all households and 3) a reduction in food price. Only the third mechanisms is found to have the potential to reduce the marginal excess burden of the overall tax system.

In general, the literature has examined the double dividend hypothesis mainly in three ways. Following Bovenberg and Mooij (1994) one stream rely on theoretical models. These studies are important in the sense that they postulate the situations in which the double dividend condition is likely to exist. However due to the simplicity of the models they tend not to distinguish the differences among employment, GDP, consumers' welfare and the efficiency of the tax system. Another stream focuses squarely on the efficiency implications of the tax system. Most notably among this family is Takeda (2007). These studies tend not to report the implications to other important economic variables such as real GDP and employment. A third stream, including (Garbaccio et al., 1999), He and Li 2009, is the opposite of the second stream in the sense that they tend not to show the efficiency implications but focuses only on the macroeconomic variables.

The current study brings these three families together. It use a simple analytical model to explain the underlying mechanisms of the model and their implications to the modeling outcome. It also distinguishes the efficiency impacts from the macroeconomic variables, and more importantly, it shows the relative importance between the assumptions and the efficiency contributions.

3. The model

database

CHINAGEM is a dynamic, multi-sector, top-down CGE model for China. The current version distinguishes 143 industries. These industries, together with the Households, comprise the fuel-users (144 in total, counting Households as one fuel-user).

Two industries produce three types of primary fossil fuels. Between these two industries (Table 1), Coal and Mining Products produces coal while Crude Oil and Gas produces crude oil and gas. These two industries cover all the total primary fossil fuel use (TPFU) – including the fuels used in the conversion activities such as the use of coal in electricity generation and the use of crude oil in petroleum refineries. Initially, in year 2002, the total quantities of primary fossil fuels are allocated to each fuel-user according to its value share of each TPFY industry's total output (thus producing a matrix of 144 by 2).

Table 1: Total primary fossil fuel use (TPFU) by source, million tons of coal equivalent (mtce), 2002

	TPFU (mtce)
Total	1478
Coal and Mining Products	*1084*
Crude Oil and Gas	*394*

Source: China Energy Statistical Yearbook, 2012, table 4-1, coal equivalent calculation.

The model distinguishes 6 types of electricity generation by fuel. Electricity-coal, Electricity-oil and Electricity-gas use fossil fuels while Electricity-nuclear, Electricity-hydro and Electricity-other rely on renewable energy sources. It treats each type of electricity generation as one industry with a unique output, such that electricity produced by different fuels may have different prices. All electricity generation industries sell only to the Electricity Supply industry.

Five industries produce five types of final energy. The six industries are Coal and Mining Products, Crude Oil and Gas, Petroleum Refinery, Coking, Electricity Supply and Gas Supply, whose final energy outputs are coal, gas, petroleum refinery products, coke, electricity supply and gas supply, respectively (Table 2). Together they cover the total final energy use (TFEU), which includes the use of primary (e.g. coal) and secondary energy (electricity supply), but does not include the energy used in conversion (electricity-coal, petroleum refinery products, etc.).

Like primary fossil fuel, the initial quantities (in year 2002) of final energy consumed by fuel-users are allocated according to their respective value shares of each TFEU industry's total output (thus producing a matrix of 144 by 5). However there are two exceptions. First, the industries of Coke, Electricity Supply and Gas Supply use coal to produce final energy outputs and therefore these industries are not counted as the final fuel users of coal. Thus the total quantity of coal as final fuel is allocated among 141 (144-3) fuel-users. Second, the industries of Petroleum Refinery and Electricity Supply use crude oil in producing final energy outputs, thus the total quantity of crude oil as final fuel is allocated among 142 (144-2) fuel-users.

Table 2: Total final energy use (TFEU) by source, million tons of coal equivalent (mtce), 2002

	TFEU (mtce)
Total	1105
Coal and Mining Products	*373*
Gas	*44*
Petroleum Refinery	*309*
Coking	*136*
Electricity Supply	*243*

Source: China Energy Statistical Yearbook, 2009, table 5-20, coal equivalent calculation.

The quantity of all kinds of energy use are updated according to variations in the quantity of all fuel-users' output or consumption.

CHINAGEM accounts for all carbon dioxide emissions from fossil fuel-combustion, hence all the emissions derive from the direct burning of Co2-emitting fossil fuels. The initial levels of emissions are embedded in three types of CO2-emitting fossil fuels, namely coal as primary energy, gas as final energy and petroleum refinery products as final energy (Table 3). Coal as primary energy are distributed among all fuel-users except the Coking industry, whose production process does not involve coal-combustion. Non-coal final energy sources are distributed among all fuel-users according to their value shares. Hence by dividing the total emissions of each Co2-emitting fuel by the corresponding total quantities of CO2-emitting fuels used by all the fuel-users, we obtain the overall emission-intensity factor for each CO2-emitting fuel (a 3 by 1 matrix). Then multiply each of these factors by the quantities of Co2-emitting fuels used by every fuel-user gives the approximated levels of CO2 emissions from each Co2-emitting fuels by every fuel-users (a 3 by 144 matrix).

Table 3: Total emissions from fossil fuel combustion, year 2002, million tones (mt)

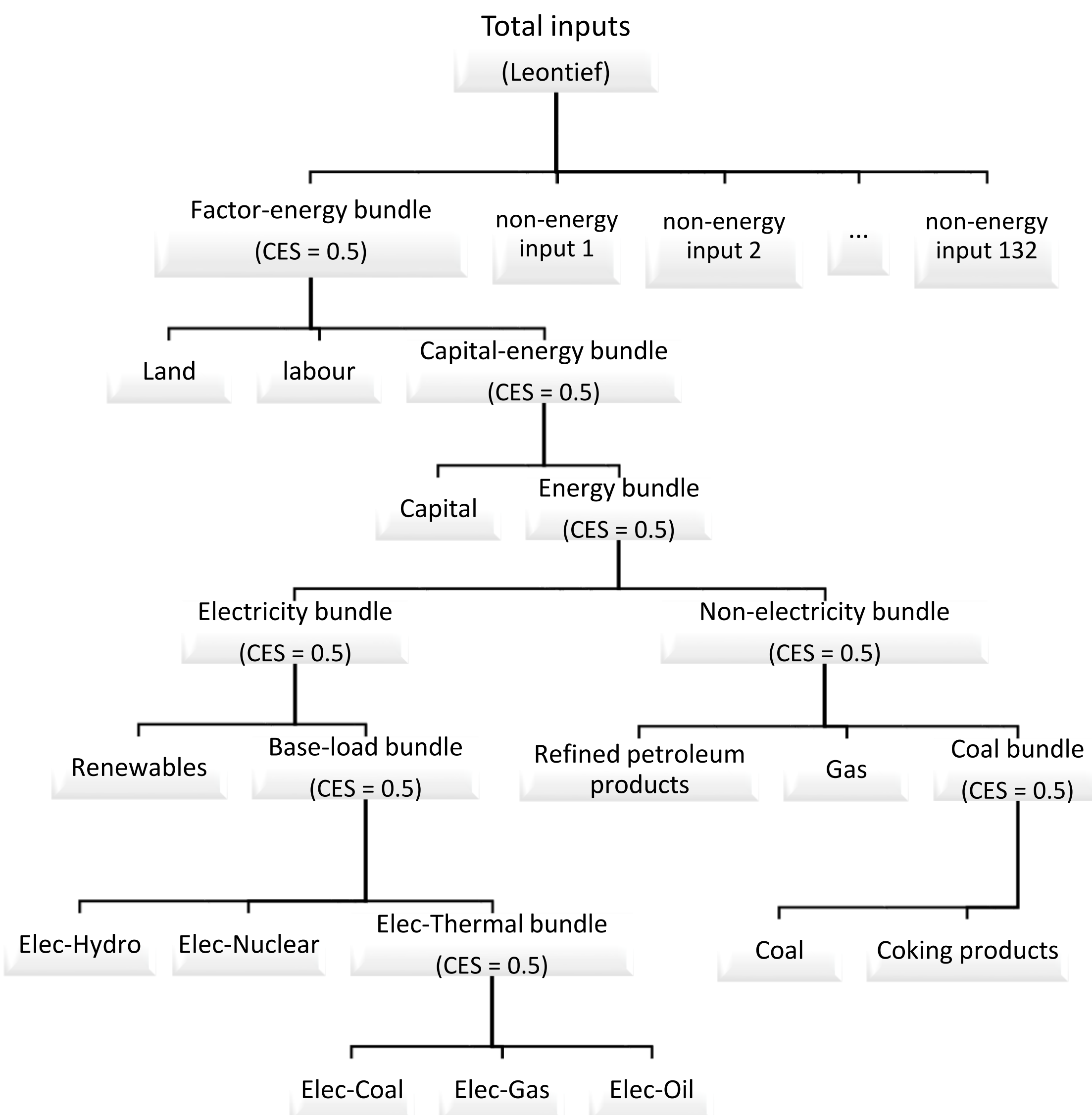
	CO2 (mt)
Total	333
coal	2669
oil	60
petroleum refinery products	603

Source: World Development Indicator

The model tracks all emission levels according to the quantities of all Co2-emitting fuels used by all fuel-users.

Firms' production structure

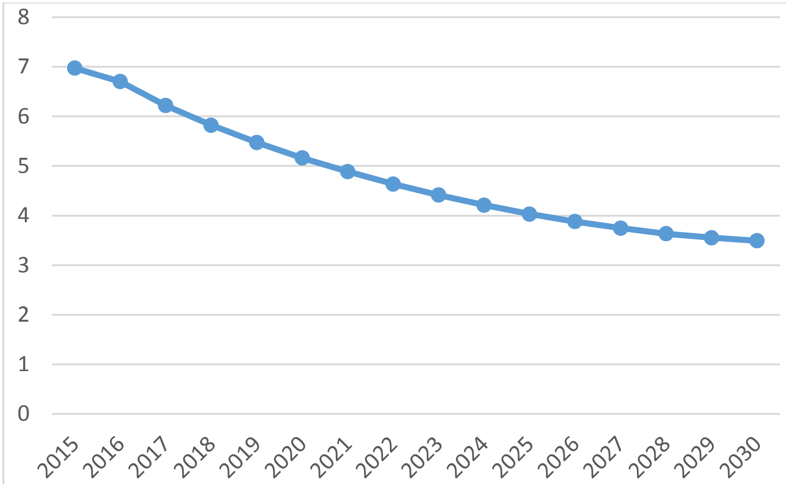
The firms' production nesting structure (Figure X) follows that of the GTAP-E model. Each industry uses factor-energy inputs and non-energy inputs in a fixed proportion (Leontief substitution). The factor-energy bundle is a CES combination of land, labour and the capital energy bundle, which in turn is a CES-composite of capital and the energy bundle. The energy bundle is a CES substitution between the electricity bundle and the non-electricity bundle. The former bundle expands from the GTAP-E model by further detailing electricity generation by source, it (CES) substitutes between the renewable electricity generation industry and the base-load generation bundle. The base-load bundle is a CES combination of three components, namely the Electricity-nuclear industry, the Electricity-hydro industry and the Electricity-thermal bundle. At the bottom of this nest, the Electricity-thermal bundle contains three fossil-fuel electricity generation industries, namely Electricity-coal, Electricity-oil and Electricity-gas. The non-electricity bundle is a CES substitution among the gas, refined oil and the coal-composite bundle, which in turn, is a CES substitution between coal and coking products. The default value for all CES parameters is 0.5.



Base-case scenario

In the baseline, real GDP grows at an average rate of 4.6 per cent per year between 2015 and 2030. The year on year growth rate are shown in **Error! Reference source not found.**.

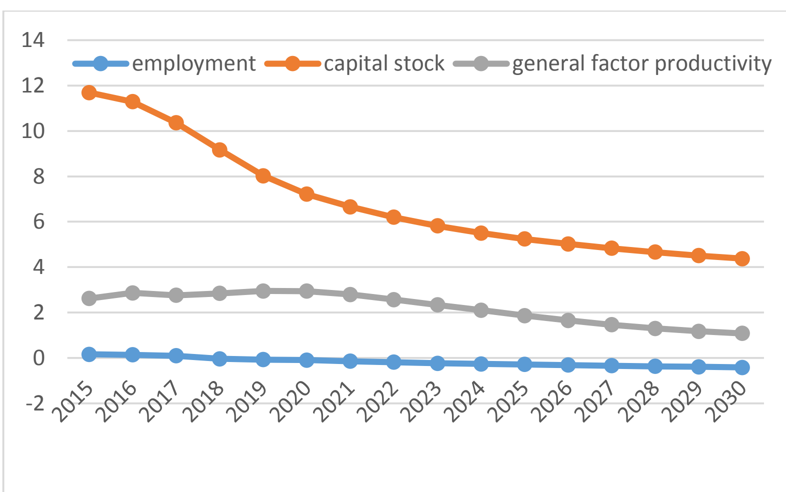
Figure 1: Annual percentage changes: real GDP



Source: Real GDP according to OECD iLibrary, accessed 09 Oct 2014 16:17 UTC (GMT); Co2 emissions: CHINAGEM, author's simulation.

On the supply side of GDP (Figure 2), capital accumulation plays the most important role. Employment growth is slow and turns to negative in 2020. The remaining gap is filled by the improvement in general factor productivity. The capital-labour ratio at the beginning of 2015 is close to 1. By 2030, capital and labour account for 56 per cent and 33 per cent of total value-added, respectively.

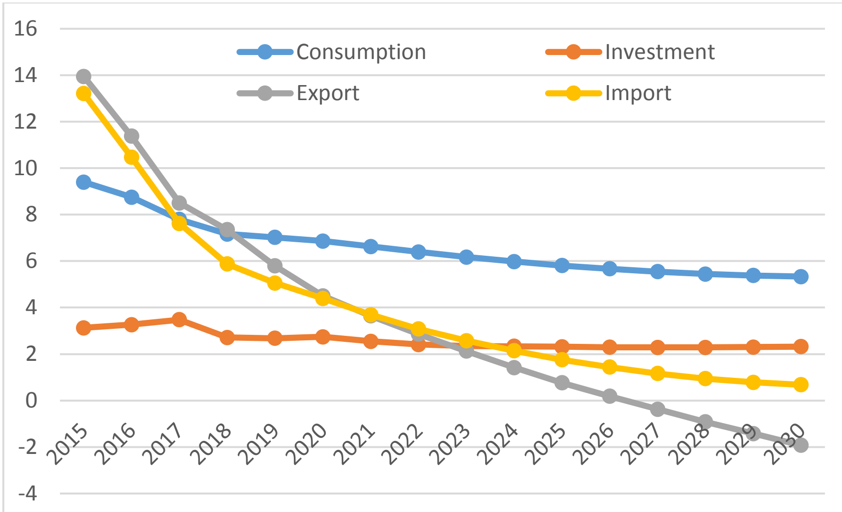
Figure 2: Annual percentage changes: supply side of GDP in the baseline, in real terms



Source: CHINAGEM, author's simulation.

On the demand side of GDP (Figure 3), consumption (private and public) grows faster than investment. Export and import grow at similar rates. Consumption and investment account for 49 and 45 per cent of GDP at the beginning of 2015, and by 2030, they account for 66 per cent and 34 per cent of GDP, respectively.

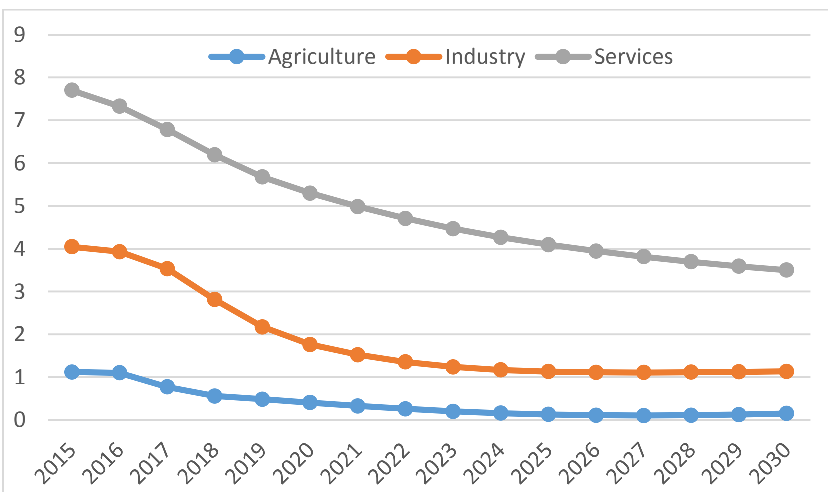
Figure 3: Percentage changes on the expenditure side of GDP, in real terms



Source: CHINAGEM, author's simulation.

Sector-wise (Figure 4), the service sector grows at an average of 5.0 per cent per year. The Industry sector and the agriculture sector grow more slowly, at 1.9 and 0.4 per cent per year, respectively. By 2030, the three sectors account for 55 per cent, 35 per cent and 10 per cent of total sector value-added, respectively.

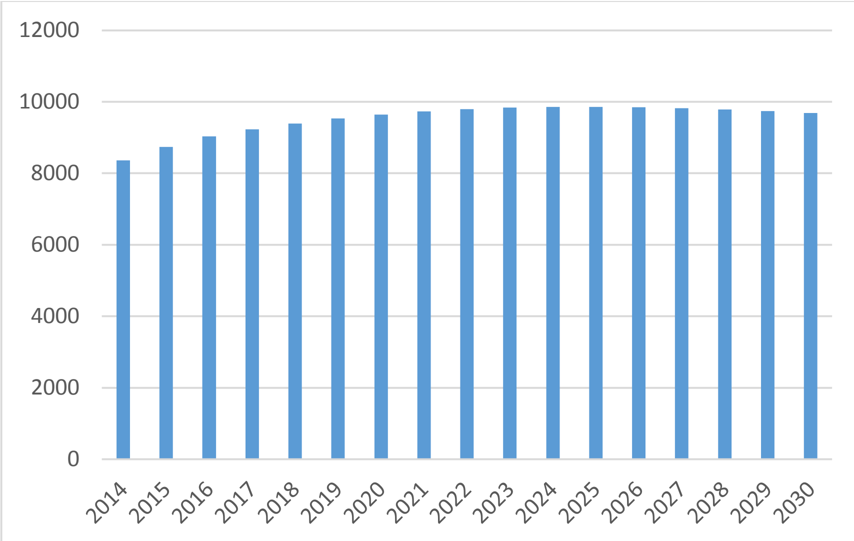
Figure 4 Percentage annual change in aggregated sectors value added.



Source: CHINAGEM, author's simulation.

Emissions grow slower than real GDP. CO2 emissions from fuel combustion grow at an average rate of 0.9 per cent per year. The annual emissions level rises from 8363 million tons in 2014, peaks at 9860 million tons in 2025 and gradually falls to 9787 million tons by 2030. Cumulative emissions between 2015 and 2030 reach 153 billion tons.

Figure 5 CO2 emissions from fuel combustion per annum (million tons).



Source: CHINAGEM, author's simulation.

4. The simulation

Key assumptions

First, real after tax labor wage is relatively stable in the short-run and gradually deviates from the baseline such that in the long-run real employment approaches the baseline. Equation 3.1 illustrates this labour market dynamic between year t and year t-1 (Dixon&Rimmer 2007).

$$W_p(t) / W_b(t) - W_p(t-1) / W_b(t-1) = \alpha [L_p(t) / L_b(t) - 1] \qquad \text{(E 3.1)}$$

where

W_p (t) and W_b (t) stand for real wage in policy case and BAU case in year t, respectively; L_p (t) and L_b (t) stand for labour employment in policy case and BAU case in year t, respectively; and parameter α satisfies the condition that $0 < \alpha < 1$.

When time t employment in the policy case is larger than it in the BAU case ($L_p(t) > L_b(t)$), real wage deviation in the policy case from the BAU case in time t becomes larger than the deviation in time t-1. But the adjustment in real wage is slower than the changes in employment rate. This is shown by the coefficient α being less than 1. Hence in year t real wage is not fully responsive to changes in employment. However in the long-run, real wage deviates in order to eliminate the deviations in labour employment. Hence employment level tends to approach the base-case in the long run. In this simulation, α is set to be 0.05. Moreover, the real wage rates here are post-tax real wages, thus changes in labour income tax rate is linked with changes in employment.

Second, in contrast to the labour market, capital is immobile in the short-run. Equation 3.2 illustrates this capital market dynamism (Dixon & Rimmer 2007).

$$EROR = (1/C)\ [\ln (KGR - KGR\_MIN) - \ln (KGR\_MAX - KGR)]$$

$$- \ln (TREND - KGR\_MIN) + \ln (KGR\_MAX - TREND$$

(E3.2)

where

KGR_MIN, KGR_MAX, TREND and C are minimum rate of capital growth, maximum rate of capital growth, natural rate of capital growth and a positive parameter denoting the sensitivity of capital growth to variations in the expected rate of return[2]. These exogenous variables adopt the values of -0.05, 0.2, 0.1 and 42, respectively (Yinhua et al 2010). EROR and KGR are expected rate of return and capital growth rate respectively. They are endogenous variables. The expected rate of return is determined by static expectation in this application. The static expectation is illustrated by Equations 3.3 to 3.5 (Dixon&Rimmer 2007):

$E_t [P_k (t+1)] = P_k (t) * [1+ \pi_t]$ [E3.3]

$E_t [P_i (t+1)] = P_i (t) * [1+ \pi_t]$ [E3.4]

and

$EROR_t = -1 + [P_k(t) / P_i (t) + 1 - D) * [(1 + \pi_t) / (1 + r)]$ [E3.5]

where

P_q and P_i represent capital price and investment price, respectively; D, π and r represent rate of depreciation, inflation and interest, respectively. Hence CHINAGEM assumes that investors adopt a static-expectation, in which they make decisions in year t on the assumption that capital rentals and asset prices will grow between years t and t+1 at the current rate of inflation and that real interest rates and tax rates will remain at their current levels.

Capital growth rate (KGR) on the other hand is illustrated by Equations 3.6 to 3.8 (Dixon&Rimmer 2007):

$K_t = K_{t-1} * (1 - D) + I_{t-1}$ [E3.6]

$K_{t+1} = K_t * (1 - D) + I_t$ [E3.7]

and

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[2] See Dixon and Rimmer (2007) p. 192 for derivatation.

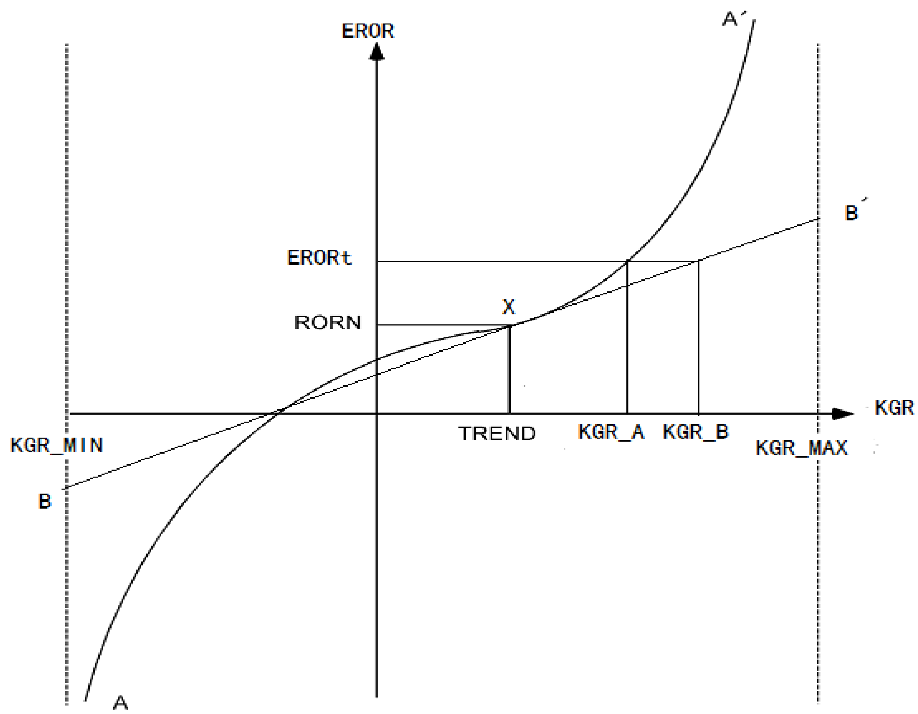
$KGR_t = (K_t / K_{t-1}) - 1$ [E3.8]

where

K_t and I_t represent capital and investment in year t, respectively.

Therefore by E3.2, the relationship between expected rate of return and capital growth rate adopts a shape that is shown in Figure 6.

Figure 6 ***Capital growth adjusts to changes in expected rate of return slowly***



Source: Dixon and Rimmer (2007), p.191.

The capital growth curve AA' in Figure 1 characterizes E3.2; and BB' is a 45 degree line that intercepts AA' at point X. It shows that if the expected rate of return at time t ($EROR_t$) deviates from the normal rate of capital return (RORN), the deviation of capital growth rate on AA' in time t from the trend of capital growth (KGR_A – TREND) would be smaller than the deviation on BB' (KGR_B – TREND). In this way, capital adjusts to external shocks more slowly than expected rate of return does.

Third, households' average propensity to consume with respect to disposable income is assumed to be constant. Hence nominal consumption follows nominal household disposable income. Real government expenditure is assumed to be keeping pace with real private consumption, except in the lump-sum scenario in which the government keeps the deficit-to-GDP ratio by altering the public expenditure levels.

Finally, the consumption price level, or the CPI, is used as the numeraire.

Last, a carbon tax of 50 yuan per ton of CO_2, at current price level, is imposed in 2015 and gradually increased to 200 yuan per ton by 2030.

A stylized model

We use the following stylized model to illustrate the simulation results:

$$\frac{w}{p_{fe}} = \frac{\overline{w}}{p_c} \frac{p_c}{p_{gdp}} \frac{p_{gdp}}{p_{fe}} \qquad \text{(E 3.2)}$$

$$\frac{w}{p_{fe}} = MP_l\left(\frac{\overline{K}E}{L}\right) \qquad \text{(E 3.3)}$$

$$Y = F(\overline{K}, L) + \mathrm{T} \qquad \text{(E 3.4)}$$

On the left hand side of equation (E 3.2) and (E 3.3), the ratio of nominal labour wage rate (w) to the price of the factor-energy bundle (Pfe) represents the real cost of labour faced by the producers. The price of the factor-energy bundle is a weighted average index of labour, capital land and energy prices.

The first ratio on the RHS of equation (E 3.2) is the nominal labour wage rate divided by the general price of consumption goods (Pc). This ratio represents the real wage faced by the employees.

The second term on the RHS of equation (E 3.2) is the price index for household consumption, or the CPI, relative to the GDP price index. Given that the GDP price index is a weighted average of the components on the expenditure side of the GDP, this term often denotes the relative changes between CPI and other price indexes on the expenditure side, such as the investment price index.

The last term on the RHS of equation (E 3.2) is the ratio of the GDP price relative to the price of the factor-energy bundle. The numerator is a price index including the factor prices and the indirect taxes, the denominator is a price index including the factor prices and the energy prices. Hence the ratio of the two indexes reflects the ratio of the indirect taxes relative to the level of the energy prices.

Equation (E 3.3) sets the zero profit condition. It states that marginal cost of labour to the producers, on the LHS, should be equal to the marginal productivity of labour, on the RHS. The RHS of equation (E 3.3), the marginal productivity of labour, is an increasing function of the capital-energy to labour ratio (KE/L) because the more capital-energy a given number of labour can use, the more productive these labour can be.

Finally, equation (E 3.4) states that real GDP (Y) is a positive function of labor and capital, plus the amount of the indirect taxes.

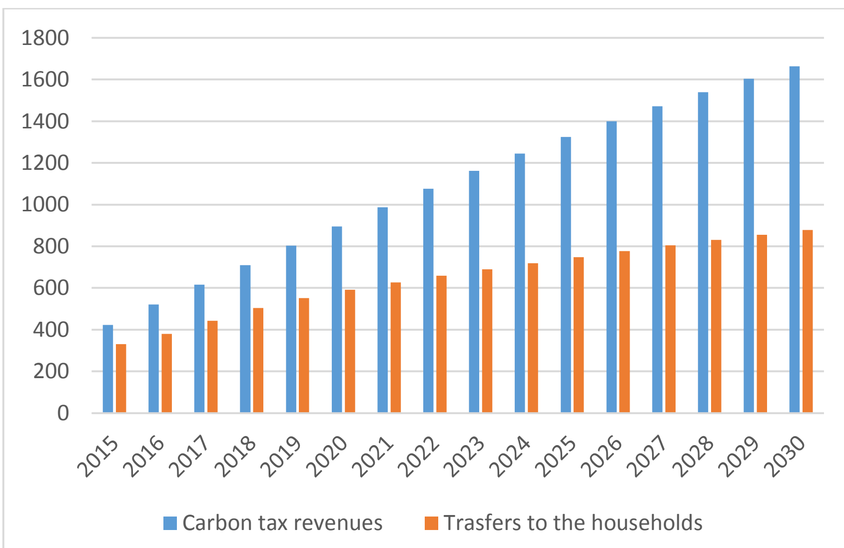
Under our assumption, capital stock and real wage are relatively fixed in the short-run. We use a horizontal bar on top of these variables to denote this.

5. Simulation results

Carbon Tax with lump-sum transfer [CG87_126B_T07R_001P]

We first show the impact of carbon tax with a lump-sum transfer. The government uses the carbon tax revenues to make direct lump-sum transfers to the households, while maintaining the deficit-to-GDP ratio at the base-case level. Figure 7 shows the amount of revenues collected from the carbon tax and the amount of transfers made to the households, per annum. In order to keep the deficit-to-GDP ratio at the base-case level, the amount of the transfers needs to be less than the carbon tax revenues. The difference has to be used to cover the erosion of the tax base, which reduces the tax revenues collected from the pre-existing, non-environmental taxes. The difference becomes larger in the later years of the simulation. In 2015, the transfer amounts to 78 per cent of the carbon tax revenues, while in 2030 it only accounts for 53 per cent. Such an increasing difference reflects the increasing distortion of the carbon price as it increases from 50 RMB per ton of Co2 in 2015 to 200 RMB per ton in 2030.

Figure 7: carbon tax revenues and cash transfers to the households, per annum (billion RMB)

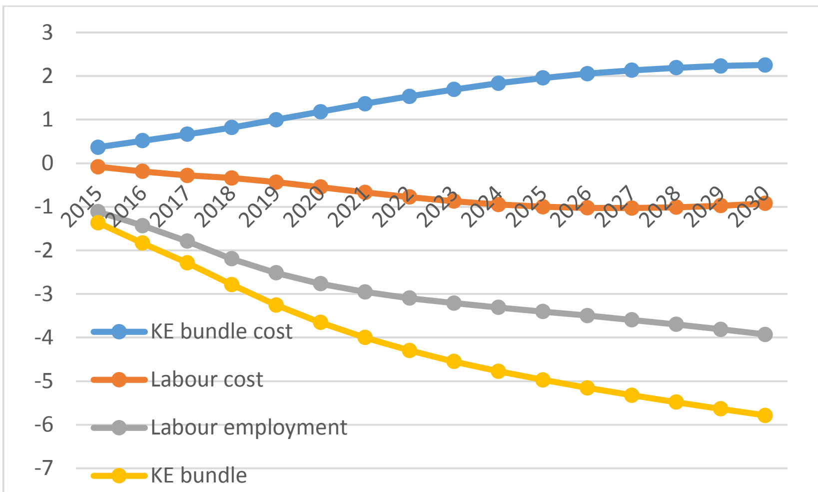


We begin to look at the simulation results from the producers' perspective. When producers choose between the KE bundle and labour[3] to produce the FE bundle, they face the relative price changes as shown in Figure 8. The real cost of the KE bundle to the producers, which is the ratio of the price of the capital-energy (KE) bundle to the price of the factor-energy (FE)

[3] we ignore land for the simplicity of the argument, because land is a small part of the economy and is assumed to be fixed at the base-case level

bundle, increases due to the higher energy prices. Hence the real cost of labour to the producers, which is the ratio of the nominal labour wage to the price of the FE bundle, must fall. Over time, as the level of the carbon price increases, the KE bundle becomes increasingly more expensive than labour, thus producers substitute labour for the KE bundle. Therefore negative deviation of the KE bundle from the base-case is stronger than that of labour employment.

Figure 8 Percentage deviation from the base-case, labour employment, the KE bundle and the real unit cost of the KE bundle and labour to the producers

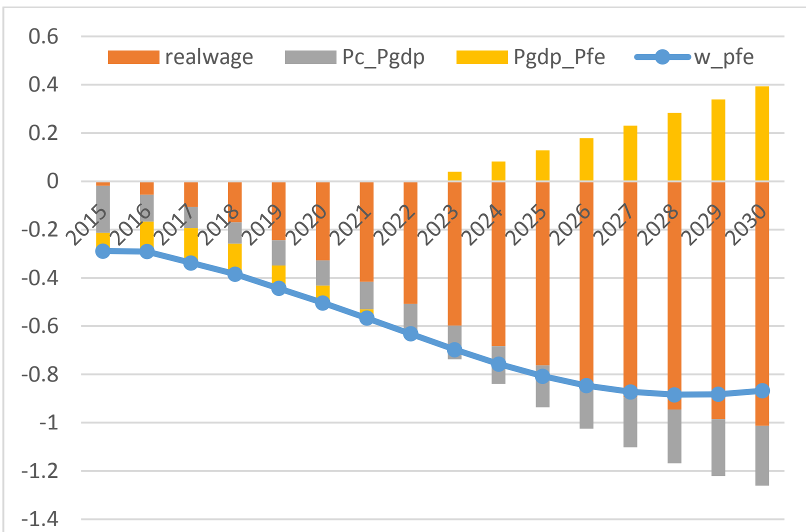


The extent of the substitution is mainly determined by the exogenously chosen CES variables and the cost ratio between the KE bundle and labour. Given that the CES value between the KE bundle and labour is 0.5 for all industries, the percentage deviation of the KE/L ratio should be roughly equal to -0.5 times the KE/L cost ratio. As it is shown in Figure 10, the simulation results show that the KE/L cost ratio deviates from the base-case by 0.45 per cent in 2015 and 3.17 per cent in 2030. By an estimation without the model, this would lead the KE/L ratio to deviate from the base-case by -0.22 in 2015 and -1.59 in 2030 (this is shown by the line 'estimated KE/L ratio' in Figure 10). The model simulation produces a set of KE/L ratio deviations that closely track the estimated line, such that the simulated deviations are -0.25 per cent and -1.86 per cent in 2015 and 2030, respectively (this is shown by the line 'simulated KE/L ratio' in Figure 10). Therefore the relative increase of the cost of the KE bundle is the main reasons for the negative deviation of the KE bundle.

The structural composition of the economy also contributes to the substitution of labour for the KE bundle. Notice that the negative deviations of the KE/L ratios obtained by the estimation are not as strong as the negative deviations obtained by the simulation. This is because the carbon price puts more downward pressure on the industries that are relatively more carbon-intensive, such as the electricity generation industry and the steel industry, which also tend to be more capital- and energy-intensive. Hence the reducing share of these industries also contribute to the negative deviation of the KE/L ratio from the base-case – albeit by a much smaller extent than the price substitution does.

Labour is lower than the base-case because of the relatively small fall in the real unit labour cost. Figure 9 shows a decomposition of the real unit labour cost using Equation 3.2. Real wage is sticky in the short-run. The price of consumption tracks the general GDP price. The increase in indirect tax, in the form of carbon tax, is also close to the increase in energy prices. As the deviations of the RHS terms are all small, the deviation of the LHS term, the real labour cost, is also small. Under the zero profit condition (E 3.3), this means a small decrease in the marginal productivity of the labour and hence a small reduction in the KE/L ratio. Since the carbon price directly impacts the energy price and generates a relatively large fall in producers' demand for the KE bundle, labour needs to fall below the base-case in order to maintain a small negative deviation in the real labour cost.

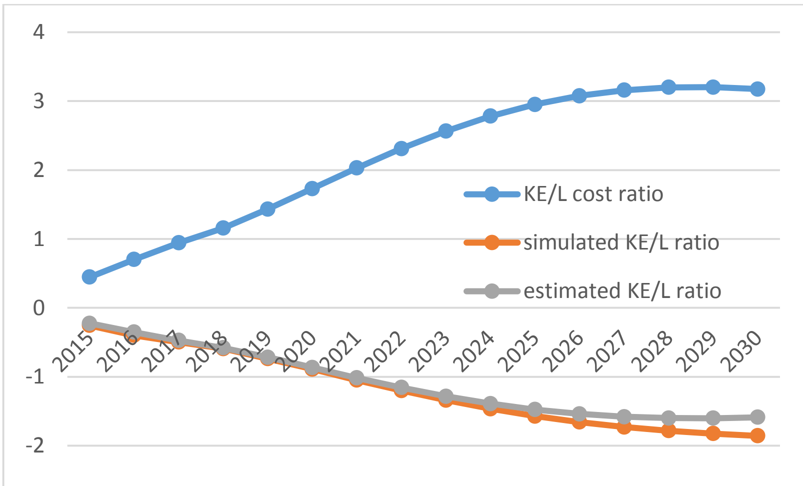
Figure 9 Percentage deviation from the base-case: a decomposition of the real unit labour cost to the producers.



Note: the stacked histograms represent the three terms on the RHS of E 3.2, the dotted line represents the LHS of E 3.2.

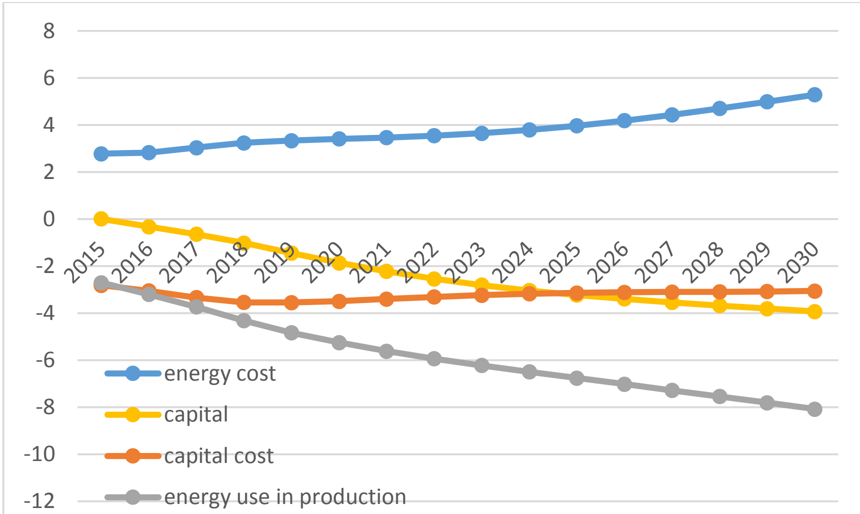
Notice that in Figure 9, the direction of the contribution of the third term on the RHS is initially negative but turns to positive in later years of the simulation. The initial negative contribution could be due to the erosion of the tax-base. As the carbon price reduces the base of the pre-existing, non-environmental taxes, the amount of the total indirect tax revenues collected is slightly lower than the increase in energy price, which is more representative of the carbon price. However the energy price include both fossil fuel energy prices and renewable energy prices. Over the years, the carbon price reduces the share of former and increases the share of latter in the energy make-up. Thus the price of the fossil fuel energy, which bears the burden of the carbon price, is attached to a decreasing weight in calculation of the overall energy price. Hence energy price increases slower than the level of the indirect taxes. The simulation suggests that rate of decarbonisation in the energy make-up is rapid such that it dominates the distortion to the pre-existing tax base. Therefore the direction of the contribution becomes positive in the later years of the simulation.

Figure 10: percentage deviations in KE/L cost ratio, KE/L ratio and the estimated KE/L ratio.



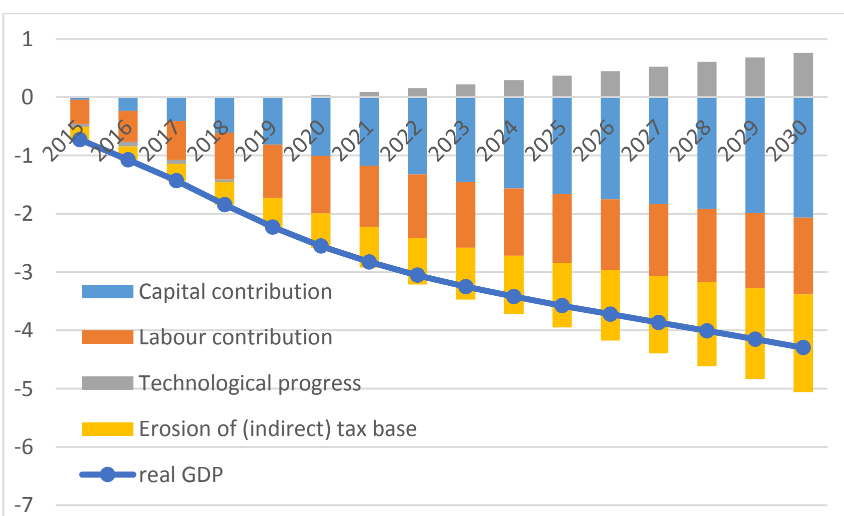
Taking producers' decision-making a level downward, next, we consider the KE bundle. Figure 11 shows the percentage deviations in the capital stock, the use energy in production, the real unit cost of capital and the real unit cost of energy to producers. The real unit cost of capital is the ratio of the nominal capital price to the price of the KE bundle; the real unit cost of energy is the ratio of the energy price to the price of the KE bundle. Due to the carbon price, the real cost of energy increases while the real cost of capital falls. The producers thus substitute capital for energy. The extent of the substitution obeys that the percentage deviation in the capital/energy ratio equals to -0.5 times the percentage deviation in the capital/energy cost ratio.

Figure 11 Percentage deviation from the base-case, capital stock, energy use in production and their respective real unit cost



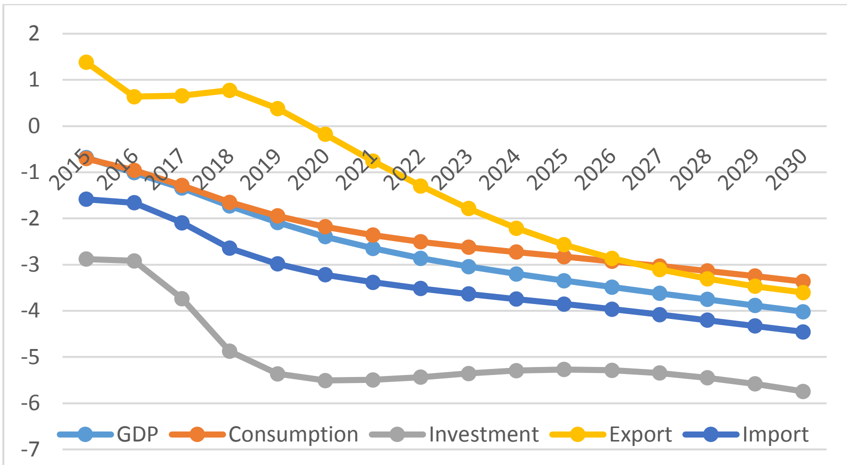
The labor and capital movements drive the movements of real GDP in Figure 12. In the short-run, as capital stock is fixed, the negative deviation of labor from the base-case accounts for the majority of the negative deviation in real GDP. Overtime, because labour employment has a tendency to approach back to the base-case, and capital becomes mobile, the majority of the fall comes from the reduction in capital stock. In addition, the erosion of the tax base contributes to an increasing amount of the negative deviation in real GDP, due to the increasing carbon price. Moreover, technological progress makes a positive and increasing contribution. The carbon price stimulates the growth of the service sector, which has a faster rate of technological progression in the base-case. Hence the positive technological contribution is due to the structural effects of decarbonisation.

Figure 12: Percentage deviation from the base-case, a decomposition of the supply side of the GDP, recycling carbon pricing revenues by lump-sum transfers to the households.



We show the percentage deviations on the expenditure side of GDP in Figure 13. Consumption, both private and public, track GDP movements as the average propensity to consume is fixed. Consumption is slightly above GDP thanks to the lump-sum transfer to the households. Investment falls due to the fall in real return to capital. Since the fall in real return to capital is big, the fall in investment is larger than the fall in consumption, requiring the trade balance to improve to maintain the equilibrium between GDP supply and demand.

Figure 13: percentage deviations on the expenditure side of GDP from the base-case



The deviation in emission growth is further below the base-case than real GDP. Figure 14 shows the percentage deviations in emissions and the emission intensity of GDP. The latter is measured as the percentage deviation in emissions divided by the percentage deviation in real GDP. By 2030, emission and emission intensity of GDP are 15.0 per cent and 11.5 per cent below the base-case, respectively. Peak emission level under the policy (lump-sum) case occurs in 2021 at 8873 million tons, 4 years earlier than and 983 million tons lower it does in the base-case, respectively (Figure 15). The cumulative emission level under the policy (lump-sum) case between 2015 and 2030 is 138 billion tons – 15 billion tons or 9.8 per cent less than it is in the base-case.

Figure 14: percentage deviations in emissions and emission intensity of GDP from the base-case

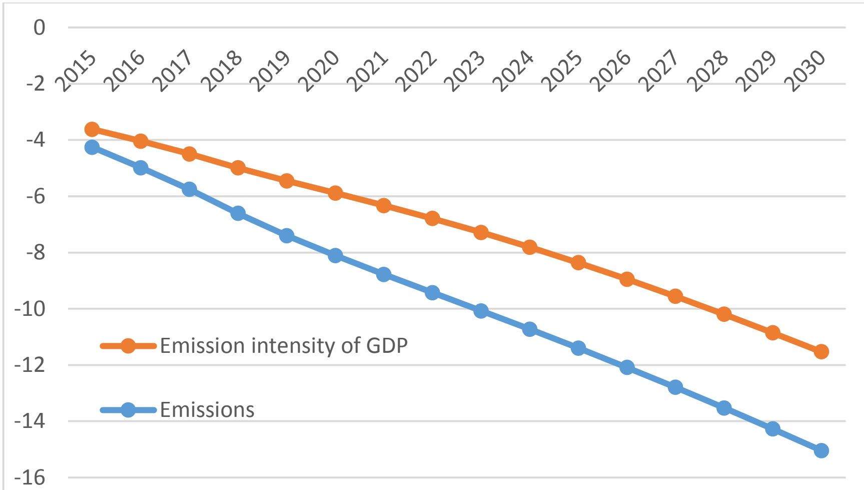
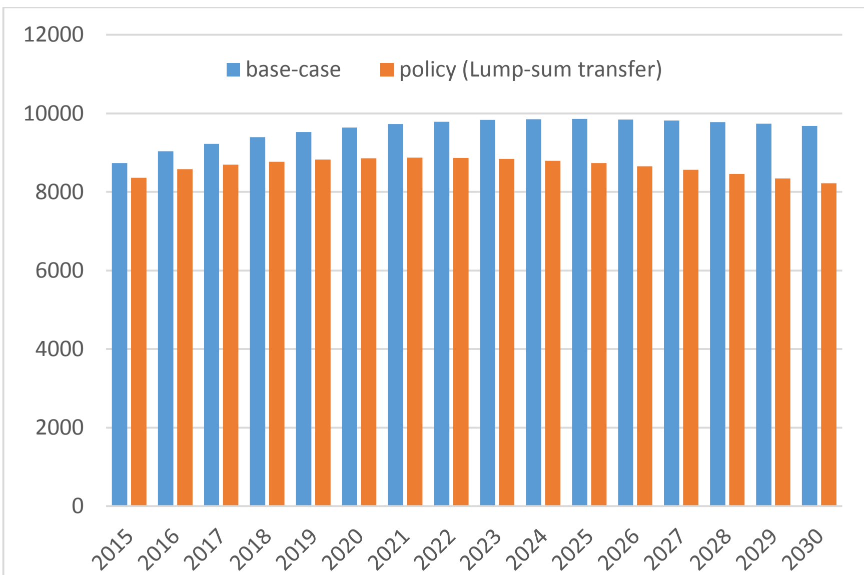


Figure 15 Annual emission levels (million tons), base-case and carbon pricing with lump-sum transfer to the households.



The nation-wide decarbonisation can also be shown on the sectoral scale. Table 4 shows the percentage deviation of the sectoral output levels from the base-case, in 2030. The agriculture sector faces the least setback because it is the least carbon-intensive. The manufacture sector and the service sector face the similar setback, despite that the manufacture sector is more carbon-intensive than the service sector. This is because the manufacture sector sells a larger share of its outputs as exports, which, as shown above, faces a relatively mild setback. Construction faces a relatively large setback due to the negative deviation in investment, as most of the construction sector outputs are sold as investment goods. Among the energy sectors, coal is the most negatively affected because of its high carbon-intensity. Electricity and oil also suffers negative setbacks, although not as severe as coal. The negative deviation of gas output is shown to be even smaller than manufacture, services and construction. As the least carbon-intensive fossil fuel source, gas is adopted as the main alternative to oil and coal.

Table 4: Percentage deviation from the base-case in 2030, sectoral output level.

Sector	Percentage deviation from the base-case, 2030	Sector	Percentage deviation from the base-case, 2030
Agriculture	-2.5	Construction	-5.5
Gas	-3.4	Oil	-6.8
Manufacture	-4.4	Electricity	-6.9
Services	-4.6	Coal	-16.9

The electricity sector is the largest source of emissions. Coal-fired power generation produces 11.5 per cent less output than the base-case level in 2030 alone. The negative deviation in all the other forms of electricity generation are smaller than the negative deviation of electricity supply.

Table 5 shows the deviation of the output levels of electricity generation by fuel source in 2030. Coal-fired power generation produces 11.5 per cent less output than the base-case level in 2030 alone. The negative deviation in all the other forms of electricity generation are smaller than the negative deviation of electricity supply.

Table 5 Percentage deviation from the base-case, 2030: electricity supply and electricity generation by fuel

ElecSupply		-6.9	
ElecCoal	-11.5	ElecNuclear	-1.1
ElecGas	-3.7	ElecHydro	-1.3
ElecOil	-4.9	ElecOtherR	-1.4

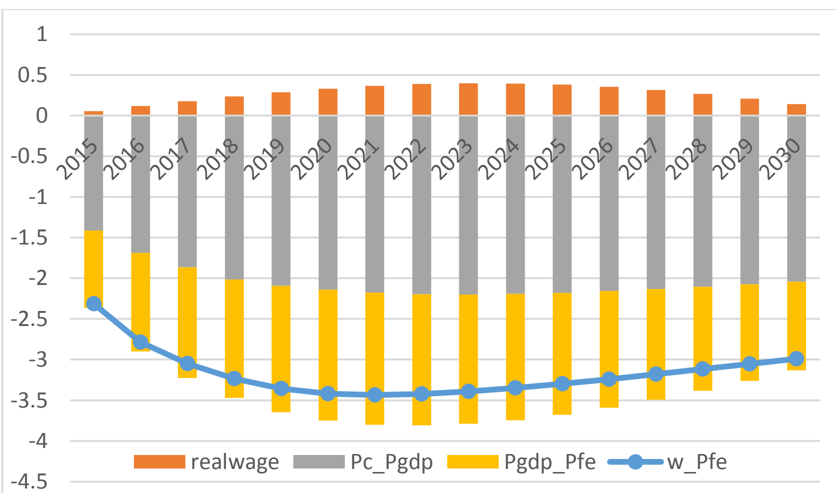
Carbon tax and revenues-recycling mechanisms

We examine six alternative, non-lump sum revenues recycling mechanisms. Under these scenarios the deficit to GDP ratio (in nominal terms) is controlled at the base-case level by using the carbon tax revenues to reduce other forms of revenues, namely investment tax, consumption tax, export tax, intermediate tax, labor tax and capital tax. We use E 3.2 to illustrate the results.

Reducing consumption tax rate

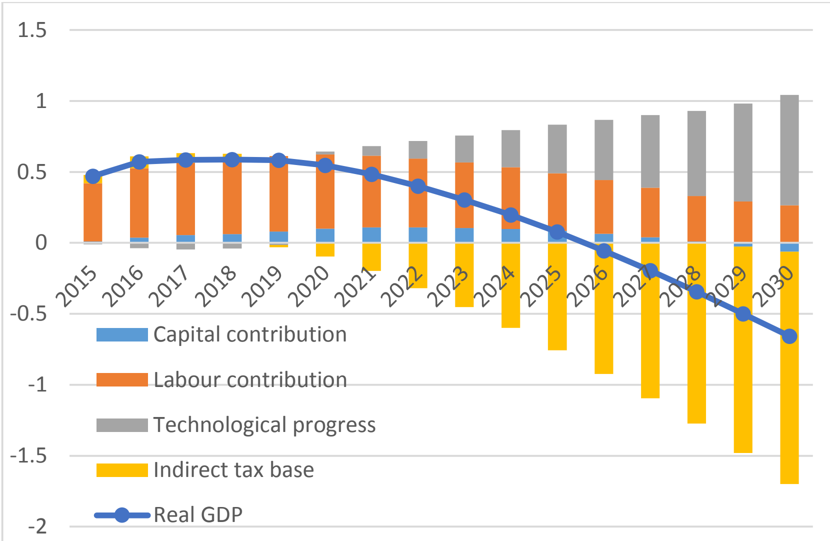
When consumption tax rate is reduced to keep the deficit/GDP ratio, the overall size of the indirect tax does not increase as much as in the lump-sum transfer case, because the increase in carbon tax revenues is roughly cancelled by the fall in consumption tax revenues. Hence the ratio of the level of indirect tax to energy price (i.e. the third term of the RHS of E 3.2) must fall (Figure 16). The second term on the RHS of equation (E 3.2) also falls because the lower consumption tax rate reduces the ratio of the price of the consumption goods relative to the GDP price. The reduction in these two terms on the RHS lead to large negative deviations in the real cost of labour to the producers. Comparing with the negative deviations of w_Pfe in Figure 10, those in **Error! Reference source not found.** are much stronger. Given the strong fall in the labour cost, the ratio of the KE bundle to labour must also fall by a larger extent. Therefore labour employment increases.

Figure 16: producers' real labor cost and its contributions: recycling carbon tax by reducing consumption tax, % deviation from the base-case



Note: the stacked histograms show variables on the RHS of the equation E 3.2; the dotted line show the LHS of E 3.2.

Figure 17 Percentage deviation from the base-case, a decomposition of the supply side of the GDP, recycling carbon pricing revenues by reducing consumption tax rate.



In the short-run, the higher employment level dictates that the real GDP deviates positively from the base-case. As shown in Figure 17. With deviations in labour and capital being relatively small, in the long-run, the erosion of the tax base reverses the deviation of real GDP into negative.

Reducing investment tax rate

Similar to the scenario of reducing consumption tax, reducing investment tax also leads to strong negative deviations of the Pgdp_Pfe ratio (Figure 18). Opposite to previous scenario though, reducing investment tax creates positive deviations in the Pc_Pgdp ratio because of the lowered investment price embodied in the GDP price. Overall the negative deviation on the LHS is small and hence generates a mild negative deviation of labour employment (Figure 19).

Figure 18

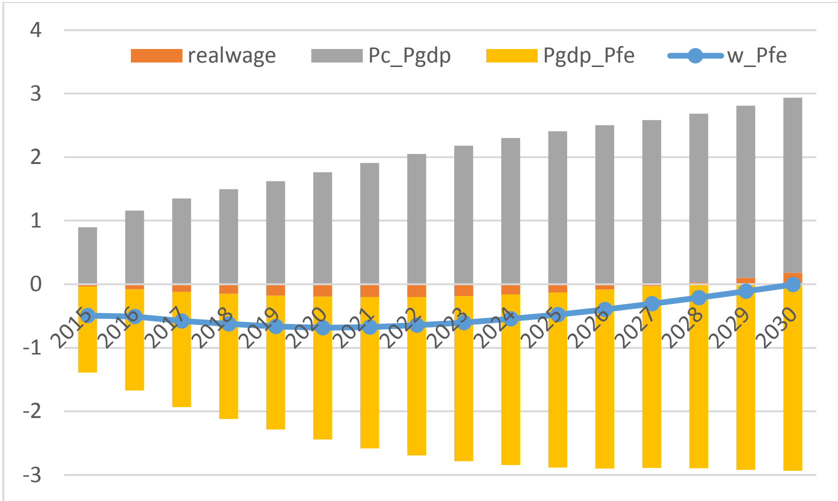
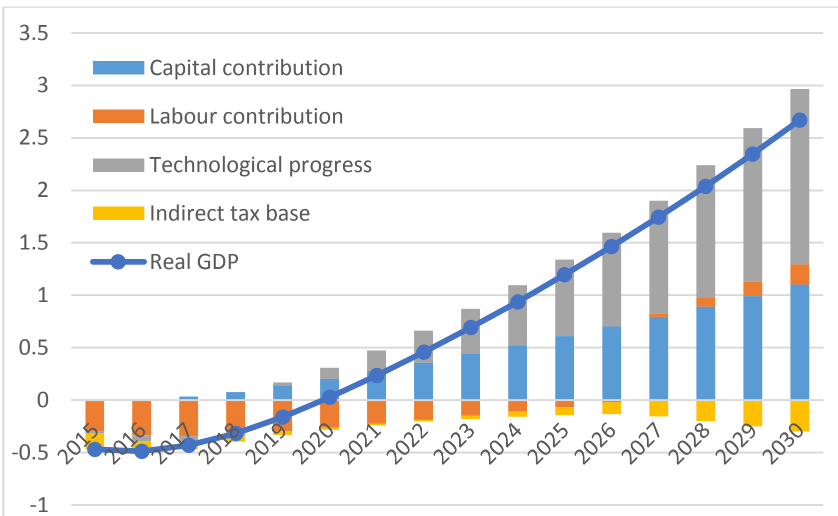


Figure 19



Real GDP deviates negatively in the short-run due to this small negative deviation in labour employment. The deviation in real GDP gradually moves into positive in the long due to first, the accumulation of capital stock, as a result of cheaper investment costs; second, the positive contribution from technological progress of investment embodied in the base-case; and third, a relatively mild tax base erosion.

Reducing export tax rate

The mechanisms of recycling carbon pricing revenues by reducing export tax are similar to those by reducing investment tax. The key similarity arises from the balancing effects of the second and the third terms on the RHS of equation 3.2. However the magnitudes of such balancing effects are not quite similar (Figure 20). On the one hand, export accounts for a smaller share of GDP than investment[4], hence the reduction in export price leads to a smaller increase in the second term on the RHS. On the other hand, the exporting industries are less carbon-intensive than investment activities. A lower export tax rate increases the share of less carbon-intensive part of the economy, hence leads to a smaller increase energy prices. Therefore overall, the negative deviation in the real unit cost of labour is larger than those in the investment tax reducing scenario. Yet, these negative deviations are still larger than those in the consumption tax reducing scenario because of the cancelling effects between the second and third terms.

Figure 20

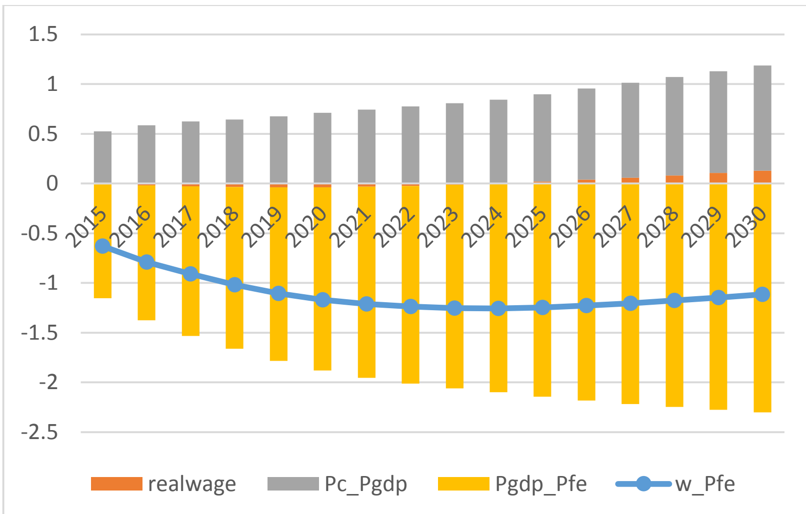
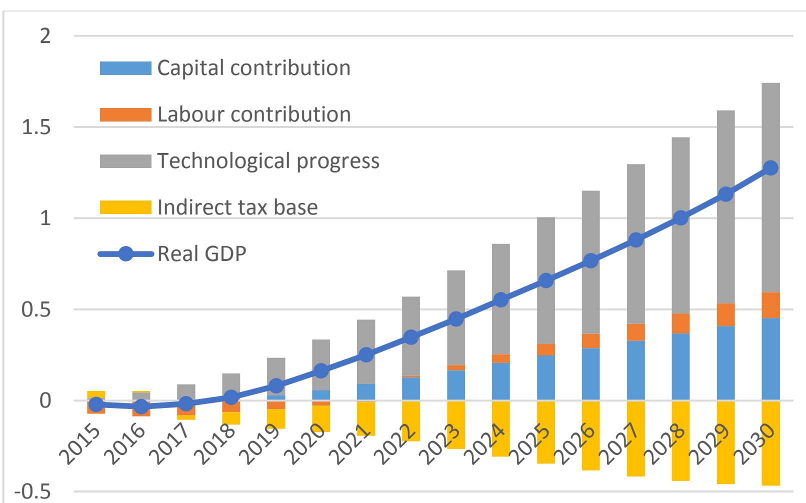


Figure 21



[4] Export accounts for 32% of GDP, investment 45%, in the base-case, end of 2014.

Deviation in employment levels are shown to be even smaller under the given path of real labour cost. In the long-run, the positive deviation in capital stock is smaller than the investment tax cutting scenario. The positive contribution from technological progression is also smaller than in the previous scenario, thanks to a faster rate technological improvement from the exporting sector in the base-case. Overall, real GDP initially stays at the base-case level, then gradually deviates positively, though the magnitude is smaller than in the investment tax reduction scenario.

Reducing tax rates on intermediate inputs to production

Unlike any of the previously discussed revenues-recycling mechanisms, reducing the tax rates on intermediate inputs does not generate significant deviations in the second term on the RHS of E 3.2 (Figure 22). Hence the only source of price impact derives from the imposition of the carbon itself. Therefore, the negative deviation in the real unit cost of labour is less than the consumption tax cut case but more than the other two cases.

Figure 22

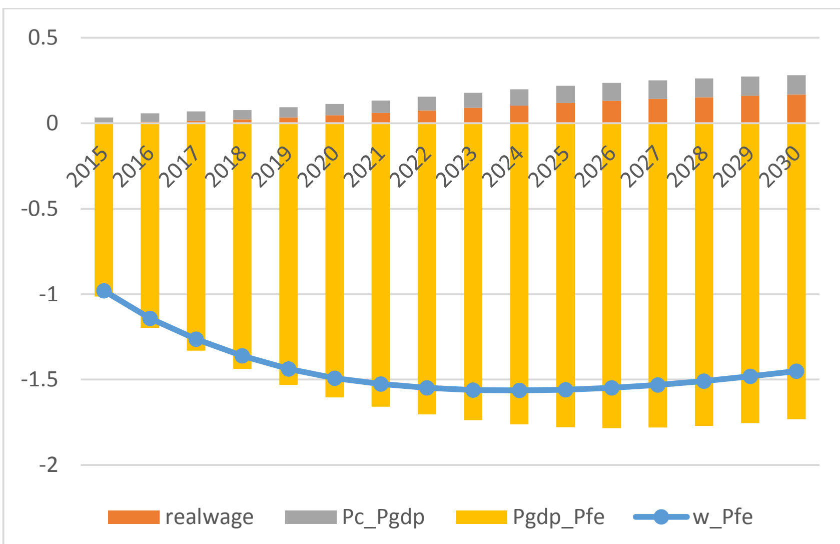
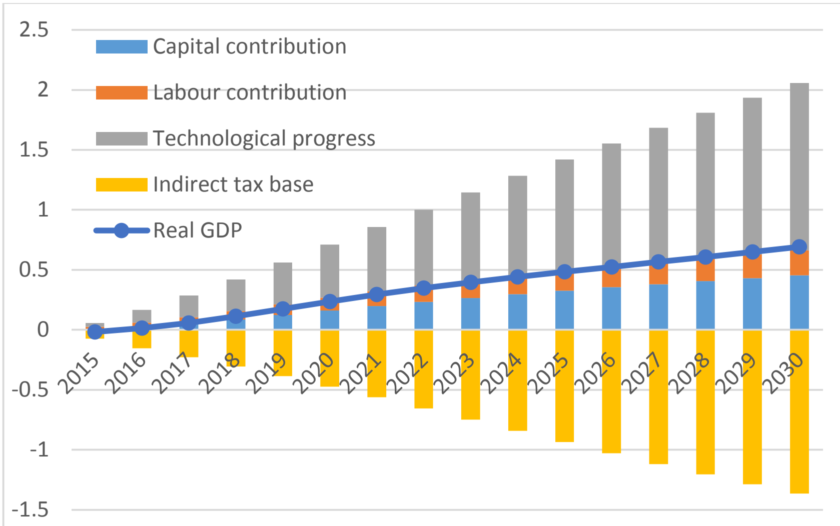


Figure 23

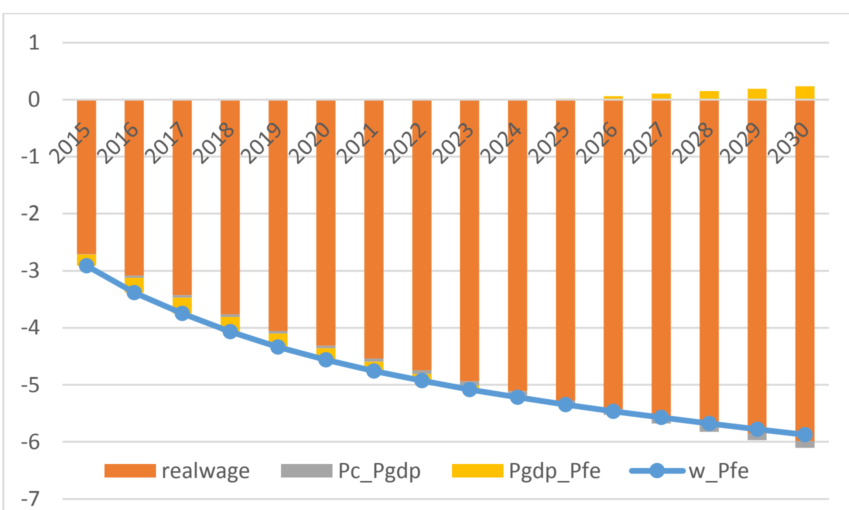


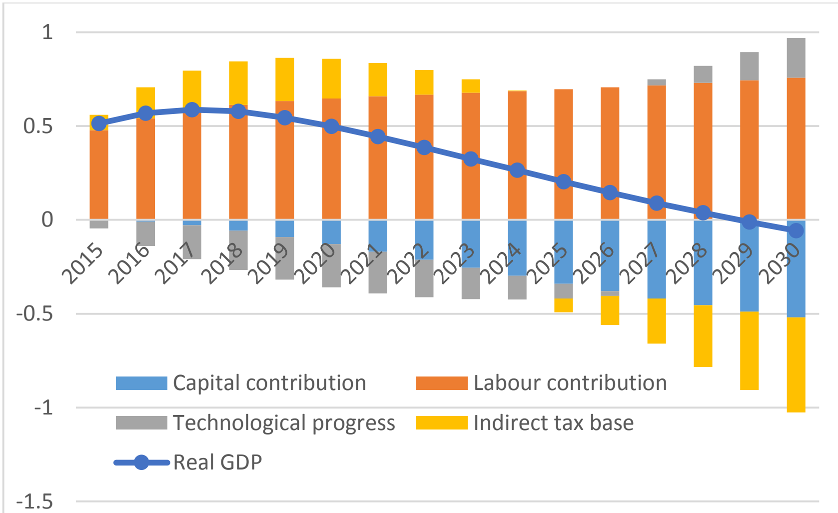
The simulation shows that the contribution of labour to real GPD is positive and small, so is the contribution of capital. The negative contribution of tax base erosion is roughly cancelled out by the positive contribution of technological progression, leaving deviations in real GDP to follow the deviations in factors of production.

Reducing labour tax rate

The price changes with regard to Equation 3.2 are straightforward. The only term that matters on the RHS is real wage. The reduction in labour tax rate leads to a large negative deviation in real wage from the base-case (Figure 24). In addition, since labour tax is a form of income tax, the total level of indirect tax remains at the base-case level. Hence the increase in indirect taxes still offset the higher energy prices and keeps the third term of the RHS to be close its base-case values.

Figure 24





The much cheaper labour cost is surely to increase labour employment, which constitutes the strongest positive force to increase real GDP in the short-run. Over the long-run, however, as producers substitute labour for capital, capital starts to make negative contributions to real GDP. This, together with the worsening tax base erosion, largely reduces the positive deviations in real GPD by 2030.

Reducing capital tax rate

This scenario is the most reminiscence of the lump-sum transfer scenario. The mechanisms of the price changes with regard to Equation 3.2 are similar between these two scenarios (Figure 25). Unlike any of the non-lump sum revenues recycling scenarios discussed earlier, the reduction in capital tax rate does not directly impact any of the three terms on the RHS of Equation 3.2. That said, the deviations in this scenario are smaller than those in the lump-sum transfer scenario.

Figure 25

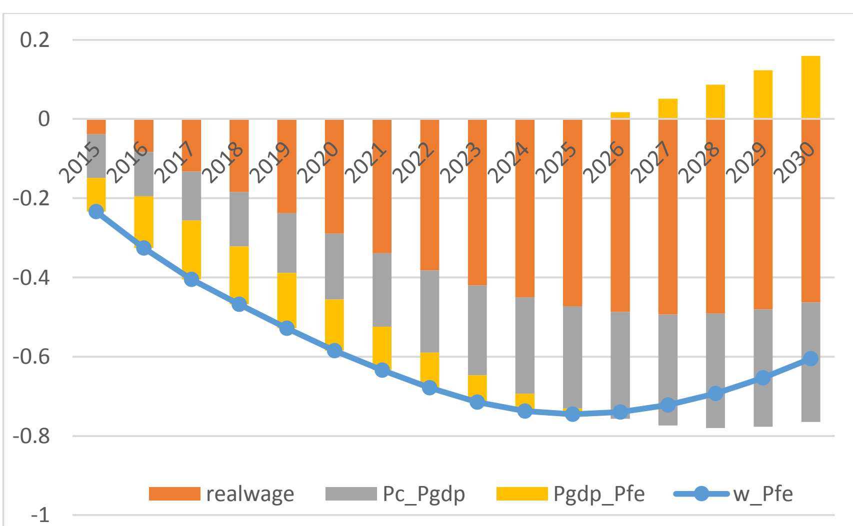
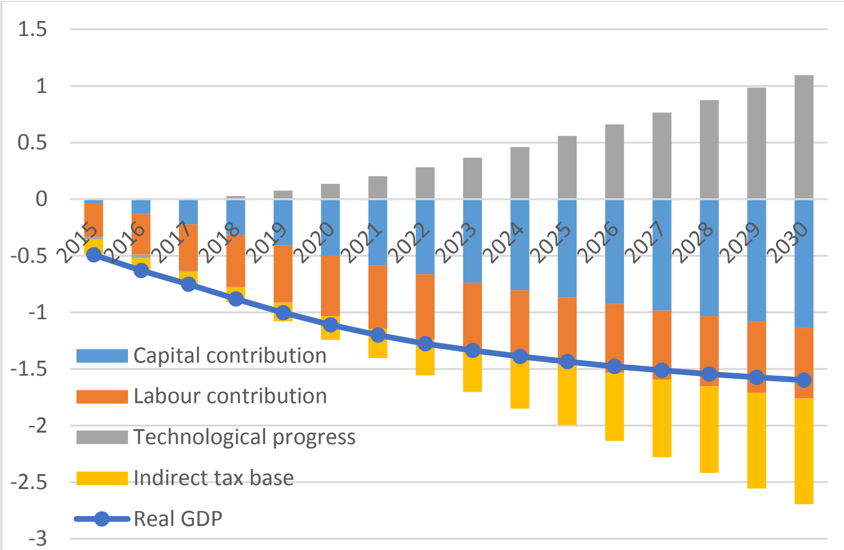


Figure 26

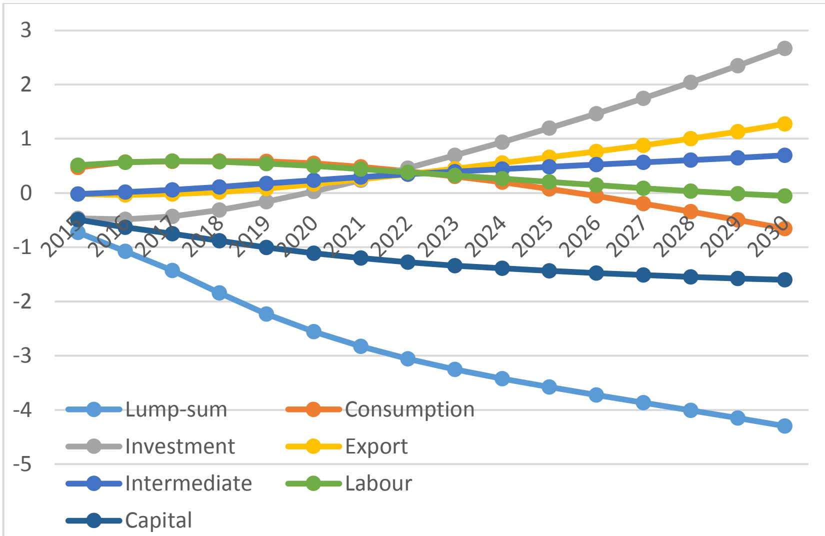


As a result, the negative deviations in real GDP are also smaller than those under the lump-sum transfer case (Figure 26). The reduction of capital tax rate uniformly reduces the negative deviations in labour, capital and the erosion of the tax base; it also leads to higher positive deviations in the contribution of technological progression. Part of these could be attributed to the gain of the capital-intensive industries who now face lower capital costs. Apart from this, given the almost identical economic mechanisms at work, the lower negative deviations shown from the current scenario are perhaps best representative of the benefits of welfare improvement of non-lump sum revenues recycling.

Comparing the results

We compare the deviations in real GPD under different revenue recycling scenarios in Figure 27. Using real GDP to indicate the efficiency dividend, all the non-lump sum revenue recycling mechanisms satisfy the weak double dividend condition throughout the policy years. Reducing labour tax rate and consumption tax rate lead to strong double dividend conditions in the short-run but not in the long-run. Reducing export tax, intermediate tax and investment tax do not lead to strong double dividend conditions in the short-run but do so in the long run. Reducing capital income tax is the only non-lump sum transfer scenario that does not realize a strong double dividend in any of the policy years.

Figure 27



The deviations in real GNP[5] show a somewhat different picture (Figure 28). The weak form of the double dividend exists in all scenarios across the policy years, except the investment tax cutting scenario, which showed negative deviation of real GNP in the short-run. Hence the most significant case of difference is that when cutting investment tax rate, real GNP is below the base-case in all policy years. This is because the reduction in investment tax significantly reduces the price of investment, which in turn reduces the GDP price level. The lower GDP price level means nominal GDP is much lower than real GDP. Since nominal GDP determines nominal GNP. Given that the GNP price level, which is a composition of private and public prices, is not directly affected by the shocks, so the deviations in GNP price level is also small. Therefore following nominal GDP, real GNP is also much smaller than real GDP.

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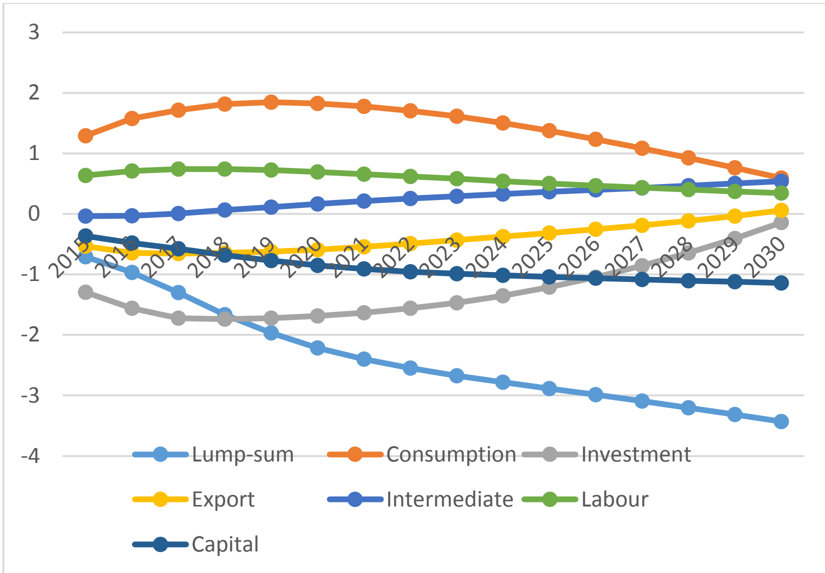
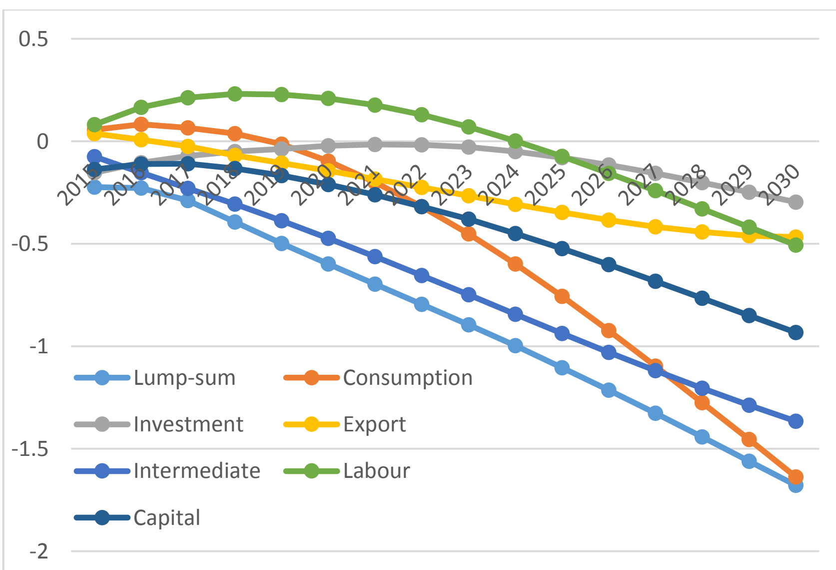
[5] Deviations in real consumption closely follow real GNP, so we do not show them here.

Figure 28



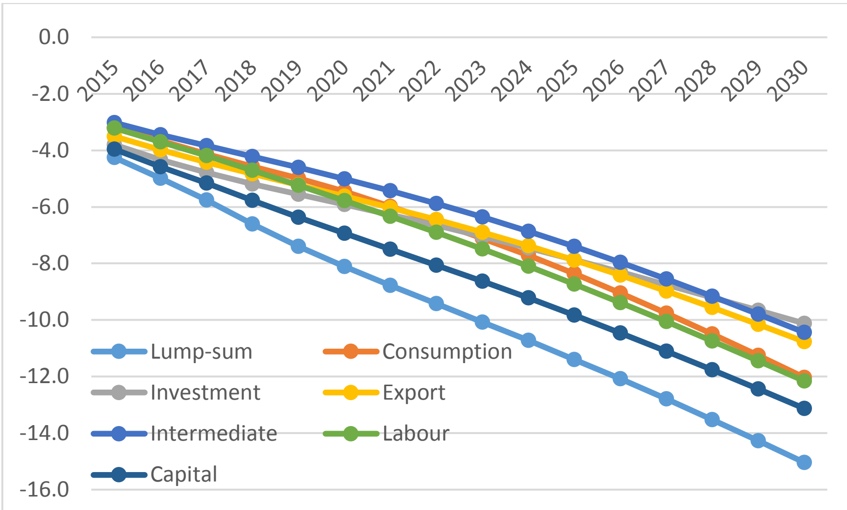
Real GNP increases the most when recycling carbon pricing revenues by cutting consumption tax rates. Lower consumption tax should reduce consumer's price level, but as CPI is fixed as the numeraire, other price indexes on the expenditure side need to increase. Hence the GDP price level deviates positively form the base-case, pushing nominal GDP to be higher than real GDP, so, as discussed above, also pushing real GNP to be higher than real GDP.

Figure 29



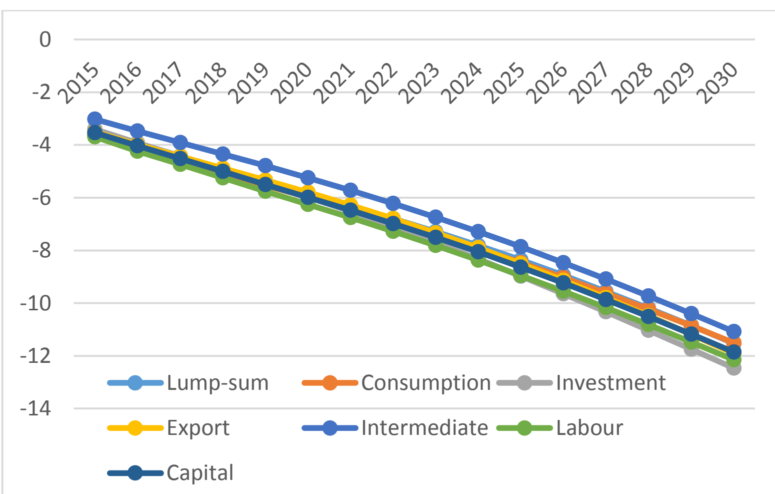
We compare the contributions of tax base erosion to real GDP in Figure 29. Using tax base erosion as an indicator for efficiency, the weak form of the double dividend is evident in all non-lump sum revenues recycling scenarios throughout the policy years. The strong form was found in the consumption, export and labour tax cutting scenarios, in the short run. By 2030, all tax base erosions make negative contributions to real GDP.

Figure 30



In spite of the positive deviations in real GDP under some scenarios, the growth rate of CO2 emissions are lower than the base-case in all scenarios throughout the policy years (Figure 30). However the higher the real GDP, the higher the emissions levels.

Figure 31



There thus appears to be a trade-off between environmental efficiency and economic efficiency, as higher GDP also increases CO2 emissions. The simulation suggests that the extent of such trade-offs are similar under different revenue recycling scenarios. As shown in Figure 31, the deviations in emission intensity of GDP are similar among the different revenue recycling scenarios.

6. Concluding remarks

We use a dynamic CGE model to simulate the impact of an initial carbon price of 50 yuan per ton of CO2 in 2015 and gradually increases to 200 yuan per ton by 2030. The deficit to GDP ratio is assumed to be at its base-case level in all revenue recycling scenarios. When carbon tax revenues are recycled by a lump-sum transfer to the households, the growth rate of real GDP is 0.7 per cent lower than the base-case growth rate in 2015 and 4.3 per cent lower in 2030.

Six alternative revenues recycling methods are tested. We use real GDP, real GNP and the erosion to tax as indicators for economic efficiency. Our simulation results are in broad agreement with the literature. The weak form of the double dividend is found in all alternative revenue recycling scenarios using all indicators for economic efficiency, with few exception. The weak form of the double dividend are non-negligible and are themselves strong arguments for adopting non-lump sum revenue recycling schemes.

The strong form of the double dividend is more elusive. Reducing consumption tax and labour tax are the only two scenarios under which the deviation in real GNP is positive all over the policy years. None of the scenarios produce the strong form throughout the policy years when other efficiency indicators are used.

Nevertheless, whether the strong form always exist seem a secondary concern in the policy debate. We've shown in our simulation that under all revenues recycling schemes, the deviation in emission intensity of GDP are similar. If China continues to set mitigation targets in terms of emission intensity of GDP, it could target either lower emission or higher GDP by selecting different revenue recycling policies. In this sense, alternative revenue recycling policies give China more freedom in deciding the policy priority.

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