

Increasing China's Coal-fired Power Generation Efficiency – the impacts on carbon intensity of GDP and the Chinese Economy

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Abstract

Despite pessimism in the progress of global climate change negotiations, efficiency improvements at industry and national levels are quietly contributing to a slower growth in CO₂ emission. In this study we investigated the case of coal using efficiency in coal-fired electricity generation in China. We found that investment in improving coal-using efficiency in coal-fired electricity generation leads to both a faster growth in real GDP and a slower growth in the ratio of CO₂ emission to GDP. However, as China is rapidly closing the efficiency gap with international best practice, this instrument alone will not be sufficient for China to achieve its emission reduction target.

1. Introduction

China's current carbon dioxide mitigation policies are engineered to achieve two sets of national targets, both written in terms of carbon dioxide emissions per unit of GDP, or carbon intensity for short. The 12th Five Year Plan (FYP) targets a 17 per cent reduction of carbon intensity from 2010 to 2015; the country's Copenhagen commitment on the other hand targets a 40 to 45 per cent reduction of carbon intensity from 2005 to 2020. During the country's 11th FYP, from 2006 to 2010 China

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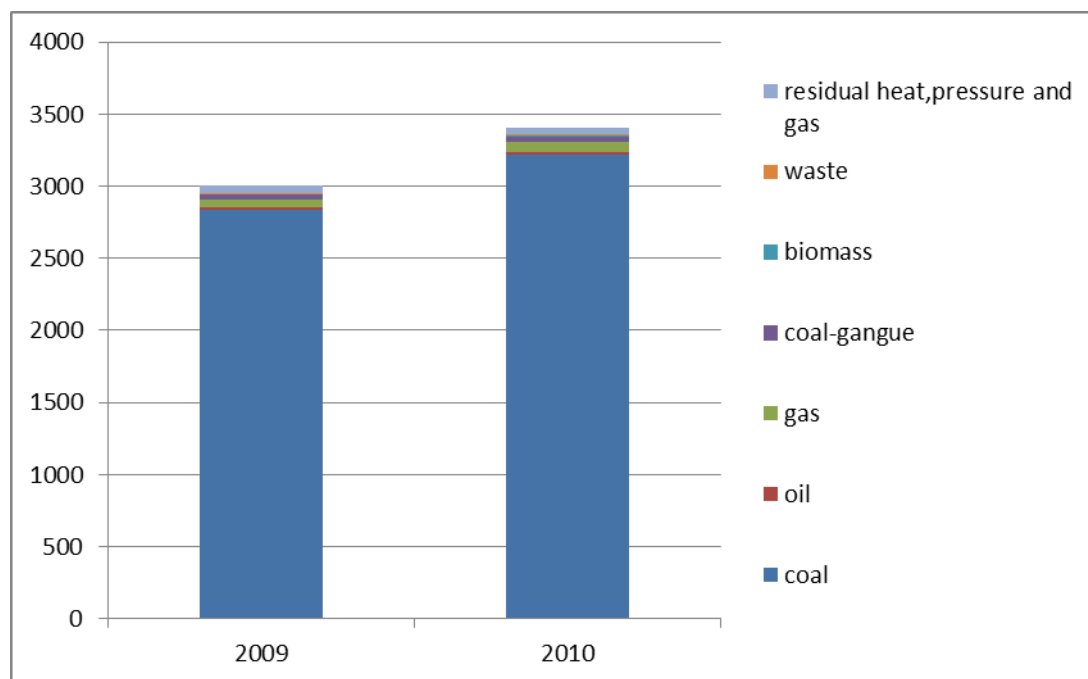
has reduced its carbon intensity by 19.1 per cent. This implies China needs to aim for a further 10.6 to 18.1 per cent reduction from 2015 to 2020³.

To understand how China could achieve these targets it is critical to understand what factors have been driving the country's carbon intensity changes in the past. A body of literature has attempted to identify such driving factors over the past 30 years. Three key messages that emerge from this literature are: 1) changes in carbon intensity has been primarily driven by changes in energy intensity (Chen, 2011); 2) changes in energy intensity has been primarily driven by changes in energy efficiency (Ma and Stern, 2008) and 3) changes in energy efficiency has been primarily driven by changes in thermal power efficiency (Li, 2011). Linking these messages, it suggests that changes in China's thermal power efficiency have been critical to changes in the country's carbon intensity over the past 30 years.

Therefore to understand how China could achieve its carbon intensity targets it is critical to understand how the country's thermal power efficiency might change in the coming years to 2020. The changes in thermal power efficiency can be represented by changes in coal-fire power generation efficiency, since coal-fire power generation constitutes almost all thermal power generation in China, see Figure 1.

Figure 1: China's thermal power generation by source, TWh

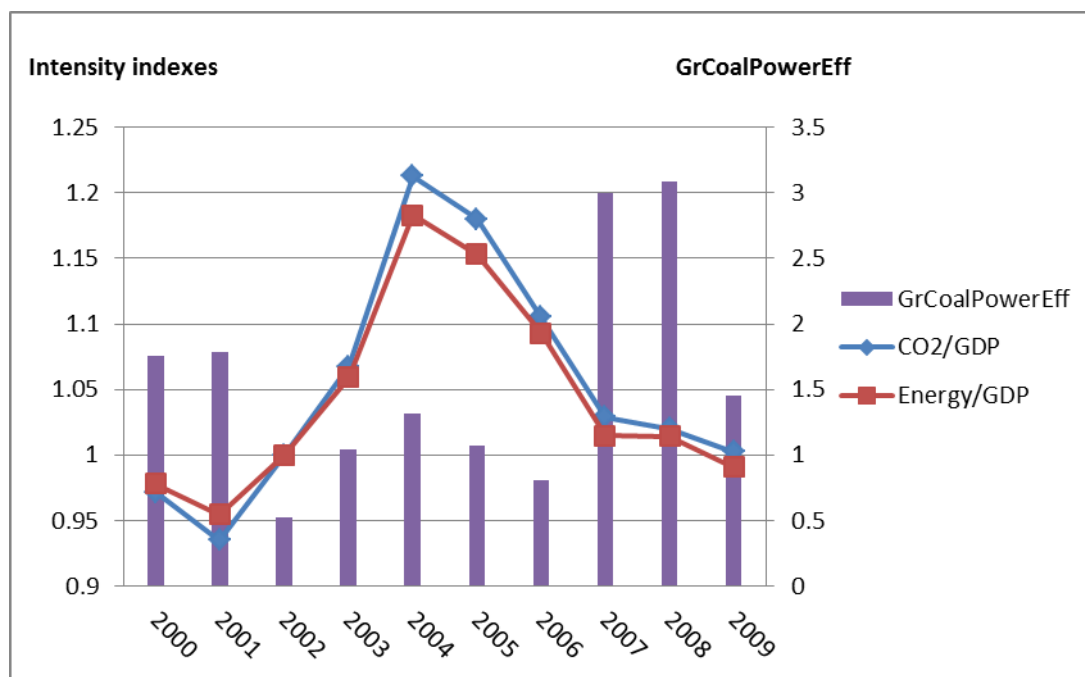
³ Or, based on the 2010 intensity level, assuming a 17 per cent reduction by 2015, another 32.6 to 38.2 per cent reduction to meet the 40 to 45 per cent target, respectively.



Source: China Electricity Council (2011)

China's policies on coal-fired power generation have had profound implications on the industry's efficiency. Figure 2 shows the correlation between carbon intensity of GDP, energy intensity of GDP and the growth rate of coal-fired power generation efficiency in China from 2000 to 2009. The two horizontal lines show China's carbon and energy intensities of GDP. The two lines closely track each other and they are both in an inversed-V shape, i.e. the intensities increased in the early years of the decade, peaked in the middle and fell to their respective beginning of the decade levels by the end of the decade.

Figure 2: Carbon intensity, energy intensity and coal-fired power generation efficiency growth in China



Note: carbon intensity and energy intensity are normalized to be 1 in 2002

Source: carbon intensity and energy intensity (EIA, 2012); thermal efficiency growth rate: China Elecpower Year Book (2003) and China Electricity Council (2011).

The shape of these lines largely coincides with the policy shifts and efficiency changes in China's coal-fired power industry. The vertical bars in Figure 2 show the growth rate of efficiency in China's coal-fired power generation. From late 20th century to early 21st century, China already had plans to phase out small and inefficient (SAI) thermal power plants. During that time plants of unit capacities below 50 megawatt (MW) were labelled as SAI and were set to be closed. As it is shown in the early years of Figure 2, efficiency improvement was relatively fast and the intensities were relatively low.

However as the country entered the WTO and began to endorse an investment-led and export-oriented growth model, it suffered a large power-supply shortage. Due to this shortage, starting from 2003, the closure of SAI units slowed down. China's 10th FYP originally targeted the closure of 13 gigawatt (GW) SAI capacities but in the end it only achieved 8.3 GW. As a result, only 50 per cent of the fleet were above 300 mw units by 2005. In Figure 2, it is evident that the rate of efficiency improvement dropped between 2002 and 2006, which contributed to the rise in the intensities.

Then as the environmental challenge became acute and the need to transform the growth model became inevitable, in early 2007, policies targeting the closure of the

SAI units were reinstated. The most notable policy is the Large Substitute Small (LLS) campaign that mandates old SAI capacities (below 200 MW) to be replaced by new, large and efficient capacities (above 300 MW). The campaign is largely deemed as a success. China's 11th FYP targeted a closure of 50 GW SAI capacities but in the end it successfully closed 76.8 GW. As a result, 70 per cent of the fleet were above 30 MW units by 2010. Thus we see in Figure 2 that the rate of efficiency improvement picked up towards the end of the decade and the intensities also fell roughly to their respective beginning-of-the-century levels.

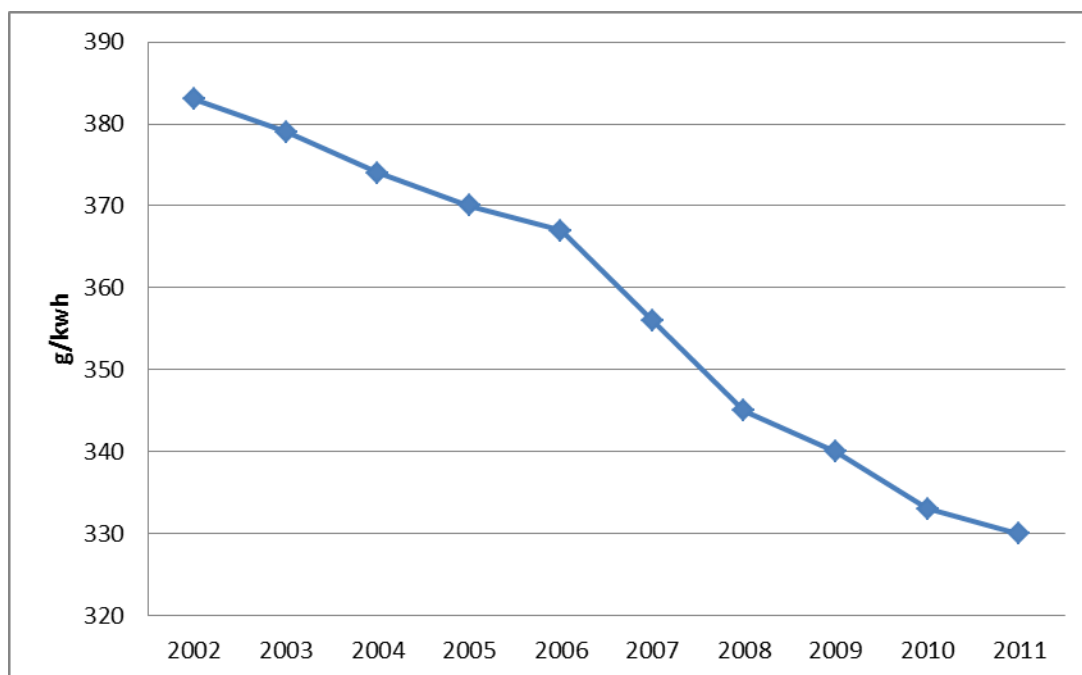
This study models the impact of efficiency improvement in coal-fired power plants on China's economy and its carbon intensity of GDP. Section 2 looks into different levels of efficiency improvement in the power industry. Section 3 uses a simple "back of the envelope" model to calculate the impact of efficiency improvement. This works as a check to see if CGE simulation results are plausible and also shows the implications of adding further considerations in the CGE analysis. Section 4 uses a CGE model to simulate the impact of efficiency improvement. We also use the CGE model to simulate the impact of a policy package that enhances efficiency through additional investment and which in turn is financed by tax. We then observe both the macro-level results and the industry-level results. Section 5 concludes.

2. Coal-fired power generation efficiency

We project different coal-fired power generation efficiency scenarios in the policy years (between 2012 and 2020). These scenarios draw a range in which the rate of efficiency improvement might evolve in the policy years. The efficiency measure we use in this study is 'grams of standard coal used to supply per kilowatt-hour electricity to the grid'. Such data are available from the China Electric Power Yearbook of various years (see Figure 3). Six efficiency scenarios are devised, namely 1) Constant, 2) Post-WTO-trend, 3) 11th FYP-trend, 4) 12th FYP-target, 5) Cutting-edge and 6) Most-likely.

Figure 3: Coal-fired power plants efficiency: standard coal per kilowatt-hour electricity supply to the grid⁴

⁴ Data for all the figures are shown in corresponding appendix.



Source: China Electric Power Yearbook (2003), China Electricity Council (2011).

Scenario Constant assumes no efficiency change in the power generation industry in the policy years. This is a highly unlikely scenario, but it serves as the baseline scenario against which the impact of other levels of efficiency change can be compared with. Thus the efficiency levels in 2015 and 2020 will be the same as it in 2011, at 330 g/kWh.

Scenario Post-WTO-trend extrapolates the average efficiency improvement rate over the past ten years. This includes a period of relatively slower efficiency improvement at 1.061 per year between 2003 and 2006 and a period of relatively faster efficiency improvement at 2.399 per year between 2007 and 2010. The overall average efficiency improvement rate between 2003 and 2010 was 1.730 per year, i.e. every year 1.730 grams of standard coal will be saved in supplying 1 kWh of electricity on to the grid. Thus if efficiency improvement rate follow the post-WTO trend in the policy years, the efficiency level will reach 308 g/kWh and 282 g/kWh in 2015 and 2020, respectively.

Scenario 11th FYP-trend extrapolates the average efficiency improvement rate over the period of most progressive efficiency improvement between 2006 and 2010. The average efficiency improvement rate over the 5 years was 2.08 per year. Following

this trend power efficiency will reach 303 g/kWh and 273 g/kWh in 2015 and 2020, respectively.

Scenario 12th FYP-target takes the efficiency improvement targets set forth in the 12th FYP. The targeted efficiency levels by 2015 and 2020 are 325 and 315, respectively, implying the rate of efficiency improvement needed are 0.38 per cent per year between 2012 and 2015 and 0.62 per year between 2016 and 2020.

Scenario Cutting-edge tries to find the fastest rate of efficiency improvement obtained from engineering-based studies. We rely on an IEA (2011) report as a rough guide for such efficiency levels. This report suggests the highest possible average efficiency in coal-fired power plants might be 320 g/kWh and 288 g/kWh in 2015 and 2020, respectively. These efficiency levels imply China's efficiency improvement rates should be 0.77 per cent per annual between 2012 and 2015 and 2.09 per cent per annual between 2016 and 2020.

We devote most of our effort in formulating the Most-likely scenario. As we have seen that closing old SAI capacities and building new large and efficient capacities have had a profound impact on overall power generation efficiency, we conjecture the Capacity-composition Scenario by detailing the a probable capacity composition over the policy years. In formulating such a scenario we need four pieces of information: 1) the latest capacity composition before 2012; 2) the capacity composition of newly commissioned plants, 3) the unit efficiency of different plant sizes and 4) total new capacities to be put into use in over the policy years.

Table 1: Capacity composition and unit efficiency, 2010

single plant capacity (10MW)	classification	total capacity (10MW)	capacity share	efficiency (g/kWh)
100	non-SAI	3300	0.048	286
60	non-SAI	22247	0.321	292
[30-60)	non-SAI	24857	0.358	334
[20-30)	SAI	5201	0.075	350

[10-20)	SAI	6072	0.088	380
[0.6-10)	SAI	7672	0.111	420
total weighted average efficiency:		non-SAI efficiency: 312		
333		SAI efficiency: 388		

Source: Productivity Commission (2011)

The latest capacity composition we were able to obtain was for year 2010 (Table 1). This table specifies the total capacity of plants, their corresponding given size, classifications and efficiencies. For example, the top row says that the total capacity of 1,000 mw plants was 33,000 mw and this constituted 5 per cent of the total capacity in the year. Moreover, such plants are classified as non-SAI units and operate on an average efficiency of 286 g/kWh. Given these information we could infer the average efficiency of SAI and non-SAI units in 2010, which were 388 g/kWh and 312 g/kWh, respectively.

The capacity composition of newly commissioned coal-fired plants is much harder to obtain. The closest proxy we managed to get was a list of newly commissioned plants published by the National Development and Research Commission (NDRC), see Table 2. In the same fashion of Table 1, Table 2 lists the total capacity of a group⁵ of newly commissioned plants, their corresponding size, technological specifications and efficiencies. By assuming that the entire new fleet put into production in the 12th FYP has the same capacity composition as this sampled group, we infer the average efficiency of the new capacities put into work during the 12th FYP will have an average efficiency of 297 g/kWh. We then further assume that the new capacities put into work during the 13th FYP will an average efficiency marginally higher⁶, which will be 290 g/kWh.

Table 2: NDRC commissioned new coal-fired power plants in 2011.

⁵ The total planned new capacity in the 12th FYP is 363 gagawatt ([Yearbook](#)). If we divide it evenly into five years it will be 73 gw per year. The total newly commissioned plants in the list amounts to 20 gw, which is 27 per cent of the total planned per annual.

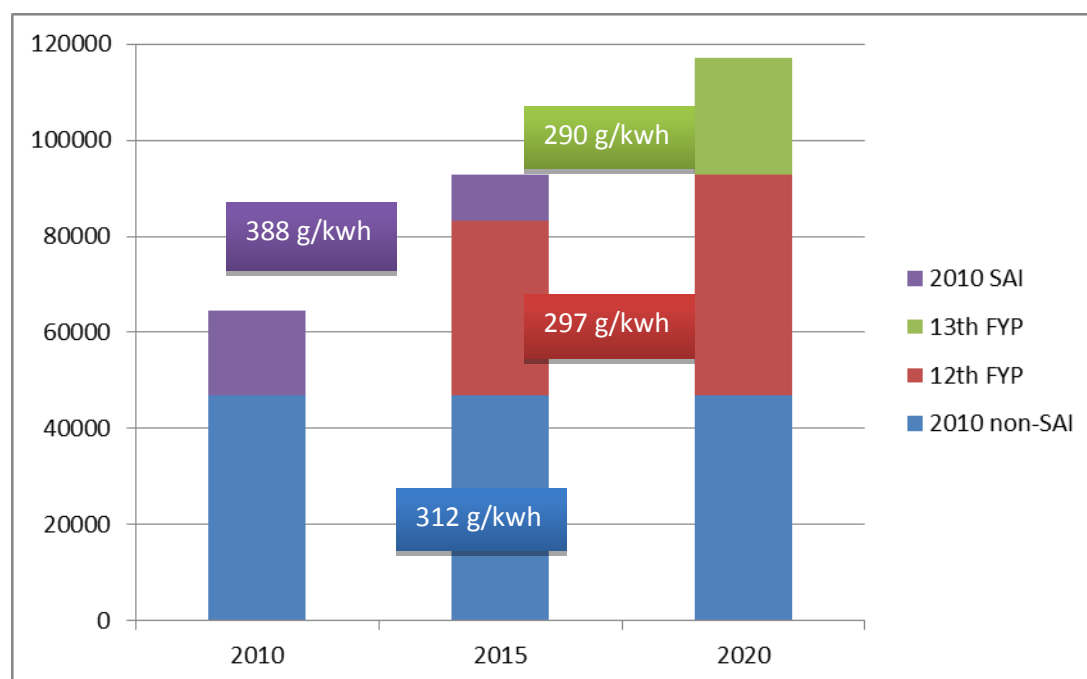
⁶ Note that a higher efficiency means to use less coal in producing per unit of electricity, hence the g/kwh number will be lower.

singles plant capacity (10MW)	technology	total capacity 10MW	capacity share	efficiency (g/kWh)
100	USC	800	0.4	286
60	USC	240	0.12	292
	SupC	60	0.03	299
	SubC	120	0.06	310
	unknow	120	0.06	299
35	SupC	175	0.09	299
	unknow	70	0.04	310
30	SupC	30	0.02	310
	unknow	330	0.17	310
20	unknow	40	0.02	330
weighted average			12 th FYP:	297
			13 th FYP:	290

Note: Ultra-supercritical (USC); Supercritical (SupC); Subcritical (SubC).

Source: NDRC (2012), Productivity Commission (2011) .

Figure 4: total new planned capacity, composition, 10 MW



Source: China Electric Power Yearbook (2012)

The target total capacity of coal-fired power plants by 2015 and 2020 are 928 GW, 1170 GW, respectively (China Electric Power Yearbook, 2012). We know total 2010 capacity and its composition from Table 1. Combining these and some further assumptions we obtain Figure 4. In Figure 4, we assume the non-SAI plants in 2010 will still be serving throughout the policy years at their current efficiency level (312 g/kWh). We also assume all of the SAI plants will be replaced by earmarked plants with similar efficiencies as we observed on the NDRC publication (297 g/kWh) – in a linear fashion between 2011 and 2020. We then further assume the average efficiency of the new plants that will be built in the 13th FYP that are not earmarked for replacing the 2010 SAI units will 290 g/kWh. Therefore by assigning efficiency levels to different shares in the total capacity composition in 2015 and 2020, we were able to conjecture the average efficiency level of the whole coal-fired power generation fleet in the two years, namely 314 g/kWh and 302 g/kWh, respectively. And these are the efficiencies obtained in for the Most-likely scenario.

Table 4 summarizes the efficiency scenarios we have set out in the above analysis. We rank the efficiency levels from low to high. Scenario 11th FYP trend turns out could lead to the most progressive rate of efficiency improvement. Both Scenario 11th FYP trend and Scenario Post-WTO trend would lead to more efficient power generation than Scenario Cutting-edge would. This suggests it is unlikely that efficiency is going to improve over the next 10 years as fast as it did over the past 10 years. On the other hand, Scenario Most-likely and Scenario 12th FYP target both have lower would both lead to lower efficiency than Scenario Cutting would lead to. This suggests these Scenarios might be more realistic. Nevertheless, these scenarios draw a range in which the rate of efficiency improvement might evolve out in the policy years.

Table 4: efficiency scenarios

Scenario	2011 (g/kWh)	12-15 p.a. Gr_R (%)	2015 (g/kWh)	16-20 p.a. Gr_R (%)	2020 (g/kWh)
Constant	330	0	330	0	330
12th FYP target	330	-0.38	325	-0.62	315

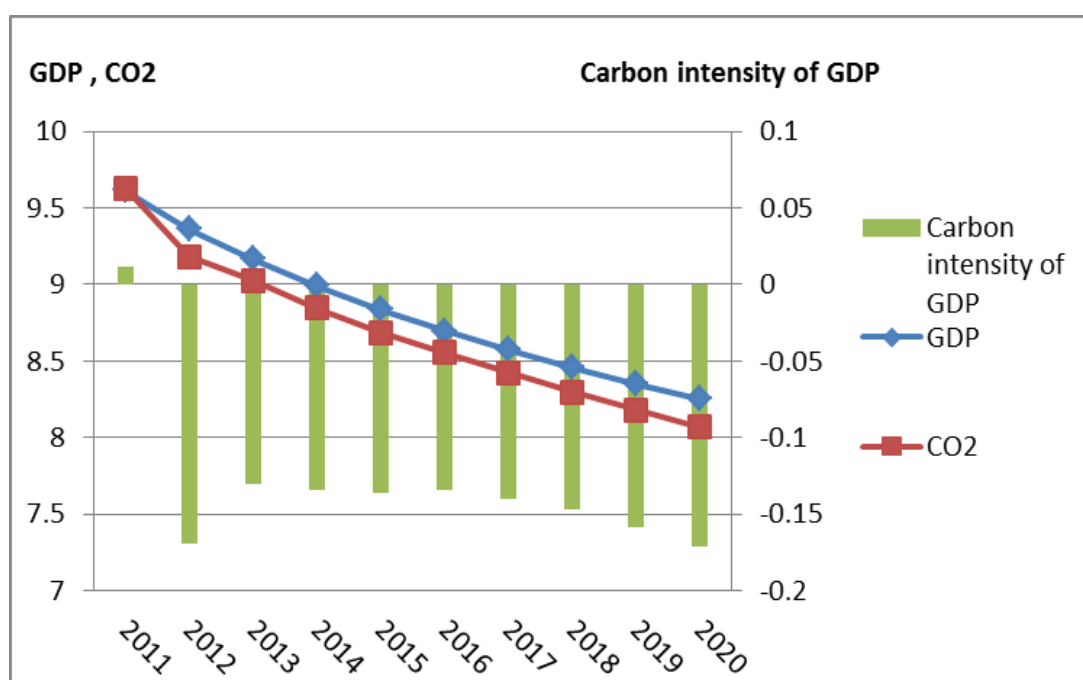
Most-likely	330	-1.23	314	-0.78	302
Cutting-edge	330	-0.77	320	-2.09	288
Post-WTO trend	330	-1.73	308	-1.73	282
11th FYP trend	330	-2.08	303	-2.08	273

Source: authors' calculation

3. The back of the envelope (BTE) model

We put these scenarios into a simple back of the envelope (BTE) model. Our BTE model adopts a baseline (Figure 5) that is the same as the one used in our CGE model (see Section 4). Thus the two simulation results are comparable. This baseline is derived from the Monash-style CGE model we used, CHINAGEM, a documentation of which can be found in [Mai et al., \(2012\)](#).

Figure 5: Baseline year on year percentage change in GDP, CO2 emissions and carbon intensity of GDP, over the policy years



Source: CHINAGEM

Since carbon intensity is defined as CO2 emissions over GDP, see Equation 1⁷:

$$INTENSITY_t = \frac{CO2_t}{GDP_t}. \quad [E1]$$

Total differentiate E1 gives Equation 2:

$$intensity_t = co2_t - gdp_t, \quad [E2]$$

where lower case *intensity*, *co2* and *gdp* represent percentage change in upper case variables *INTENSITY*, *CO2* and *GDP*, respectively. We assume in this BTE analysis that changes in coal-fired power plants efficiency do not change GDP, thus all efficiency scenarios have the same percentage changes in GDP, which is the baseline percentage GDP changes as shown in Figure 5.

The derivation of percentage change in CO2 emissions, as defined in Equation 3, is also straightforward.

$$co2_t = \frac{CO2_t - CO2_{t-1}}{CO2_{t-1}} * 100 \quad [E3]$$

In CHINAGEM database, the total carbon dioxide emissions in 2010 ($CO2_{2010}$) are 8081 million tonnes. Thus $co2_{t+1}$ can be derived by finding $CO2_{t+1}$, from Equation 4:

$$CO2_t = CO2_{t-1} + \Delta CO2_{t-1} \quad [E4]$$

Which in turn can be derived by finding the changes in CO2 in time t ($\Delta CO2_t$), from Equation 5:

$$\Delta CO2_t = \partial * \Delta COAL_t \quad [E5]$$

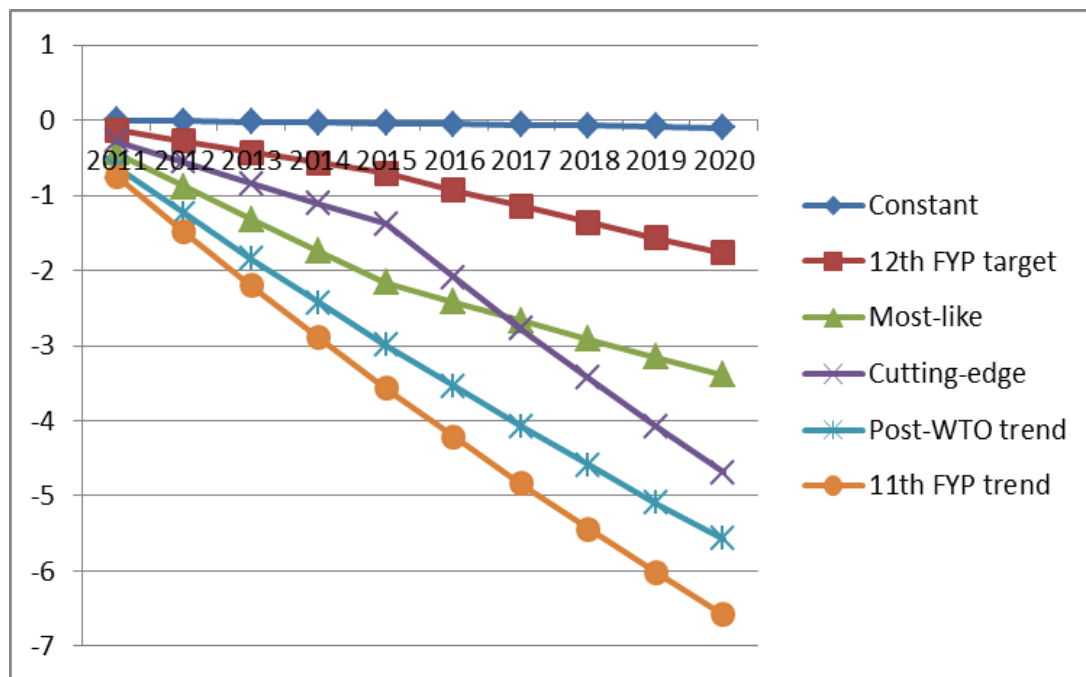
Where $\partial = 2.47$ is a fixed coefficient and $\Delta Coal_t$ represents the change in total consumption of standard coal in time t, which in turn can be derived from Equation 6:

$$\Delta COAL_t = \Delta A_t * COALELEC_t \quad [E6]$$

⁷ Following a tradition in Monash-styled notation, we denote quantity changes in upper-case letters and percentage changes in lower case letters.

Where ΔA_t is the change in the efficiency of coal-fired power generation plants (g/kWh). This is where the different efficiency scenarios (as shown in Table 4) come in. And $COALELEC_t$ is the quantity of power-fired electricity projected to be used in year t . Again, we use the quantity⁸ of coal-fired electricity projected to be used in year t from our CHINAGEM baseline. By this we are assuming that the change in power-generation efficiency will not change the quantity of electricity consumed (another unsatisfactory assumption due to the limitation of partial equilibrium analysis). Solving the equation system E2 – E6, with five equations and five unknowns ($intensity_t, co2_t, CO2_t, \Delta CO2_{t-1}$ and $\Delta COAL_t$), we were able to obtain $intensity_t$ in each of the efficiency scenarios (see Figure 6).

Figure 6: Cumulative percentage deviation in carbon intensity of GDP from baseline under different efficiency scenarios, BTE simulation



Source: authors' calculation

⁸ A CGE database is in value. Here we divide the value of coal-fired electricity output in 2010 by external quantity data (3216 TWh) from the China Electric Power Yearbook 2011 and gets the average coal-fired electricity on-grid price to be 0.25 yuan per kWh, which, in the absence of data, we believe to be plausible. Thus we assume the quantity of coal-fired electricity generation in 2010 is 3216 TWh in our database.

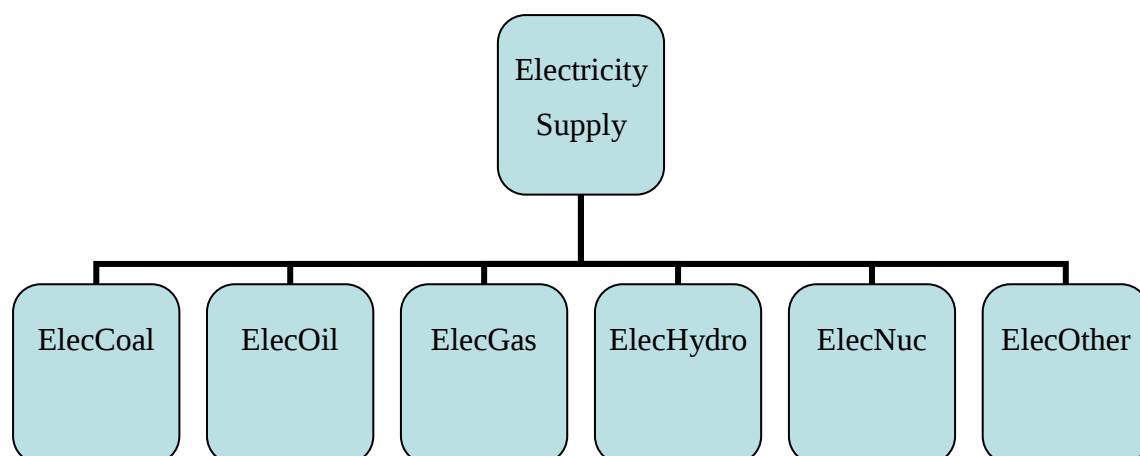
Figure 6 shows that even under the most progressive efficiency improvement scenario (11th FYP trend), coal-fired power plant efficiency improvement will not contribute to more than 7 per cent of total carbon intensity reduction from 2010 to 2020. Compared with the targets of 32.6 to 38.2 per cent, the 11th FYP scenario (6.58 per cent) will contribute only 17 to 20 per cent of the total reduction in carbon intensity. Moreover, under the Most-likely scenario, the cumulative contribution by 2020 will only be 3.4 per cent, which is 8.9 to 10.4 per cent of the total carbon intensity reduction. Hence these BTE results show that coal-fired power generation efficiency improvement over the policy years may not play a defining role in delivering the intensity targets by 2020.

4. General equilibrium analysis

4.1 General equilibrium results

In this section we put the efficiency scenarios developed in Sector 2 and applied in Section 3 into a CGE model. Our CGE simulations are based on the following key assumptions in our general equilibrium simulation. First, the coal-fired power sector (ElecCoal in Figure 7) is one of the electricity generation sectors that only sell to the Electricity Supply sector. The elasticity of substitution among the generation sectors is set to be 0. In the absence of trusted elasticity data, we opt to delineate our CGE results from dubious fuel substitution effects. This is nevertheless a reasonable assumption since it is found in the literature that fuel substitution has had little impact on carbon intensity in China [Ma and Stern \(2008\)](#). Second, we assume both nominal private consumption and nominal public consumption to be a fixed proportion of nominal gross national product (GNP). Third, we let investment to be a positive function of real capital return (see [Dixon and Rimmer, \(2007\)](#)).

Figure 7: Electricity production structure



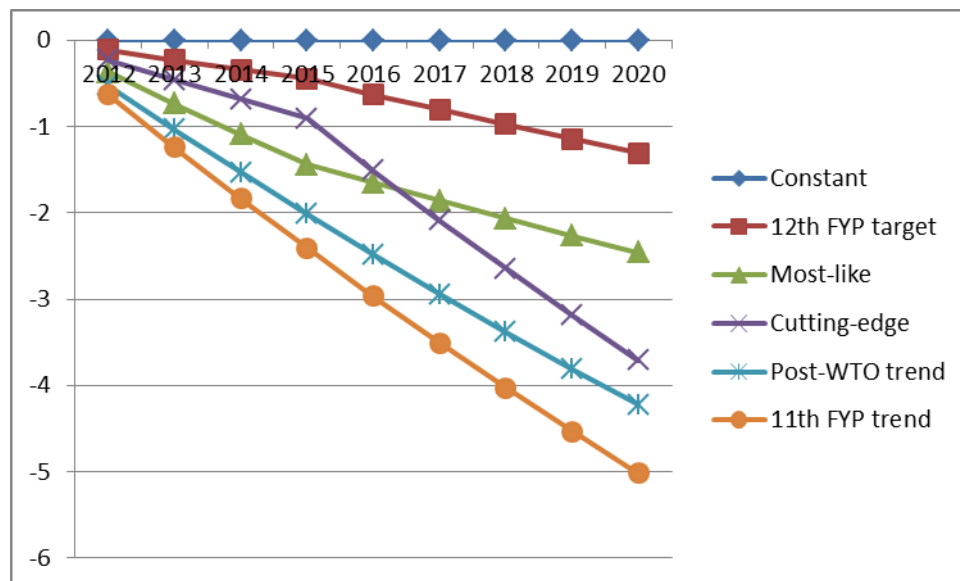
Moreover, factor market assumptions are distinguished between short-run and long-run. We assume in the short-run (year of shock), real wage is sticky and employment can deviate from the baseline to accommodate the shock created by the shock. Capital employment on the other hand is fixed thus a shock can cause real capital return to deviate from baseline. In the long-run however, we assume real wage can change over time and the level of employment tends to approach its long-run level (the baseline level). Capital employment on the other hand could vary in the long-run but real return to capital tends to approach its baseline levels. These factor market assumption as summarized in Table 5:

Table 5: Factor market assumptions

Factor market		Short-run (2012)	Long-run
Labour market	Real wage	Sticky	Deviate from baseline
	Employment	Deviate from baseline	Approach baseline
Capital market	Real return	Deviate from baseline	Approach baseline
	Capital	fixed	Deviate from baseline

Figure 8 shows the efficiency impacts on carbon intensity of GDP obtained from CGE simulation. In comparison with Figure 6, Figure 8 shows yet smaller contributions to carbon intensity reductions. This is due to the rebound effect. An efficiency increase reduces the cost of producing coal-fired electricity which in turn electricity retail price. Electricity users thus benefit from the lower electricity price. Consumers increase their consumption and industries increase their electricity input and expand their activity levels. These second-order changes lead to a slightly higher demand for electricity that is not captured in our BTE analysis. The higher demand in electricity on the one hand leads to smaller reduction in carbon emissions and on the other hand leads to higher GDP levels. Overall, the rebound in carbon emissions is larger than the increase in GDP. This is because the increase in GDP is driven by higher electricity demand, so the rebound in GDP is secondary to the rebound in electricity demand and is thus smaller than the rebound in carbon emissions.

Figure 8: Cumulative percentage deviation in carbon intensity of GDP from baseline under different efficiency scenarios, general equilibrium simulation



Source: CHINAGEM simulation results

4.2 An investment and taxation package to improve efficiency

The efficiency improvement cannot be treated as a gift from ‘heaven’, it has to be financed. We assume the government invests in the coal-fired power generation industry to achieve the efficiency improvement and it finances the investment by

imposing a production tax on the industry. In this section we only focus on the Most-like scenario since it is the only scenario for which we have managed to obtain data. We observe the industry-level impacts to the economy under this scenario. The impacts of other efficiency scenarios should follow the same pattern as it is observed in the Most-likely scenario.

Inevitably, we need to estimate the amount of investment needed to achieve the efficiency improvement. We estimate the amount of investment needed by using what we call the ‘premium investment’ measure. Table 6 illustrates how the premium investment is measured. First we know from the NDRC website how new capacities are commissioned in 2011 and their respective plant type. Second we know much investment is needed to build a certain type of coal-fired power plant from the Productivity Commission study (2011). We treat the unit investment required for building subcritical plants as the basis and subtract this basis from the unit investment required for building more advanced plants, namely supercritical and ultra-supercritical plants. We call the differences after subtracting the basis as ‘technological premium’, which estimates the extra unit investment required for investing in more efficient plants. Then we multiply the technology premium by their respective commissioned capacities to get the premium investment. The premium investment⁹ thus estimates the amount of investment accountable for efficiency improvement that is needed for the NDRC commissioned projects in 2011 (10020 million yuan).

Moreover, we also know from the CEPY the total planned new capacities to be built over the 12th and 13th FYP years. By assuming a linear fleet expansion pace, we are able to estimate how much new capacities are needed per annual. By dividing the total capacities commissioned by the NDRC in 2011 by the annual capacity expansion, we obtained NDRC commissioned capacities in 2011 as shares of planned annual capacity expansion over the 12th and 13th FYP periods (23 and 29 per cent, respectively). Then by scaling the 2011 investment up according to these shares we are able to estimate the annual premium investments needed during the 12th and 13th

⁹ This may marginally underestimate the total investment needed for efficiency improvement since a small margin in investment for building subcritical plants may also contribute to efficiency improvement.

FYP periods (42819 and 34008 million yuan, respectively). Accordingly the amount of the production tax collected is be the same as the amount of investment.

Table 6, estimating premium investment

Plant Type	NDRC capacity ¹ (10MW)	Cost ² (10m yuan/10MW)	Technology premium (10m yuan/10MW)	Premium Investment (10m yuan)
SubC	560	4.06	0	0
SupC	385	4.54	0.475	182.875
USC	1040	4.85	0.788	819.52
sum capacity	1985		sum inv	1002
		Capacity p.a.	NDRC shr	inv p.a.
total 12th FYP new	42396	8479	23%	4281.9
total 13th FYP new	33673	6735	29%	3400.8

Source: NDRC (2012), China Electric Power Yearbook (2012) , Australia Productivity Commission (2011), authors' calculation

We apply these estimations into four scenarios. Scenario Efficiency simulates the original efficiency improvement under the Most-likely scenario without investment or tax. Scenario Investment and Scenario Taxation each simulates the investment and taxation, individually. Scenario Overall simulates the efficiency improvement, the investment and the taxation together. By comparing these four scenarios we observe the contribution from each policy component as well as the overall policy impact.

4.3 Financing the efficiency improvement – macro level analysis

Set 1 shows simulation results from the income side of GDP for the four scenarios. Despite the initial fall in GDP, which is due to a fall in labour employment, by 2020 the overall impact of the policy package will be positive on all the income-side components of GDP¹⁰. The initial fall in labour employment originates from the Taxation scenario. Referring to Table 5, every year when more indirect tax is imposed, real wage is sticky in reacting to the incremental tax but real return to capital can adjust quickly, thus producers will face a relatively higher labour cost than capital

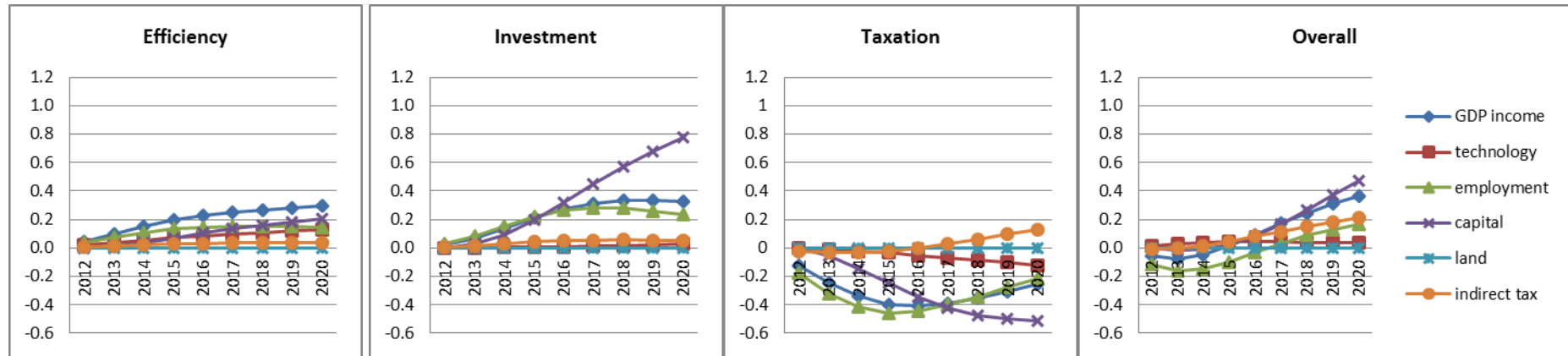
¹⁰ Except for changes in land is zero, which is specified by consumption.

cost on the margin. While capital employment is slow in reacting to the incremental tax, employers will employ less labour in response to the relatively higher marginal labour cost, thus reduces labour employment.

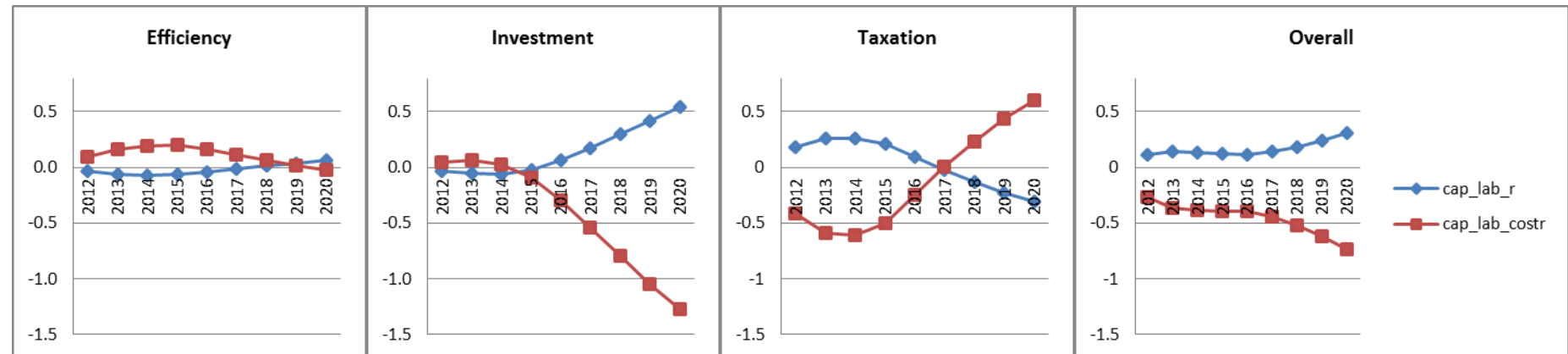
In the long-run however, wage starts to accommodate the fall in labour demand and this allows labour employment to approach the baseline. On the other hand, capital return approaches the baseline from above, leading to a fall in capital employment. Despite the fall in capital employment originates from the Taxation scenario though, among all the income-side components capital will experience a higher growth. This mostly derives from Scenario Investment in which the positive investment shock stimulates capital demand overtime.

Set 2 plots the relative changes in capital to labour employment ratio (cap_lab_r) and in capital to labour marginal cost ratio (cap_lab_costr). It shows that while the Efficiency scenario is relatively neutral, the Investment scenario is more capital-enhancing whereas the Taxation scenario is more labour-enhancing. Overall, as capital becomes relatively cheaper than labour in the long-run, more capital will be employed than labour. This is good news to capital intensive industries and bad for labour intensive industries, a point examined later in the industry analysis (Section 4.3).

Set 1, GDP from income side, cummulative percentage deviation from baseline



Set 2, relative change in capital labour employment and marginal cost ratios, cummulative percentage deviation from baseline

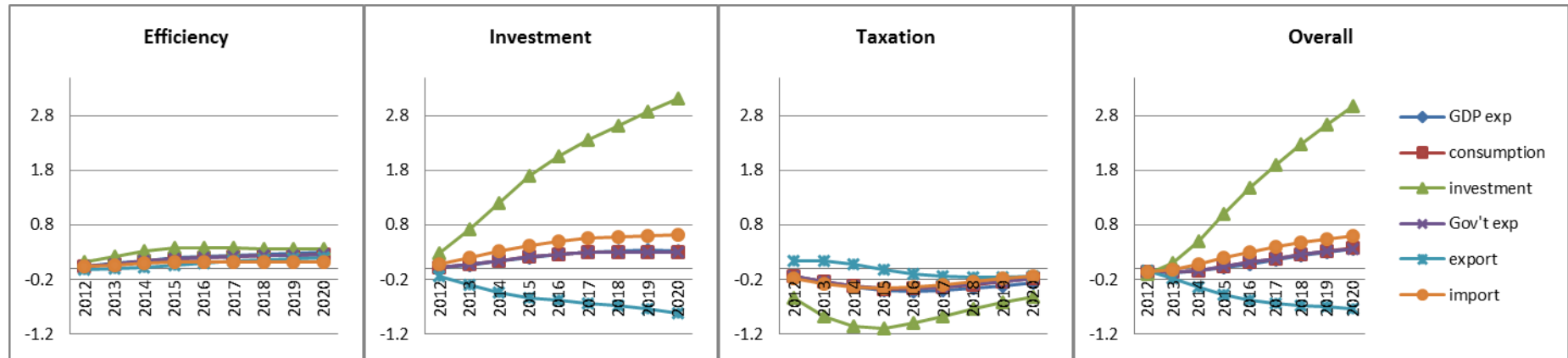


We then turn to the expenditure side of GDP. Set 3 shows simulation results from the expenditure side of GDP for the four scenarios. The Overall scenario shows that apart from export, all components from the expenditure side of GDP increase, with investment increasing the most. This is primarily driven by the increase in investment originates from Scenario Investment. Although the increase in investment in this scenario is again partially offset by the fall in investment originates from Scenario Taxation in the early years of the simulation. This fall in investment is due to the decline in capital return. Recall from Section 4.1 that investment is a positive function of real return to capital, the decline in capital return will lead to a decline in investment. But this second-order decline is not enough to offset the first-order shock that increase the investment in the coal-fired power generation sector.

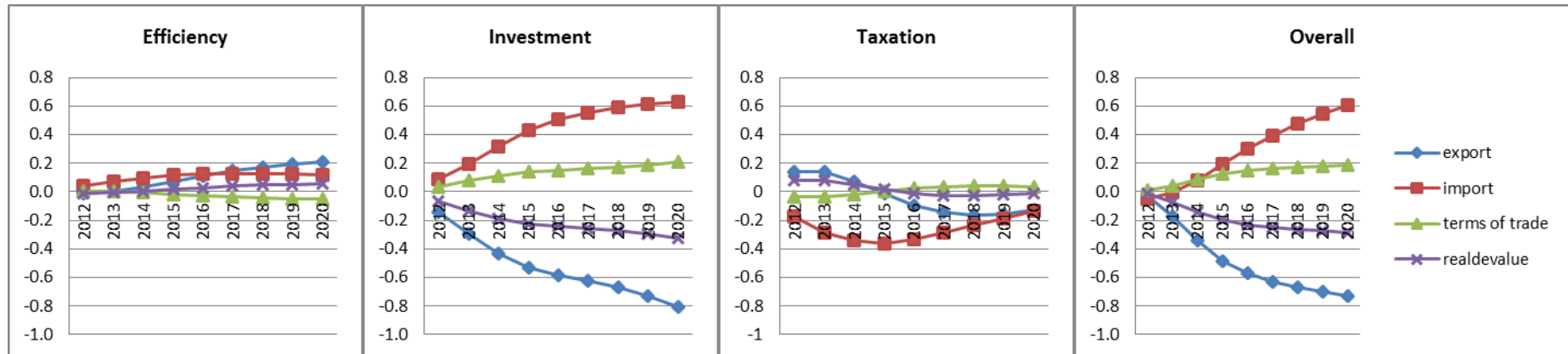
Set 4 explores the dynamisms in the trade sector. The simulation shows import will increase while export will fall, accompanied by an increase in terms of trade and a real RMB appreciation. Again, the most significant changes originate from the increase in investment. The increase in investment is a demand side shock, in a general equilibrium setup that is constrained by the given levels of production factors and technology, the increase in investment does not impact supply side variables as large as the increase in itself. Hence to maintain equal changes from both supply and demand sides of GDP, other components in the demand side of GDP will fall to accommodate the big investment increase.

Given that private and government consumption follows national income, net export needs to fall. Import on the one hand will increase in response to the higher domestic demand due to higher investment. But on the other hand the increase in import will be smaller than the increase in investment since not all the incremental investment are imported, thus export also fall in order to facilitate a fall in net export that is comparable to the increase in investment. Since a relatively stable import price and a downward sloping export demand curve, the fall in export increases export price and increases terms of trade. Moreover, the lower net export signals a reduction in the country's competitiveness, which is accommodated by a real RMB appreciation. Such dynamisms in the trade sector are negative signals to both export-oriented and import-competing sectors.

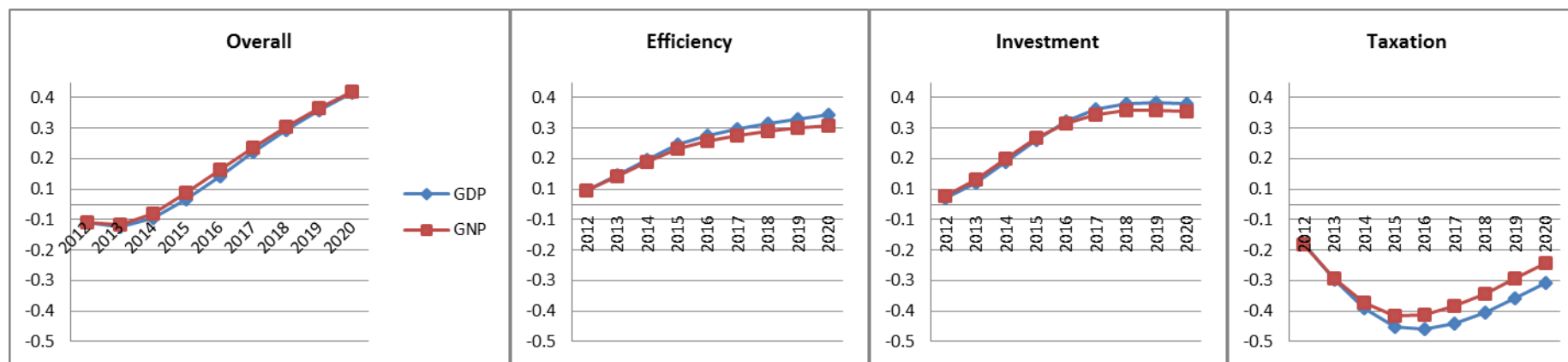
Set 3, GDP from expenditure side, cummulative percentage deviation from baseline



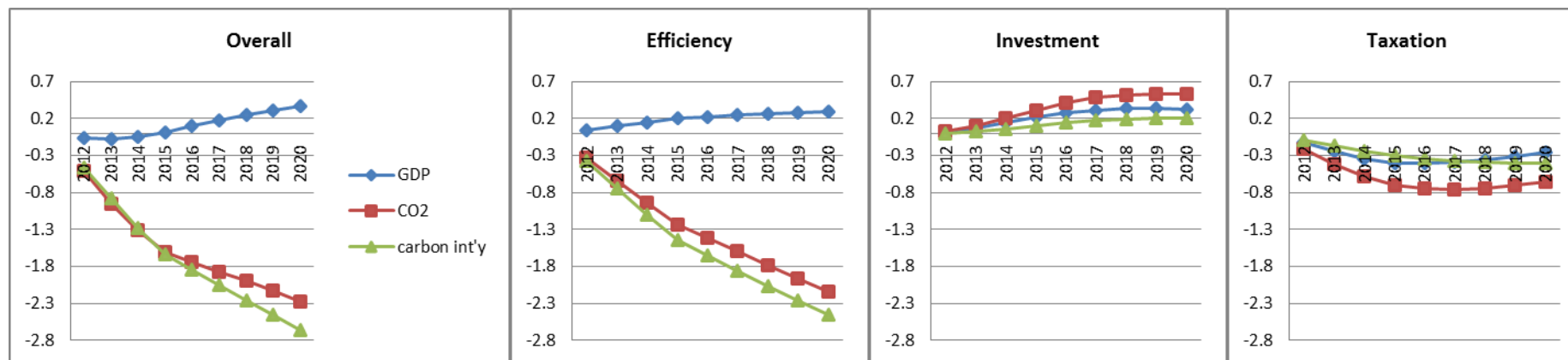
Set 4, trade and trade-related prices, cummulative percentage deviation from baseline



Set 5 GDP and GNP, cumulative percentage deviation from baseline



Set 6, GDP, CO2 and carbon intensity of GDP, cumulative percentage deviation from baseline



GNP, which more correctly measures a country's welfare, can be different from GDP. Set 5 illustrates the difference between the two, or the indifference as it is shown in Scenario Overall. Under Scenario Efficiency and Investment, GDP is slightly higher than GNP, since under these scenarios investing in China yields higher return in the short-run, and as net-international lending reduces GNP becomes slightly smaller than GDP. The opposite mechanism operates in Scenario Taxation. The overall difference between GDP and GNP is negligible.

Set 6 shows changes in GDP, CO₂ emissions and carbon intensity of GDP. Comparing Scenario Overall and Efficiency, the difference between with and without the policy package (investment and taxation) is very small. However, all the small differences act in the more favourable direction: GDP is slightly higher and CO₂ emissions and carbon intensity are slightly slower.

4.4 Financing the efficiency improvement – industry level analysis

Industry-level results are consistent with macro-level results. Sets 7, 8, 9 and 10 each shows the 10 most positively affected and the 10 most negatively affected industries under Scenarios Efficiency, Investment, Taxation and Overall, respectively.

When only the efficiency improvement is considered, all income and expenditure components of GDP are affected roughly the same (with small increases). Hence the industries that are most directly involved with the efficiency improvement will gain the most. As it is shown in the left panel of Set 7, these are the electricity generation industries. They benefit from the lower cost of producing electricity and an economy-wide higher demand for electricity. Although the industries of Basic Chemical (BasicChem) and Salt Mining (SaltMine) stand out as the most positively affected, which seems unreasonable. However the fact that the Basic Chemical industry uses up the largest share of electricity output explains the results, since it gains the most from the fall in electricity price. The Salt Mining industry on the other hand simply benefits from selling most of its outputs to the Basic Chemical industry.

The industry that is most adversely affected is the industry of Coal and Mining Products (CoalMineProc), shown in the right panel of Set 7. This is due to the efficiency gain that requires less coal as an input to coal-fired electricity generation. The industry of Railway Freight (RealFreight) is found to be the second most

adversely affect, this is because a large share of the industry's activities involves the transportation of coal.

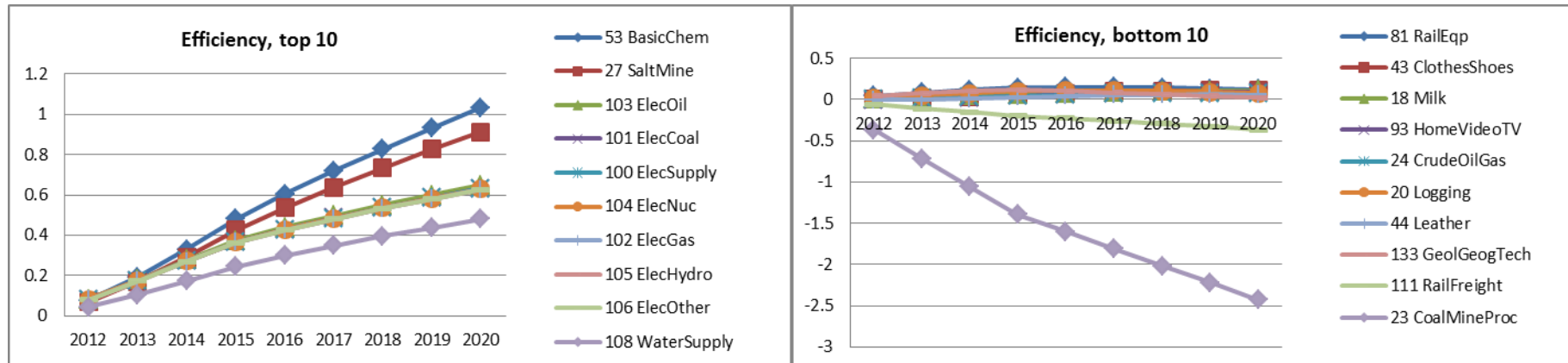
Scenario Investment shows a different pattern from Scenario Efficiency. From the macro-level results we observe from the expenditure side of GDP that investment increase more in relation to the other components whereas export fall more. On the income side we observe capital labour ratio increase over time. This suggests capital intensive industries are likely to gain more than the labour intensive industries. Again, industry level results are consistent with the macro-level results. On the left panel of Set 8, industries such as Construction and Cement benefit the most from the positive investment shock. This is because they both sell a large share of their outputs as investment goods as well as being relatively capital-intensive in the production process. On the right panel of Set 8 however, industries that are trade exposed and are relatively more labour intensive such as Textile Products (TextProc) are found to be most adversely affected.

Scenario Taxation has yet a different combination of winners and losers. Since the tax does not create much difference on the expenditure side of GDP, changes from the income side of the GDP dictate the industry-level results. Given that by 2020 more capital will be employed than labour – compared with the baseline – labour intensity industries are likely to gain more than the capital intensive industries. As it is shown in the left Panel of Set 9, Leather, Knit Mill and other traditional labour-intensive industries are least affected by the tax. On the other hand, the tax increases the cost of electricity generation, increases electricity price thus reduces electricity output and those industries that use a large share of electricity output.

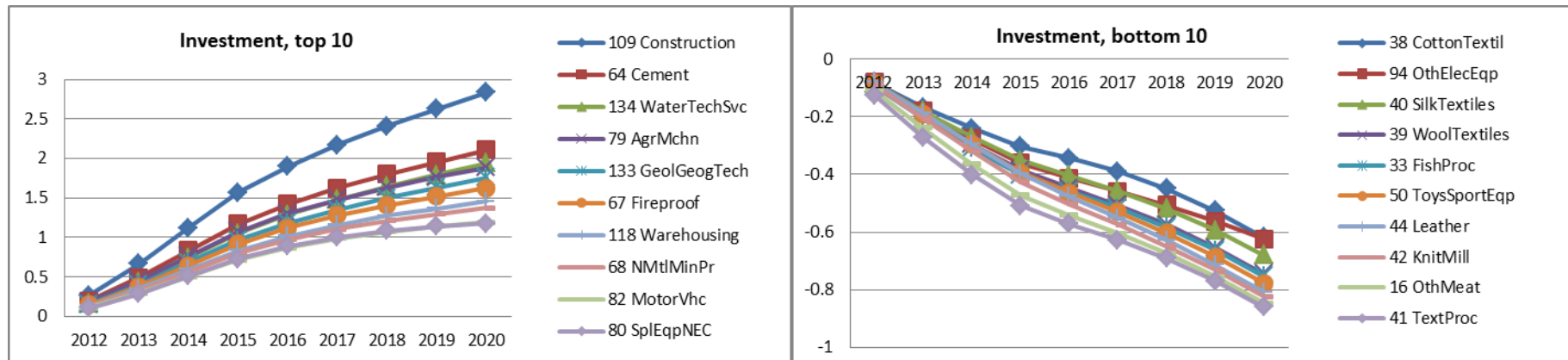
The overall impacts of the policy package on industries are such that 1) the increase in investment is a strong demand side stimulus that alleviates industries that specialize in selling investment goods – especially those who are also relatively capital-intensive. 2) the higher investment however crowds out export and increases imports, thus hurting the trade-exposed industries – especially those who are also relatively labour-intensive. 3) The Coal Mining industries will be mostly hurt due to the adoption of more coal-saving technologies. 4) The production tax has a big negative effect on the electricity generation industries that neither the improvement in efficiency nor the increase in investment could lead to an overall positive impact to these industries.

This is characterised by the results that the Basic Chemical industry becomes one of the biggest net losers overall. The result of the Basic Chemical industry losing indicates higher overall electricity price and lower overall electricity output. This last result is interesting because it contrasts to the thinking that higher efficiency in the power sector should lead to higher output at lower price. It also explains why total carbon emission in the Overall scenario is slightly lower than it in the Efficiency scenario.

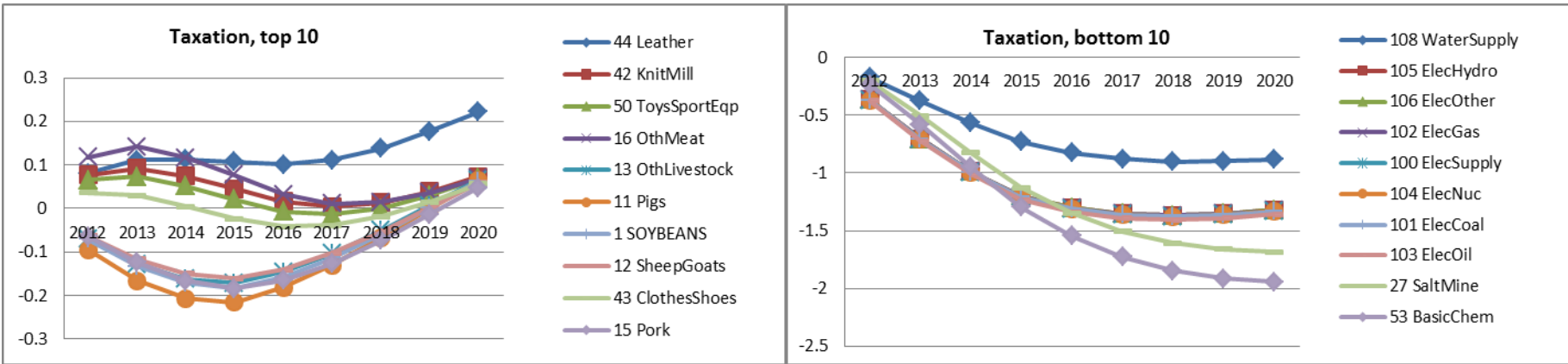
Set 7, Scenario Efficiency, cumulative percentage deviation in industry-activity level from baseline, top and bottom 10



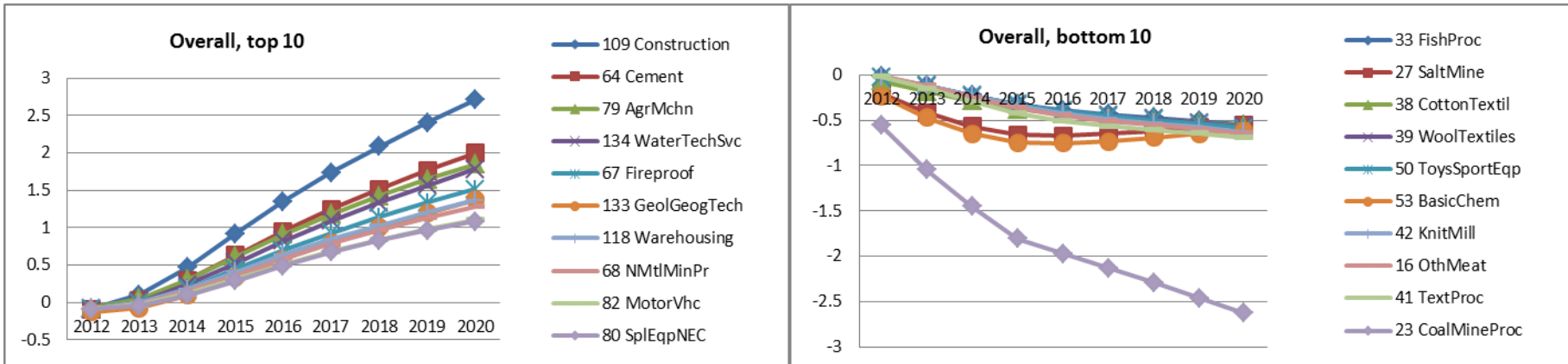
Set 8, Scenario Investment, cumulative percentage deviation in industry-activity level from baseline, top and bottom 10



Set 9, Scenario Taxation, cumulative percentage deviation in industry-activity level from baseline, top and bottom 10



Set 10, Scenario Overall, cumulative percentage deviation in industry-activity level from baseline, top and bottom 10



5. Conclusion

The simulation results shows that investment in improving coal using efficiency in coal fired electricity generation leads to a faster growth in real GDP due to the productivity improvement and resulted faster growth in capital employed in current production. Despite this rebound effect, the investment in the efficiency improvement still leads to an overall reduction in CO₂ emission, resulting in an overall reduction in emission to GDP ratio.

The efficiency scenarios in Section 2 show that given the current predictions of technological advancement it is unlikely that China's coal-fired power plants are going to enjoy the same rate of efficiency improvement in the coming 10 years as they did over the past 10. This is partly because China was able to phase out small and inefficiency old power plants in the past and such opportunities are shrinking. It is also partly due to China's new power plants quickly approaching the technological frontier in the world. However our assumption here is that China is not going to be expanding the world technological frontier in the coming 10 years.

From our simple back of the envelope calculation we find that efficiency improvement in the coal-fired power generation sector is unlikely to bring major reductions in China's carbon intensity of GDP – even if the rate of efficiency improvement can be as high as it was during the 11th FYP period. This suggests there should be other factors (e.g. renewable energy development and carbon pricing) that are strong enough to help China achieve its intensity-based targets.

The CGE simulation further emphasizes this point by showing that the rebound effect is going to lead to even smaller contribution to carbon intensity reduction from more efficient power generation. Our simulation also shows when the efficiency improvement is made possible through higher investment which in turn is financed by higher tax, it could lead to slightly more reduction in carbon intensity, although such a reduction is still smaller than the reduction obtained from the BTE analysis. It is important to notice that this slightly more reduction in carbon intensity is achieved by lower carbon emissions and higher GDP, both are positive results on their own. Taking into the consideration of investment and tax, the impact of efficiency improvement on GNP is almost identical to the impact on GDP. This is slightly

different from the scenario in which only the efficiency improvement is considered, where GNP is slightly lower than GDP. But the difference is very small.

The industry level results are consistent with macro level results. When the financing package is considered, we find investment has the strongest impact in driving industries to expand, hence industries that have large outputs sold as investment goods are set to gain the most. While input-output linkage, trade-exposure, and relative capital to labour ratio in production technology all play some part in determining the results. However the most interesting industry level result is that the electricity generation industries are not expected to expand as much as when only the efficiency improvement is considered, because of the tax bestowed on the industry.

As a further note, the financing package is by itself an interesting exercise since it is replicable when the financing tool is used for other purposes, such as investing in renewable energy. The impact of investment and taxation should have similar patterns regardless of how the money raised is spent. However the amount of the tax collected may be different in every case.

There are also many aspects where our study could improve. The study would benefit from extending to a longer time span, for example to 2030. Then we can observe the impact to the economy as the lagged policy effects began to dominate after the shocks are all employed by 2020. Second, our efficiency scenarios are very simplistic and we look forward to integrate our model with more advanced models from outside the economics discipline. Moreover it also has to be noticed that the pricing mechanism in China's electricity market is not fully market-oriented, further efforts are needed to study the impact of liberating China's energy market.

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