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A MODEL-BASED ANALYSIS

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1. INTRODUCTION

China took the lead as the world's largest CO_2 emitter in 2007. Over the last decade, it has adopted measures to lower the energy and carbon intensity of its economy, partly in response to worsening local air pollution from energy generation. This is not surprising since air pollution in China is estimated to contribute to about 1.6 million deaths per year, roughly 17 percent of all deaths in China. China committed to furthering its efforts to lower the energy and carbon intensity of its economy at the 21st Conference of the Parties (COP) to the United Nations Framework on Climate Change (UNFCCC), held in Paris in late 2015, by affirming its previously announced goal to cause its emissions to peak around 2030 and to increase the share of non-fossil fuels in its primary energy consumption to around 20 percent by the same year. China's intended nationally-determined contribution (INDC) to the Paris accord also puts forward two new goals for 2030: reducing China's CO_2 emissions per unit of GDP (known as its carbon intensity) by 60 to 65 percent relative to 2005 levels, and increasing the volume of its forest carbon stock by around 4.5 billion cubic meters from 2005 levels.

This paper models the policies China could adopt to achieve its energy-related INDC commitments with an eye to understanding how the policies could affect both the Chinese and global economies. We use an updated version of the G-Cubed model, a global intertemporal computable general equilibrium (CGE) model, to explore the possible effects of emissions control policies on the Chinese macroeconomy, individual industrial sectors in China, and other outcomes, such as trade flows, currency values, emissions levels, and economic activity. The major innovation in the version of the G-Cubed model used in this paper is a significant disaggregation of electricity generation technologies with a focus on non-fossil fuel technologies.

The paper is structured as follows. Section 2 reviews China's INDC and summarizes the relevant literature. Section 3 documents how we disaggregated electricity-generating technologies in the G-Cubed model to conduct this study. Section 4 describes the two Chinese policy scenarios that we model. Both are emissions trading programs with emissions caps that are consistent with the country's INDC; one is economy-wide and one is confined to the electricity generating sector. Section 5 explores the results of the modeling exercise, and Section 6 concludes.

2.   BACKGROUND

Over the past few years, China has begun a shift from command-and-control regulation to policies that use market forces to allocate resources.[1] This transition has included reforms of subsidies and taxes and the instigation of seven pilot emissions trading systems (ETS) for carbon dioxide.[2] The ETS programs cover energy-intensive sectors comprising 35 to 60 percent of the total emissions of the participating regions in China, and collectively they cover about 10 percent of the nation's total carbon emissions.[3] Jointly, they covered 650-700 million metric tons of CO_2 in 2014, amounting to the second largest ETS in the world following the European ETS, which covers 2.1 billion tons.

Although the regional Chinese emissions markets remain immature, they inform the potential development of a broader system. A survey of experts in 2013 predicted that China will eventually develop an economy-wide ETS, possibly in combination with a carbon tax.[4] It has since been confirmed—in the joint announcement between the US and China in September 2015—that China plans to launch a national ETS market covering key industry sectors in 2017 and that carbon taxes are still under consideration.[5] It is not clear how China would impose both policies, but one option would be to exclude regions or firms covered by the ETS from the carbon tax.

Along with other measures that China has taken to transform its economy and energy systems (such as upgrading traditional industries, expanding the service sector, subsidizing renewables, and phasing out obsolete facilities), the ETS programs have reduced the growth in coal use and the associated emissions intensity of the Chinese economy.[6] Table 1 shows the rapid growth in non-fossil electricity generation capacity from 2010 to 2014.

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[1] See for example, China's Third Plenum of the 18th Central Committee of Communist Party in 2013, "Decision of the CCCPC on Some Major Issues Concerning Comprehensively Deepening the Reform" (in Chinese). http://www.gov.cn/jrzg/2013-11/15/content_2528179.htm
[2] Munnings et al (2014). The seven pilots are Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Hubei, and Chongqing.
[3] See Greenovation Hub (2013) and Zhang (2015)
[4] Jotzo et al (2014)
[5] The Finance Minister Lou Jiwei confirmed that China would expand environmental taxes to include carbon "in due time" at China-US Strategic and Economic Dialogue in July 2013. In addition, the Draft Environment Tax Law (the carbon tax) was issued in May 2013 by the Ministry of Finance and sent to China's most carbon-intensive industry associations for comments and review.
[6] National Development and Reform Commission of China (NDRC) (2015). Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions.

Table 1: Non-Fossil Generation Capacity in China, 2010 and 2014, in Gigawatts

	2010 (GW)	2014 (GW)	Growth from 2010 to 2014 (%)
Hydro	216.06	301.83	40
Wind	29.58	96.37	226
Biomass	5.50	9.48	72
Solar	0.86	28.05	32
Geothermal	0.028	0.03	7
Nuclear	10.82	19.88	84
Total	262.85	455.64	73

Prior to the COP 15 in 2009, China set a target for 2020 to reduce the carbon intensity of its economy by 40 to 45 percent relative to 2005. In June 2015, in the lead-up to COP 21, China committed to reducing its carbon intensity by 60 to 65 percent by 2030 compared to 2005. It also promised to cause its carbon emissions to peak around 2030.

These commitments appear in China's INDC, President Xi Jinping's announcement in Washington, DC, in November 2014, and China's official planning documents.[7] Table 2 presents China's targets over the 11th Five-Year-Plan (FYP) (2006-2010) and the 12th FYP (2011-2015). The table also reports the target shares of renewable energy in primary energy consumption.

Table 2: Chinese Energy and Carbon Targets

Target	2006-2010	2011-2015	2020	2030
Reduction in energy intensity	20% below 2005	16% below 2010		
Reduction in carbon intensity		17% below 2010	40-45% below 2005	60-65% below 2005
Renewable energy share	10%	11.4%	15%	20%

Data Source: NDRC 2015. Note: The years in brackets marked (rt) indicate the base years to which the targets are relative.

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[7] See the U.S.-China Joint Announcement on Climate Change (https://www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change) and NDRC (2015).

A few recent studies have used computable general equilibrium (CGE) models to study China's climate policies.[8] As Munnings et al. (2014) note, much of this literature focuses on different regional ETS configurations (such as across regions within China and links with systems outside China) and the implications of different allowance allocation strategies. Here our focus is on macroeconomic outcomes and global spillovers of Chinese policy, and in this vein the literature is more sparse. Hubler et al. (2014) assess recent Chinese climate policy proposals in a multi-region, multi-sector CGE model. Their simulation of an ETS policy that lowers China's emissions intensity in 2020 to 45 percent below 2005 levels resulted in estimated losses of GDP and welfare of about 1 percent relative to baseline in 2020, not counting environmental benefits.

Cao (2009) simulated carbon taxes in China in a recursive dynamic CGE model.[9] The study analyzes carbon taxes beginning in 2010 at rates ranging from RMB 50 to 200 (about 7 to 29 U.S. dollars) per metric ton of carbon, keeping tax revenues neutral under two different regimes, lump-sum transfers and a tax swap. The results show that GDP in 2015 declines by 0.1 percent and 0.51 percent respectively for carbon taxes of RMB 50 and 200, assuming revenues return to households in lump-sum transfers. If the carbon tax is offset by reductions in the rates of other distortionary taxes, the negative impacts on the economy are much smaller than in the lump sum rebate scenario, but the environmental benefits are also slightly lower.

Wang et al. (2009) also simulate carbon taxes in China. They use a CGE model[10] developed by Energy Research Institute of China's National Development and Reform Commission (NDRC) to simulate carbon three carbon tax policies: (1) a low rate scenario: the tax starts at RMB 20 per metric ton of carbon in 2012 and increases to RMB 30 in 2010 and RMB 40 in 2030; (2) a middle rate scenario: the tax starts at RMB 50 per metric ton of carbon in 2012 and increases to RMB 75 in 2020 and RMB 100 in 2030; (3) a high rate scenario: the tax starts at RMB 100 per metric ton of carbon in 2012 and increases to RMB 150 in 2020 and RMB 200 in 2030. They find that GDP losses are small while carbon emissions are significantly reduced. More specifically, the GDP loss in 2025 is 0.45 percent under the high rate scenario and less than 0.15 percent under the low rate scenario, while carbon emissions are reduced in 2025 by around 24 percent under the high rate scenario and by 7.5 percent under the low rate scenario.

Shi et al. (2013) use a recursive dynamic CGE model to simulate a carbon tax scenario (as well as a cap-and-trade scenario and a hybrid scenario). In the carbon tax scenario, they implement a constant carbon tax at RMB 40 per ton of CO_2 beginning in 2013. The tax revenues fund

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[8] For a summary of earlier studies, also see Jorgenson et al (2013).
[9] Also see Cao (2007).
[10] See the model details at https://unfccc.int/files/meetings/workshops/other_meetings/application/vnd.ms-powerpoint/jiang.pps.

revenue neutral cuts in corporate taxes. They show that GDP loss is 0.2 percent and carbon emissions are reduced by 6.6 percent in 2020.

3.   MODELING APPROACH

This study models two Chinese climate policy scenarios consistent with the Chinese INDC. One policy achieves Chinese emissions targets with an ETS covering all energy-related fossil CO_2, and the other achieves the same economy-wide emissions targets with constraints applied only in the electricity sector. Projecting how China's climate policy would affect the evolution of its electricity sector required disaggregating G-Cubed's electricity sector into specific technologies: coal, natural gas, oil, nuclear, wind, solar, hydro and other (largely biomass and other renewables). A technical discussion of the original version of G-Cubed appears in McKibbin et al. (2009), and the theory behind the model appears in McKibbin and Wilcoxen (1999) and McKibbin and Wilcoxen (2013).[11] This section describes the innovations to the model that were necessary for this study.

Our work involved adding a total of eight new goods and sectors to the model. We also redefined several of the model's original sectors:

- Sector 1, electric utilities, is now "electricity delivery";
- Crude oil and gas extraction (5) is now split into crude oil extraction (new sector 5) and natural gas extraction (new sector 6);
- Other mining has been renumbered (now sector 7) to accommodate the new gas extraction sector; and
- The agriculture and forestry sectors (previously 7 and 8) are merged into a new "agriculture and forestry" sector (new sector 8).

The full list of sectors in the new model is shown in Table 3. Sectors we added or redefined are highlighted in gray; the "code" column provides short names for the sectors that will appear in tables and graphs of results.

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[11] G-Cubed, which includes macroeconomic dynamics and various nominal rigidities, is similar to dynamic stochastic general equilibrium models that feature in the macroeconomic and central banking literatures.

Table 3: Sectors in the Extended G-Cubed Model

Num	Sector Name	Code
1	Electricity delivery	ElecU
2	Gas utilities	GasU
3	Petroleum refining	Ref
4	Coal mining	CoalEx
5	Crude oil extraction	CrOil
6	Natural gas extraction	GasEx
7	Other mining	Mine
8	Agriculture and forestry	Ag
9	Durable goods	Dur
10	Nondurables	NonD
11	Transportation	Trans
12	Services	Serv
13	Coal generation	Coa
14	Natural gas generation	Gas
15	Petroleum generation	Oil
16	Nuclear generation	Nuc
17	Wind generation	Win
18	Solar generation	Sun
19	Hydroelectric generation	Hyd
20	Other generation	Oth

G-Cubed distinguishes between sectors and goods to allow for joint production. An "agent" is an entity that demands products or services: either one of 22 producing sectors or a final demand (FD) category. For clarity, G-Cubed sector numbers are prefixed with "a" (for agent) and goods numbers are prefixed by "g." The new sectors are thus a13-a22 and the new goods are g13-g22. The new goods, g13-g22, are "generation goods" purchased only by the electricity delivery sector (a01). All other sectors buy electricity from sector 1. The generation goods are not intermediate inputs to other sectors, nor are they purchased by final demand sectors or traded between regions.

Figure 1 shows the model's new organization of production across sectors and goods in an input-output table. Each column of the table corresponds to an agent (labeled a01 to a22 for producing sectors and FD for final demand). Each row corresponds to a good, service or primary factor. Shaded blocks represent those elements that involve demand equations. There are no demand equations associated with any of the unshaded blocks.

The new sectors and goods appear as shaded and numbered blocks 2, 6, and 4. The input demands by the new sectors appear in shaded blocks 2 (intermediates) and 6 (value added, or VA). The demands for the new generation goods (purchased only by a01) appear in block 4.

The remaining numbered blocks (1, 3, 5, and 7) show demand equations that are unchanged from earlier versions of the model. Blocks 1 and 5 show intermediate and value added demands by the standard sectors other than electric utilities (a02-a12), and blocks 3 and 7 show demands by final demand sectors.

Figure 1: Expanded Input-Output Table

	a01	a02-a12	a13-a22	FD
g01-g12		1	2	3
g13-g22	4			
VA		5	6	7

The factor demands and investment models for new sectors a13-a22 are structurally similar to those for sectors a02-a12 and follow a tier-structured approach. Output is a function of inputs of capital, labor, energy, and materials. However, energy inputs are sector-specific and only apply to the fossil-fuel-based technologies: the coal-fired generating sector (a13) uses inputs of coal (g04); the gas-fired sector (a14) uses inputs of gas (a06); and petroleum-fired generation (a15) uses oil (g05). The remaining electricity sectors (a16-a20) do not purchase energy inputs.

Sector 1 (a01) is redefined from electricity production to "electricity delivery". It purchases the outputs of generation sectors a13-a22 and produces good 1 (g01) "delivered electricity" or just "electricity" for short. All sectors that use electricity other than sector 1 buy only good 1 and not the output of any of the individual generation sectors.

The new electricity sector 1 buys only the outputs of the generation sector; it does not buy any conventional goods nor any capital or labor.[12] Sector 1's production function is shown schematically in Figure 2, where "CES" indicates a constant elasticity of substitution function. New variables $X_{1,13}$ through $X_{1,22}$ give intermediate demands by sector 1 for generation goods g13 through g22.

Figure 2: Production of Delivered Electricity
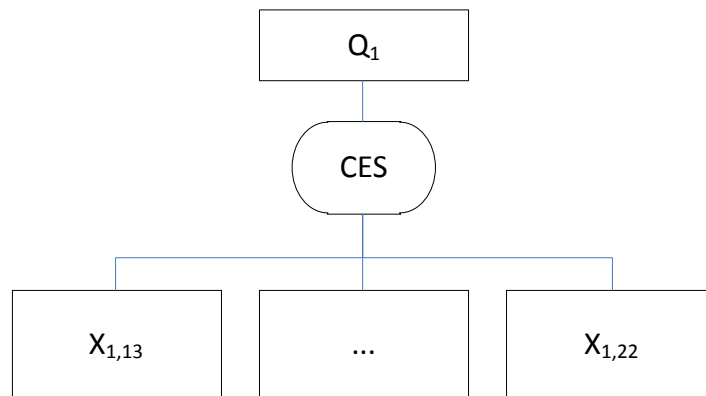
Because the generation goods are not traded internationally, the market clearing equation for each one is very straightforward. Demand for generation good j by sector 1 ($X_{1,j}$) must equal the supply of good j (Q_j):

(1) $$X_{1,j} = Q_j$$

Domestic producer prices for electricity generation are treated symmetrically with ordinary sectors g02-g12: they are built from the duals of nested KLEM production functions. Domestic supply prices for generation goods may be higher than producer prices when carbon or energy taxes are imposed. The producer price for the delivered electricity sector, a01, is defined by the dual from the production function diagrammed in Figure 2 and depends on the domestic supply prices of the generation goods.

Each sector in the model now has two new parameters, γ_i and ϕ_i, that together determine the sector's production of electricity and its potential supply of clean energy credits (CECs). CECs are not used in this analysis but were included to support future work. Parameter γ_i indicates the number of GWh produced per unit of sector i's output and parameter ϕ_i indicates the

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[12] This may subsequently be relaxed to allow sector 1to include costs associated specifically with transmission and distribution; in the current version, these costs are split among generating technologies.

fraction of each GWh produced by the sector that qualifies as clean under a given policy. Each sector's electricity output (G_i) and qualifying clean output (G_i^c) are thus:

(2) $\qquad G_i = \gamma_i Q_i$
(3) $\qquad G_i^c = \phi_i G_i$

CECs from different sources are perfectly substitutable. The total supply of electricity in a given region, G_T, is the sum across sectors of G_i. The total supply of CECs in a region, G_T^c, is the sum across sectors of G_i^c, and the fraction of electricity production qualifying as clean is S^c:

(4) $\qquad S^c = G_T^c / G_T$

Note that under this approach, only domestic generation is considered for determining compliance with a clean electricity policy.

When a clean energy policy is in effect, CECs are demanded by the electricity distribution sector (a01) and the market clearing price of a CEC is P^c. The policy can be imposed as a percent of generation or as an absolute requirement. When a clean energy standard is not in effect or not binding (and banking is not allowed), the price of a CEC may be zero. Revenue from the sale of CECs contributes to the overall revenue of each generation sector. As a result, the revenue term in Equation 5 is augmented and now takes the form shown below:

(5) $\qquad (P_i^* + P^c \gamma_i \phi_i) Q_i$

Purchases of CECs are included in the electricity delivery sector's costs and raise its producer price. We assume that the cost is passed on to all electricity users via a fixed markup equal to the total amount spent on CECs divided by sector 1's sales. The markup per unit of sector 1's output, m_1, will thus be:

(6) $\qquad m_1 = P^c G_T^c / G_T = P^c S^c$

A key source of international data on electricity production used in expanding the model was the International Energy Agency's electricity database described in IEA (2010). The database's EleHeatGen table provides figures on electricity generation by 56 source categories and two plant types (utility or CHP). Plant types were summed to obtain total electricity generation and then converted to gigawatt hours (GWh). Table 4 shows the mapping between the categories defined in the IEA database and the sectors in the extended version of G-Cubed. Table 5 shows the mapping between the OECD countries in the database and G-Cubed regions.

Table 4: Mapping Between IEA and G-Cubed Sectors

G-Cubed Number	G-Cubed Name	IEA Categories
13	Coal	17 subcategories: antcoal, bitcoal, bkb, blfurgs, brown, coaltar, cokcoal, cokeovgs, gascoke, gaswksgs, lignite, mangas, ovencoke, oxystgs, patfuel, peat, subcoal
14	Gas	5 subcategories: gbiomass, indwaste, munwasten, natgas, sbiomass
15	Oil	12 subcategories: bitumen, crudeoil, gasdies, jetkero, lpg, naphtha, ngl, ononspec, othkero, petcoke, refingas, resfuel
16	Nuclear	nuclear
17	Wind	wind
18	Solar	3 subcategories: solar, solarpv, solarth
19	Hydro	2 subcategories: hydpump, hydro
20	Other	15 subcategories: boiler, chemheat, geotherm, heatns, heatpump, landfill, munwaster, obiogas, obioliq, oprods, other, renewns, sludgegs, tide, woodveg

Table 5: Mapping Between IEA and G-Cubed Regions

G-Cubed Region	IEA Country Codes
Australia	Australi
Europe	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembou, Nethland, Norway, Portugal, Spain, Sweden, Switland, UK
Japan	Japan
Other OECD	Canada, NZ
USA	USA

The version of G-Cubed we use in this study includes the nine geographical regions listed in Table 6 below. The United States, Japan, Australia, and China are each represented by a separately modeled region. The model aggregates the rest of the world into five composite regions: Western Europe, the rest of the OECD (not including Mexico and Korea); Eastern Europe and the former Soviet Union; OPEC oil exporting economies; and all other developing countries.

Table 6: Regions in the G-Cubed Model

Region Code	Region Description
U	United States
J	Japan
A	Australia
E	Western Europe
O	Rest of the OECD, i.e. Canada and New Zealand
C	China
B	Eastern Europe and the former Soviet Union
L	Other Developing Countries
P	Oil Exporting Developing Countries

The Baseline Scenario

One of the largest challenges in this project was dealing with a range of apparent inconsistencies in the Chinese data on output and emissions by sector. Different assumptions regarding data can change the quantitative magnitudes of some results so the figures below should be considered to be indicative of the expected outcomes of the policies explored rather than precise estimates. Recent announcements of the underestimate of coal use in China[13] and possible overestimate of Chinese carbon dioxide emissions[14] illustrate the uncertainty in the data underpinning the modelling in this paper. We primarily use official data but adjust it where necessary to reduce inconsistencies.

The model's projections of future emissions and economic activity in the absence of climate policy is our business-as-usual (baseline) scenario. A detailed discussion of the baseline construction process for G-Cubed appears in McKibbin, Pearce and Stegman (2009). The baseline in this study is broadly consistent with the emissions and GDP growth in the Department of Energy's Updated *Annual Energy Outlook* Reference Case Service Report from May 2015.[15] It sets G-Cubed's projected productivity growth rates so that the model's baseline results approximate the report's forecasts for U.S. real gross domestic product (GDP) and other key variables.

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[13] See Energy Information Administration note on "Recent Statistical Revisions Suggest Higher Historial Coal Consumption in China", September 16, 2015 based on new data in the *China Statistical Abstract 2015* (CSA2015) http://www.eia.gov/todayinenergy/detail.cfm?id=22952#
[14] See Liu (2015).
[15] The report appears at the DOE's Energy Information Administration website: http://www.eia.doe.gov/oiaf/servicerpt/stimulus/index.html.

Along with the baseline for China, we construct a baseline scenario for the other regions in the world that reflects our best estimate of the likely evolution of each region's economy without concerted climate policy measures beyond those announced by the end of 2014. To generate this scenario, we begin by calibrating the model to reproduce approximately the relationship between economic growth and emissions growth in the United States and other regions over the past decade and then impose already-implemented carbon policies. In the baseline, neither the United States nor other countries adopt an economy-wide price on carbon.

The greenhouse gas emissions included in G-Cubed comprise only CO_2 from energy-related fossil fuel consumption, including combustion of coal, natural gas, and oil. This represents a large majority of total Chinese greenhouse gas emissions. For example, according to the Belfer Center's Report on China's Carbon Emissions in 2015, "fossil fuel combustion comprised 90 percent of all Chinese CO_2 emissions in 2012."

Figure 3 shows the model's projections from 2012 to 2050 for global CO_2 emissions from energy use across four major regions: China, the United States, Europe, and the rest of the world (ROW). These projections do not include the INDCs submitted to COP21 in Paris.

Figure 3: Global Carbon Dioxide Emissions
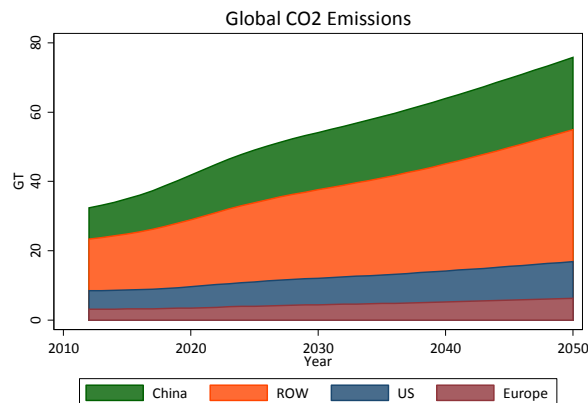
4. POLICY SCENARIOS

In this study, we examine two cap-and-trade policies that China could adopt to cause its emissions to peak in 2030 and hold steady thereafter. The first is an economy-wide ETS applying to all sources of CO_2 emissions from energy use in China. The second is an ETS that achieves the same total national emissions but constrains only those emissions from the generation of electricity. As the coverage any future national ETS remains speculative, we

choose these two plausible examples to illustrate the key differences between sector-specific and economy-wide approaches. We can then see how the different policies to cause emissions to peak in 2030 contribute to two other components of China's INDC, namely the commitments to decrease emissions intensity of the economy by 60 to 65 percent relative to 2005 levels and to achieve a 20 percent share of renewables in all primary energy (not just electricity).

In both policy scenarios, we assume the ETS permits are auctioned and the revenue redistributed to households in lump sum rebates. We hold government purchases of goods and labor constant relative to baseline levels in each year.

Figure 4 shows the model's projections for China's emissions under the baseline projections outlined above and then under a trajectory consistent with the recent INDC, which calls for the leveling of CO_2 emissions by 2030. The two policy scenarios achieve the same emissions path by design; the policy labeled National is the economy-wide ETS and the policy labeled Electricity is the ETS confined to the electricity sector. Emissions in the policy scenarios gradually depart from the rising baseline emissions curve to level out at 14 gigatonnes (Gt) of CO_2 in 2030. This emissions trajectory is essentially arbitrary; the INDC does not specify the actual level at which emissions will stabilize. In Appendix A, we show that a less ambitious path would lead to lower economic costs (and greater emissions), but the differences between the alternative policies are similar to the trajectory presented here.

Figure 4: China's Carbon Dioxide Emissions
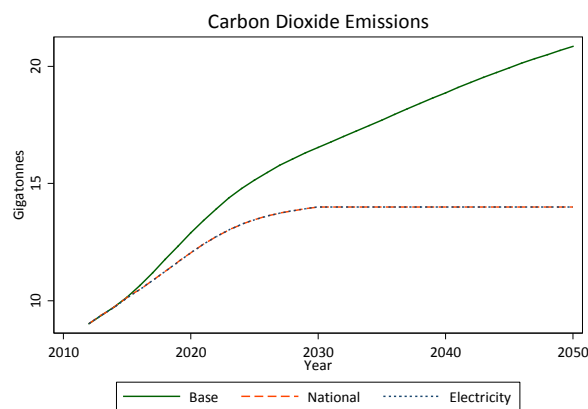
5.   RESULTS

As shown in Figure 4, China's INDC reduces its carbon dioxide emissions substantially relative to its baseline: emissions are lower by 1 Gt in 2020, by almost 5 Gt in 2040, and by almost 7 Gt

in 2050. The difference as a percent of baseline emissions is shown in Figure 5. Emissions are 6 percent lower than baseline in 2020, 26 percent lower in 2040 and 33 percent lower by 2050.

Figure 5: Change in Emissions Relative to Baseline
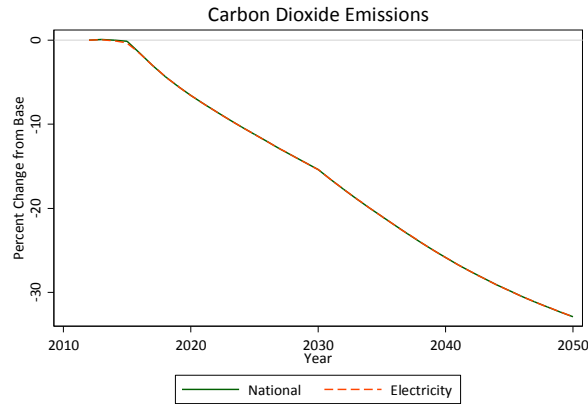
The two policies produce the emissions permit prices shown in Figure 6. Under the electricity-only policy, permit prices are double those under the economy-wide approach. That is consistent with the fact that the electricity policy produces the same reduction in emissions as the national policy, but in a narrower slice of the economy.

Figure 6: Emissions Permit Prices
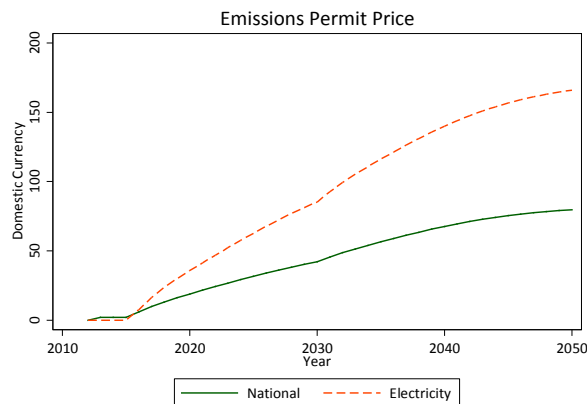
As shown in Figure 7, which reports China's GDP in each year relative to its value in 2012, both policies slow China's growth slightly. Under the baseline, China's 2050 GDP is 3.7 times its 2012 value. Under the two carbon policies it is slightly lower: 3.6 times its 2012 value. As shown in Figure 8, by 2030 the difference is roughly 1.5 percent, and in 2050 the difference is a drop of 2.5 percent relative to baseline. The electricity-only policy is slightly more costly than the economy-wide approach in terms of GDP, but the two policy results are very close.

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Figure 7: Real GDP in China Relative to 2012
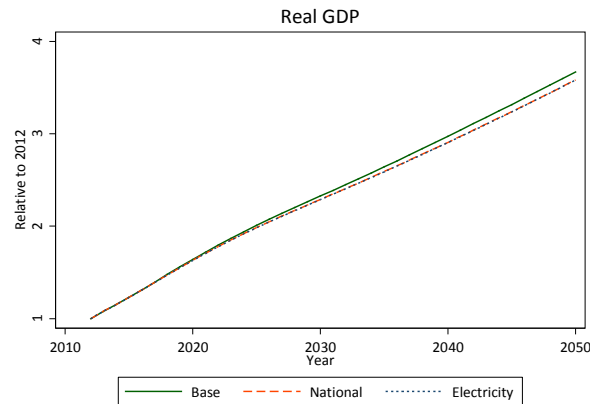
Real GDP

Figure 8: Change in Real GDP Relative to Baseline

Change in Real GDP
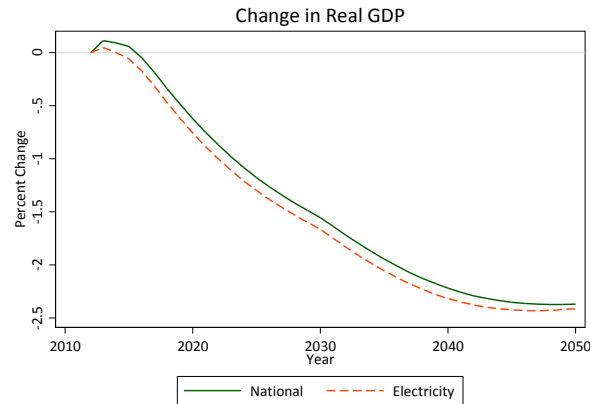
Because the policies reduce emissions sharply but have only a small effect on GDP, they significantly reduce China's emissions intensity as measured by emissions per unit of real GDP. However, that reduction comes on top of a baseline reduction in emissions intensity. Figure 9 shows real GDP and carbon dioxide emissions in the baseline, with both series normalized to one in 2012. Emissions grow more slowly than GDP throughout the period, and the difference in growth rates increases after 2025.

Figure 9: Baseline Relative Growth in GDP and Carbon Dioxide Emissions

Real GDP and CO2 Emissions, Base
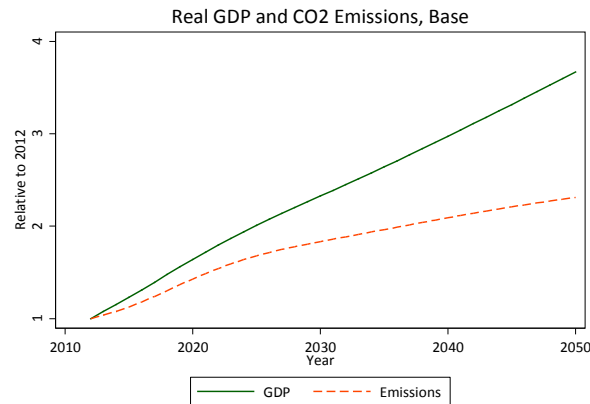
Figure 10 shows China's carbon emissions intensity relative to 2005 for the baseline and the policy simulations. In its INDC, China committed to reducing the carbon intensity of its economy by 60 to 65 percent by 2030 compared to 2005. Figure 10 shows that in the baseline, China would go far towards that goal; emissions per unit of GDP in 2012 are already substantially below 2005's value, and the model projects the trend would continue to about 51 percent below 2005 by 2030. Both of the ETS policies we posited reduce the intensity further, to about 59 percent by 2030—a bit shy of China's goal. Shortly thereafter, the goal is achieved, and by 2050 the carbon intensity is down by nearly 75 percent relative to 2005.

Figure 10: Emissions Intensity of China's Economy Relative to 2005

Reduction in Emissions Intensity
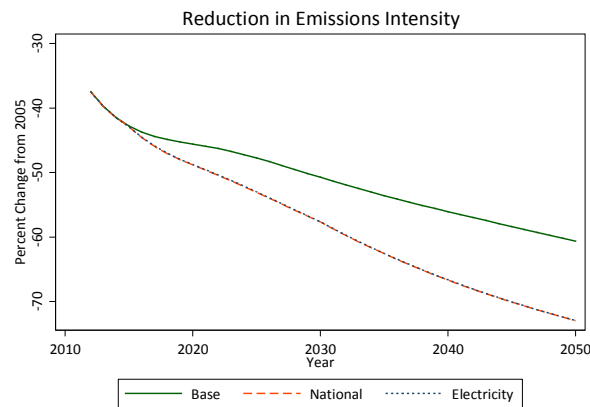
Figure 11 shows the share of renewables in total primary energy in the baseline and policy scenarios. We find that our illustrative path to cause emissions to peak in 2030 would not quite suffice to hit China's INCD target of a 20 percent share of renewables (marked by the gray horizontal line) in the same year. At 17 percent renewables in 2030, the electricity-sector

policy comes the closest, but neither policy hits the 20 percent renewables target until about five years after 2030.

Figure 11: Renewables as a Share of Primary Energy

Renewable Share of Primary Energy
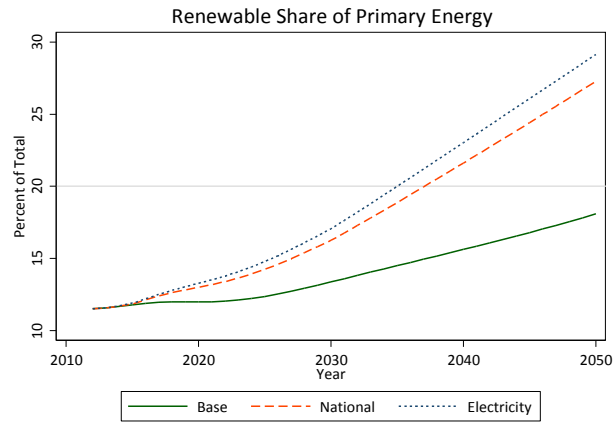
As shown in Figure 12, sales of emissions permits raise considerable revenue. The economy-wide policy produces almost $80 billion (in US dollars) of revenue at its peak while the electricity-only policy produces somewhat less: about $60 billion. Although the permit prices are nearly double in the electricity-sector-only policy, the substantially smaller coverage of the ETS results in lower total allowance value than in the economy-wide program.

Figure 12: Revenue from Sales of Emissions Permits

Emissions Permit Revenue
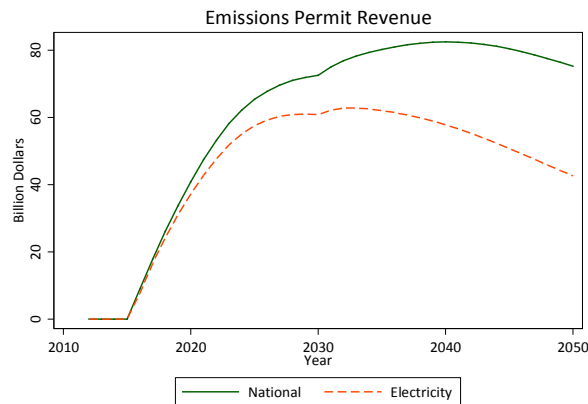
Figure 13 shows the change relative to baseline in 2020 producer prices for each sector (as shown in Table 3) under the two policies. Note that the graph shows the change in broad prices charged to all buyers of each good and does not reflect the sector-specific price changes for coal, oil and gas sold to the electric sector under the electricity-only policy. (That is, the change in the price of coal, for example, is the change in the price of coal seen by users other than the electric sector; the electric sector's coal price would be substantially higher.) Under

the economy-wide policy, the price of coal (sector 4) increases by about 35 percent and the price of natural gas (sector 6) increases by about 9 percent. Downstream, the price of coal and gas-fired electricity (sectors 13 and 14) increase, as does the overall price of delivered electricity (sector 1). Reflecting the higher emissions permit prices under the electricity-only policy, the prices of coal and gas-fired electricity increase substantially more, as does the price of delivered electricity.

Figure 13: Changes in Producer Prices in 2020
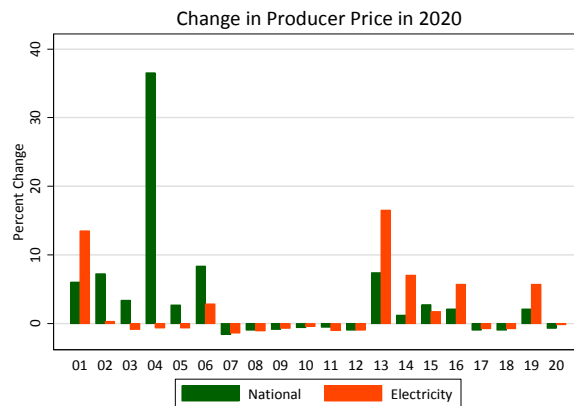
The 2020 changes in industry output are shown in Figure 14. Output of coal (sector 4) falls by 7-8 percent relative to baseline under both policies and output of delivered electricity (sector 1) falls 3-4 percent. Outputs of other fuels (sectors 2, 3, 5 and 6) fall modestly but somewhat more under the economy-wide policy than under the electricity policy. The two policies differ most in their impact on electricity generation (sectors 13-20).

Figure 14: Changes in Industry Output in 2020
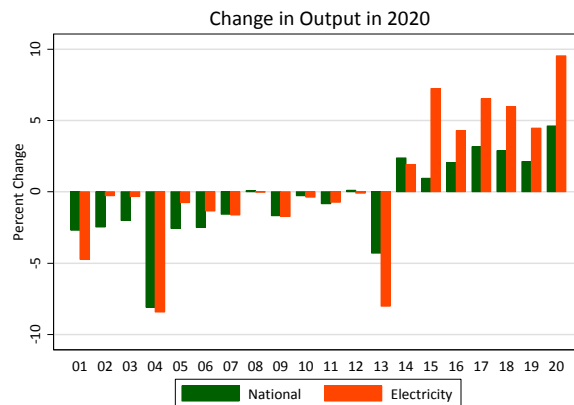
Figure 15 shows electricity generation in more detail. The higher emissions permit prices under the electricity-only policy cause significantly more substitution away from coal-fired generation ("Coa" in the figure) toward oil-fired and non-fossil generation.

Figure 15: Changes in Electricity Generation in 2020
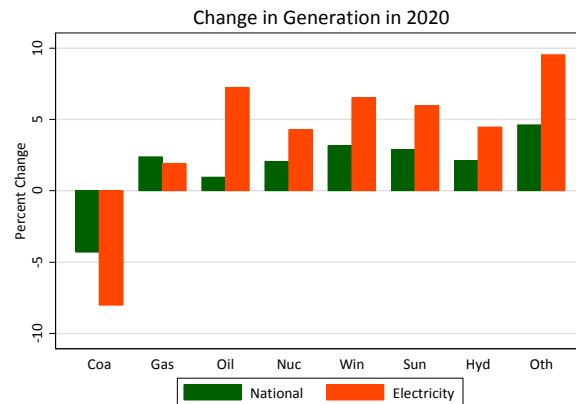
Figure 16 shows the effects on producer prices in 2040 as the policies cause a sharper divergence from the baseline. Coal prices (sector 4) rise by nearly 250 percent under the economy-wide policy. The price of delivered electricity (sector 1) rises by about 25 percent under the economy-wide policy and by more than 60 percent under the electricity-only policy.

Figure 16: Changes in Producer Prices in 2040
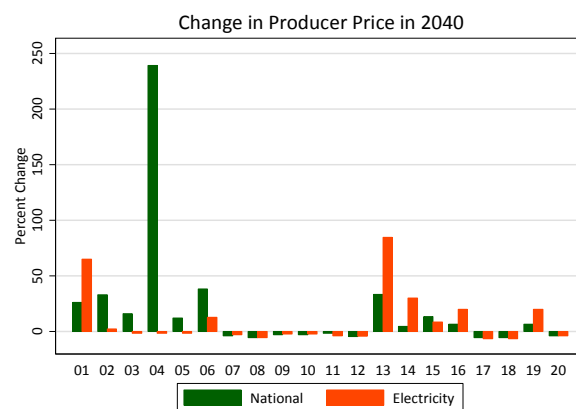
As shown in Figure 17 and Figure 18, the pattern of changes in output and electricity generation are similar to 2020 but larger in magnitude. Coal output falls by nearly 40 percent relative to baseline, and delivered electricity falls by 10-15 percent. Coal-fired drops substantially under both scenarios and by nearly twice as much under the electricity-only policy.

Figure 17: Changes in Industry Output in 2040

Change in Output in 2040
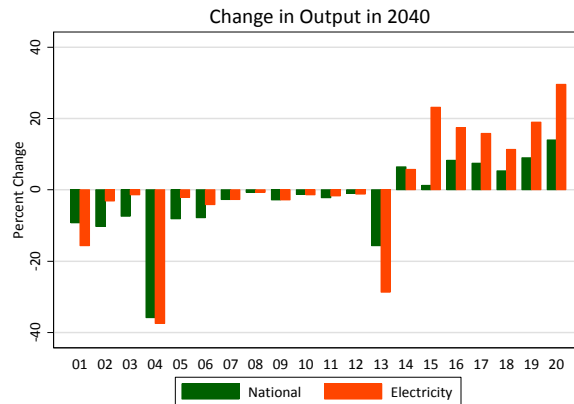
Figure 18: Changes in Electricity Generation in 2040

Change in Generation in 2040
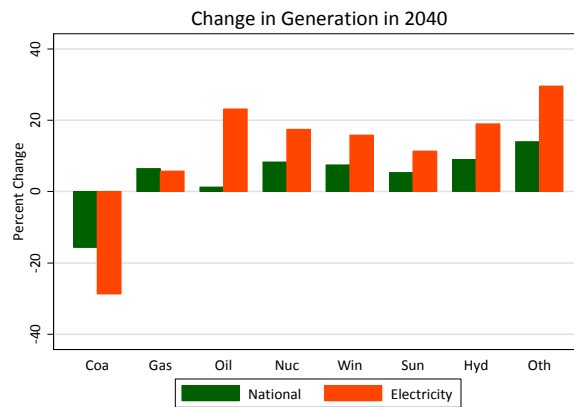
Much of the emissions reductions under both policies occur through reductions in coal consumption. Unlike the United States, China uses large amounts of coal outside the electric sector; consumption is quite large in refined petroleum products (sector 3), as well as in the production of durable goods (sector 9) and household consumption. Figure 19 shows the use of coal by industry in 2040 under the baseline and both policies. The economy-wide policy reduces coal consumption in all sectors, with significant changes in petroleum refining, durables and households (not shown). In contrast, under the electricity-only policy the changes are confined to coal-fired electricity generation (sector 13) but are larger there as a result.

Figure 19: Use of Coal by Industry

Industry Use of Coal in 2040
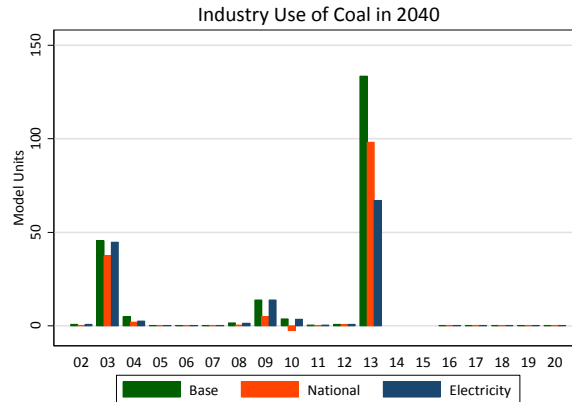
At the macroeconomic level, the impact of the economy-wide policy on real GDP and its components is shown in Figure 20. The change in GDP and each component is shown as a percent of baseline GDP. Investment falls most, dropping relative to its baseline value by about 3 percent of baseline GDP by 2050. In contrast, consumption rises slightly in the short term as a result of an increase in household income (Figure 21) due to the revenue from permit sales that is returned to households as a lump-sum rebate. Real government spending on goods remains essentially at baseline because government purchases of goods are held constant by construction and the price of the government's consumption bundle (other than labor) changes very little relative to the overall price level. However, the government's real expenditure on labor falls significantly. The reason is that government demand for labor is held constant by construction and, as we will show below, the real wage falls significantly under the policy. As a result, real government spending on labor falls by about 2.5 percent in the long run.

Figure 20: Impact of the Economy-Wide Policy on Components of GDP

Change in Real GDP and Components
National Policy

22
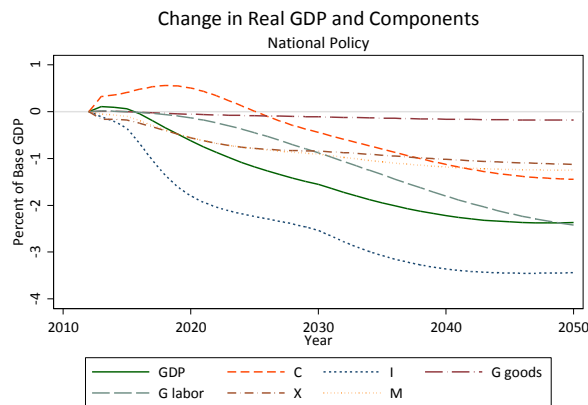
Figure 21: Impact of Policies on Nominal Household Income

Effect on Household Income
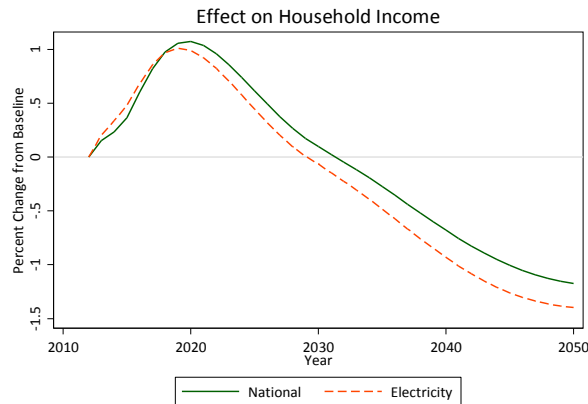
Figure 22 shows the impact of the electricity-only policy on real GDP and its components. Overall, the effects are very similar to the economy-wide policy. The main differences are in investment and exports, both of which fall slightly less under the electricity-only policy.

**Figure 22: Impact of the Electricity-Only Policy on Components of GDP**

Change in Real GDP and Components
Electricity Policy
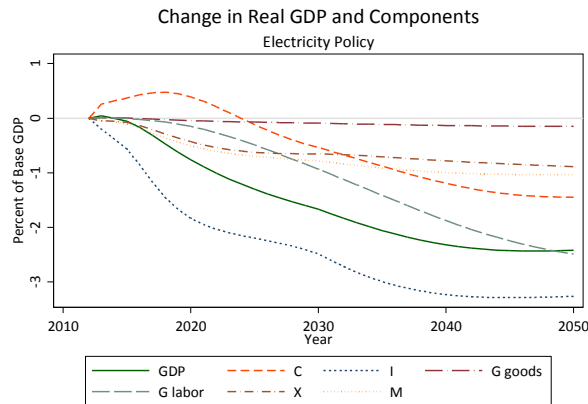
Under both policies, China's currency appreciates slightly relative to the US dollar, as indicated in Figure 23 which shows the percent change in the number of dollars per RMB. The ETS policies cause imports to fall more due to the reduction in domestic demand than exports fall due to the increase in production costs, causing China's trade balance to move further toward surplus and appreciating the currency.

**Figure 23: Effect on the Real Exchange Rate**
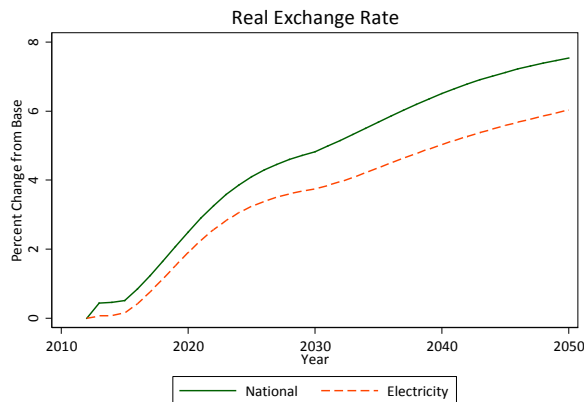
The effect of the two policies on employment is shown in Figure 24. Employment falls relative to its baseline by about 0.6 percent in 2025 and then gradually returns to baseline in the long run. There is a slight kink in 2030 when emissions are stabilized and the rate of growth of the emissions price increases slightly.

**Figure 24: Effects of the Policies on Aggregate Employment**
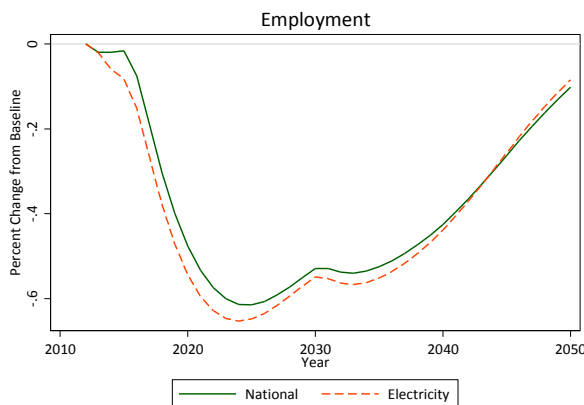
As noted above, the policies lower real wages significantly relative to baseline, as shown in Figure 25 (the level of wages) and Figure 26 (the change in wages relative to the baseline). Wages rise substantially in the baseline and under the policy simulations as well. However, wages rise more slowly with either ETS in effect. By the time emissions peak in 2030, wages are over 6 percent lower than baseline. The wage-depressing effect of the policies worsens through 2040.

**Figure 25: Real Wage under the Baseline and ETS Policies**

Real Wage Relative to 2012
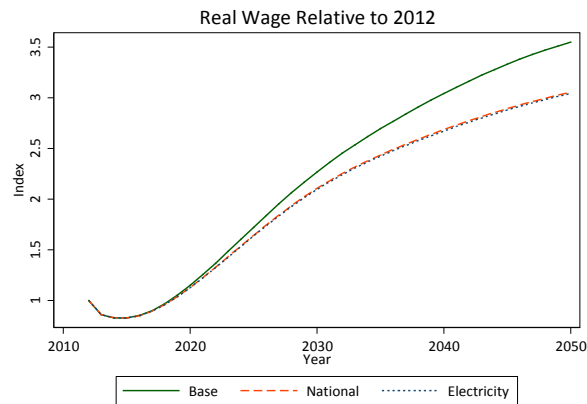
Figure 26: Effects of the Policies on the Real Wage


Wage
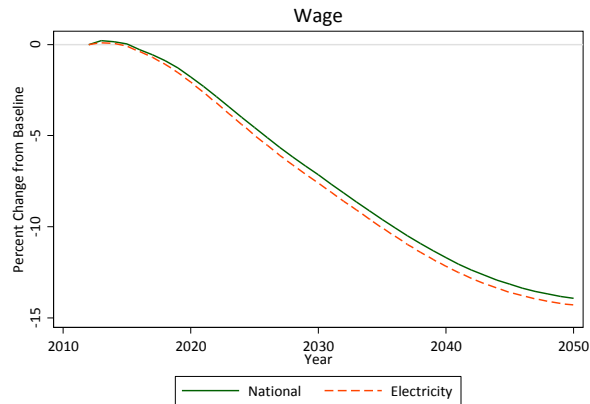
As shown in Figure 27, China's policies cause changes in the real GDP of other regions, as enumerated in Table 6. Real GDP in 2020 falls slightly for most regions although the changes are very small for Europe (E) and the United States (U).

Figure 27: Impacts on 2020 Real GDP by Region

Change in Real GDP in 2020
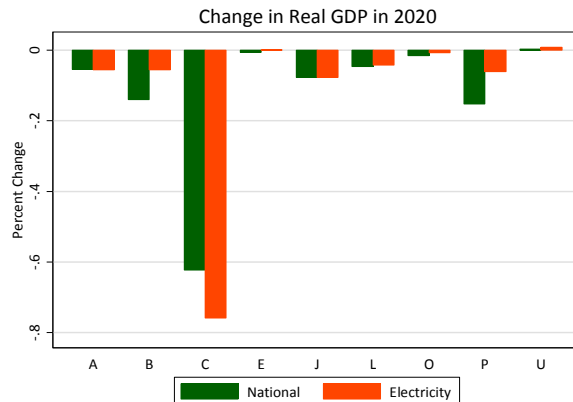
By 2040, as seen in Figure 28, when the effects on China (C) are significantly larger, the impacts on real GDP outside China are most significant for Eastern Europe and the Former Soviet Union (B) and OPEC (P). Both fall by about 0.3 percent relative to baseline under the economy-wide policy. Under the electricity-only policy, international effects are more muted and GDP changes are very small, even in the regions that are affected most.

Figure 28: Impacts on Real GDP by Region in 2040

Change in Real GDP in 2040
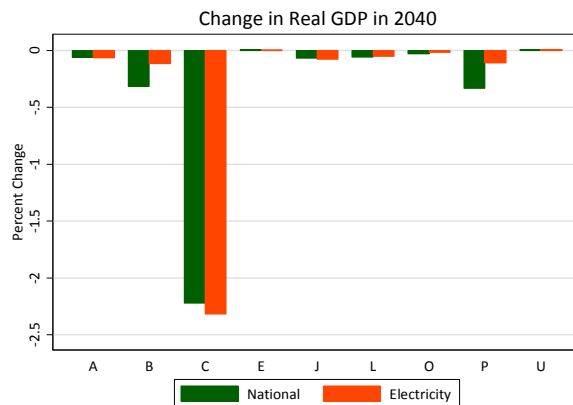
Finally, we find very little emissions leakage associated with either Chinese policy. Figure 29 shows 2040 carbon dioxide emissions by region under the baseline and both policy scenarios. Emissions are slightly higher than baseline in Europe and OPEC under the economy-wide policy, and slightly lower than baseline in Japan under the electricity-only policy, but the effects are very small and nearly undetectable at a scale measured in Gt.

Figure 29: Carbon Dioxide Emissions by Region
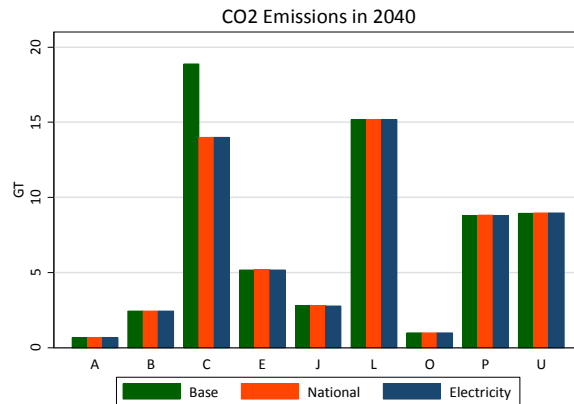
6. CONCLUSION

It is challenging to model China's climate policy both because of the uncertainty about the quality of data and problems with consistency of data and because of the nature of commitments (i.e., leveling of emissions in 2030 at an unspecified level). We converted these commitments into concrete assumptions for modeling purposes, and we found that different assumptions change the quantitative outcomes. Nonetheless, our new model of China's economy enables us to quantify key Chinese policy announcements and develop some key insights for policy design in China.

Overall, our results show that illustrative policies to achieve China's commitment to cause its emissions to peak in 2030 imply a substantial departure from baseline emissions, even after accounting for large baseline reductions in China's emissions intensity. In our scenarios, Chinese emissions are 6 percent lower than baseline in 2020, 26 percent lower in 2040 and 33 percent lower by 2050. The reductions come at a cost; in 2030 in our policy scenarios, China's real GDP would be about 1.5 percent lower than baseline, and real wages would grow less rapidly than they otherwise would have. At the same time, the target appears quite credible: the changes to peak emissions in 2030 are manageable for a country that will be growing rapidly in the coming decades and do not involve disruptions that would be likely to cause the commitment to be abandoned.

Comparing the two policies shows that China's leaders have discretion over the means by which they achieve the INDC target. Both policies operate mainly through reducing the use of coal. Under the economy-wide permit system, the reductions are spread throughout the economy while under the electricity-only policy they are concentrated in the electric sector.

However, both policies have similar impacts on real GDP and its components. The economy-wide policy is slightly more efficient, but the difference is small.

We also find that China's policies to control emissions have little effect on emissions elsewhere; there is almost no shift in emissions from China to its trade partners. There are, however, small reductions in real GDP in other countries as China's economy grows more slowly than under the baseline. Those changes are most important for Eastern Europe and the Former Soviet Union and OPEC, and are very small for Europe and the United States. Thus we find that countries that import energy-intensive goods from China would bear little of the burden of Chinese emissions control efforts.

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APPENDIX A: ALTERNATIVE 2030 EMISSIONS TARGET

The policy scenarios in the body of the paper offer one illustrative path China could follow to cause its emissions to peak in 2030. This appendix examines a pair of less ambitious policies that stabilize emissions in 2030 at 15 Gt in 2030 rather than 14 Gt, as shown in Figure 30 where "Main" indicates the target examined in the body of the paper and "Alternate" is the less ambitious version. Although the difference per year appears small, the cumulative impact is substantial: the "Main" target reduces China's cumulative emissions through 2050 by 119 Gt relative to the baseline while the "Alternate" target only reduces emissions by 91 Gt.

Figure 30: Alternate Carbon Emissions Target
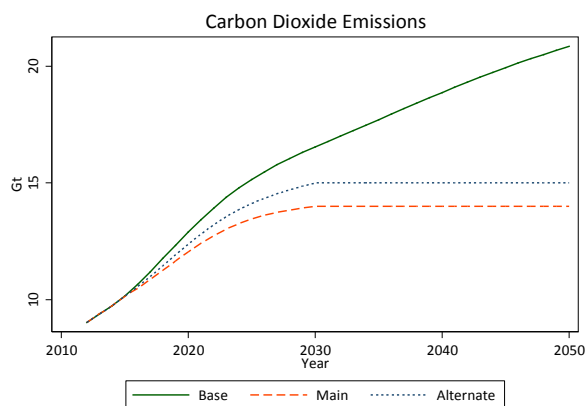
The change in carbon emissions as a percent of baseline is shown in Figure 31 for both the main and alternate targets and is substantially smaller for the latter: a 4 percent reduction by 2020 rather than 6 percent, a 21 percent reduction in 2040 rather than 26 percent, and a 28 percent reduction in 2050 rather than 33 percent. In addition, the transition to stable emissions in 2030 is slightly more abrupt than under the previous target, generating the kink in the emissions reduction in that year.

Figure 31: Change in Emissions, Alternate Target
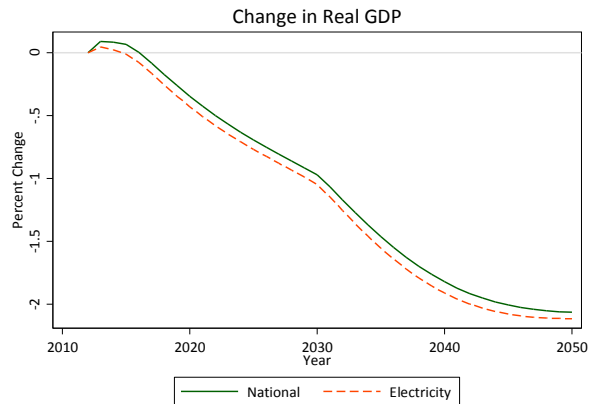
Carbon Dioxide Emissions
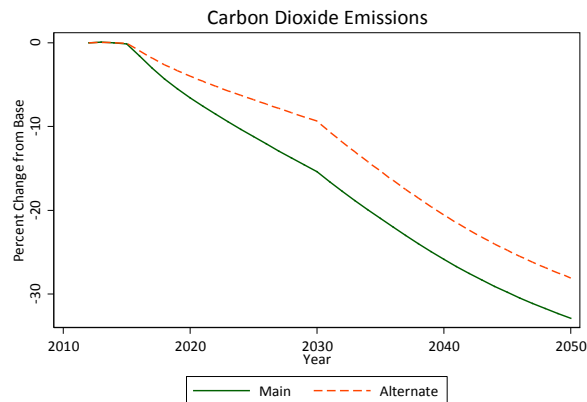
The emissions permit prices are lower in all years, as shown in Figure 32. In addition, they grow more slowly prior to stabilization in 2030 because the looser target is significantly closer to baseline emissions during that period (see Figure 30).
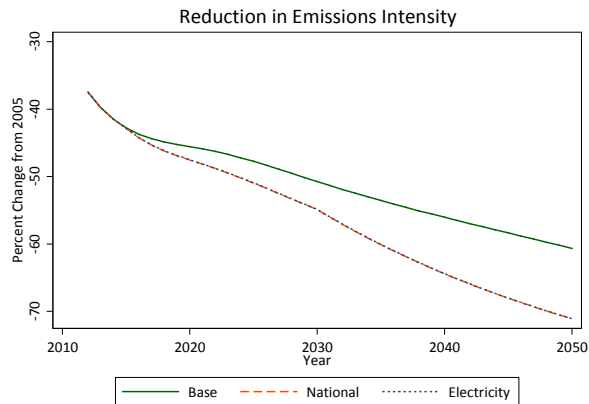
Figure 32: Emissions Permit Prices, Alternate Target

Emissions Permit Price
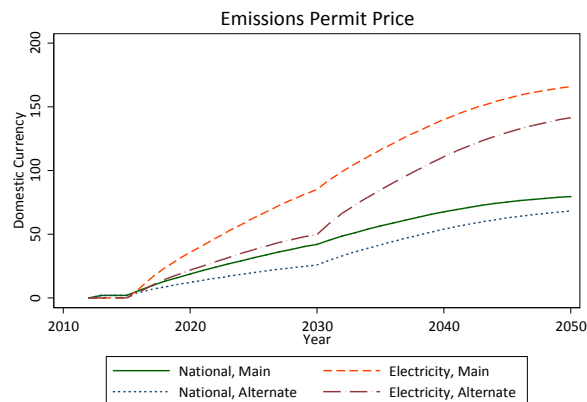
As shown by Figure 33, the impact on real GDP is more modest in the long run: a decline of about 2 percent relative to baseline rather than 2.5 percent. In addition, the pattern of the GDP effect over time differs: the decline under the alternate target is slower before 2030 and more rapid after that.

Figure 33: Change in Real GDP, Alternate Target

Change in Real GDP

Both real GDP and carbon dioxide emissions are higher under the alternate target. As a result, the change in emissions intensity is very similar to the tighter target, as shown in Figure 34.

Figure 34: Emissions Intensity, Alternate Target

Reduction in Emissions Intensity

Emissions permit prices are lower under the alternate target but emissions are higher so it's not obvious a priori whether permit revenue is higher or lower. As shown in Figure 35, however, total revenue would be lower under the looser target and would peak later.

Figure 35: Revenue from Emissions Permits, Alternate Target

Emissions Permit Revenue
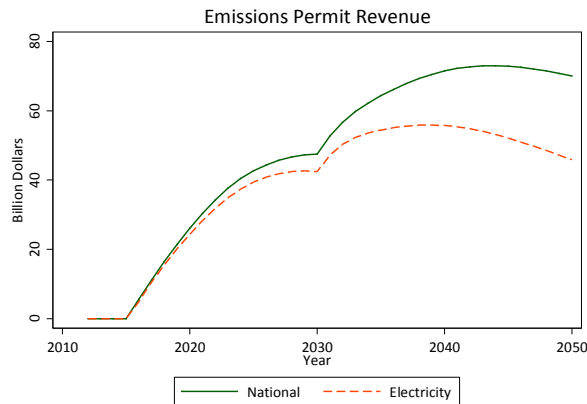
As shown by Figure 36 through Figure 39, the pattern of changes across sectors is very similar to the tighter policy but smaller in magnitude.
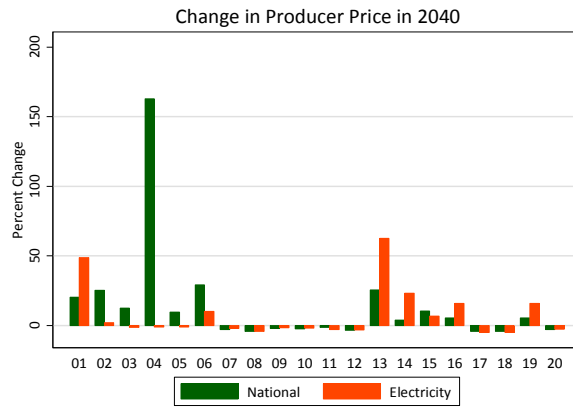
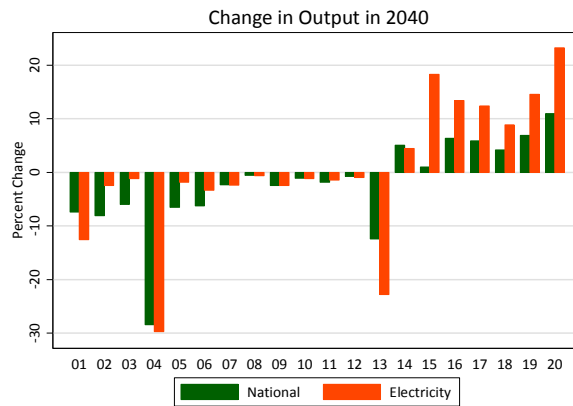**Figure 36: Change in Producer Prices in 2020, Alternate Target**

Change in Producer Price in 2020
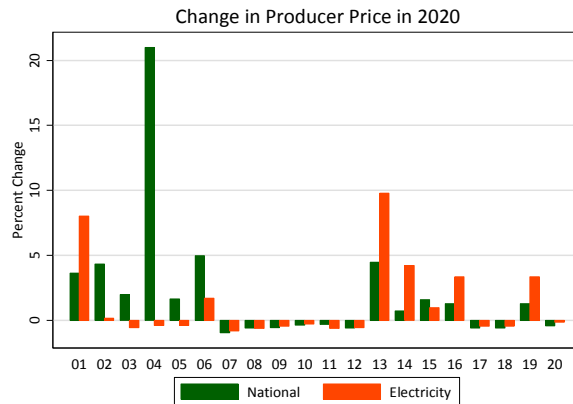
Figure 37: Change in Industry Output in 2020, Alternate Target

Change in Output in 2020
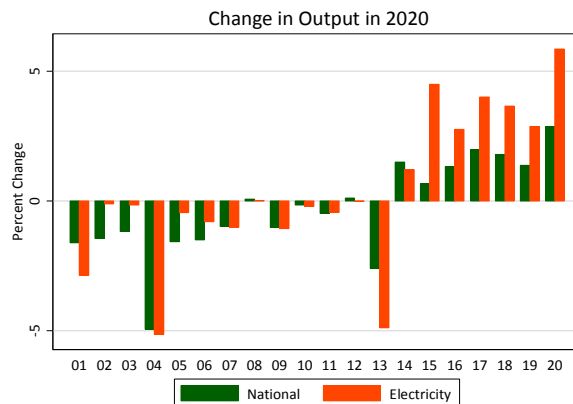
Figure 38: Change in Producer Prices in 2040, Alternate Target

Change in Producer Price in 2040

Percent Change

National   Electricity

Figure 39: Change in Industry Output in 2040, Alternate Target

Change in Output in 2040

Percent Change

National   Electricity

An interesting difference between the targets is the timing of their impact on aggregate employment. As shown in Figure 40, the alternate target has a peak employment impact of -0.6 percent, similar to the tighter target, but the peak effect occurs a decade later in 2035 rather than 2025. That reflects the fact that the alternate policy is relatively looser in the period prior to 2030 than the period after that.

Figure 40: Effect on Employment, Alternate Target
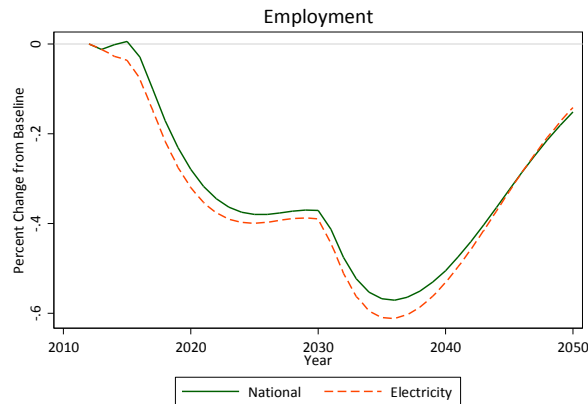
The effect of the alternate target on real wages is shown in Figure 41. As with the other variables, the impact is more muted and occurs later in the period.

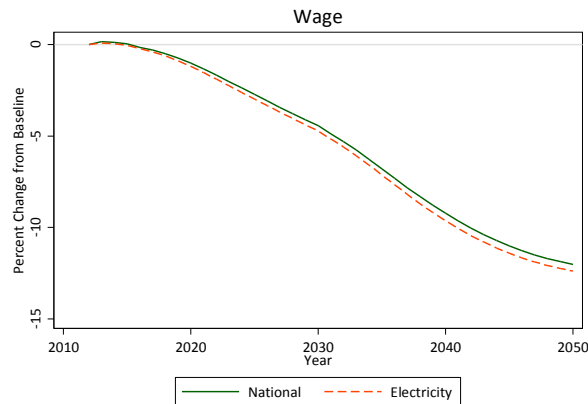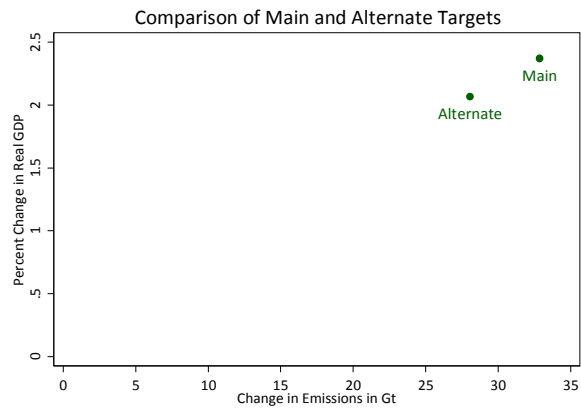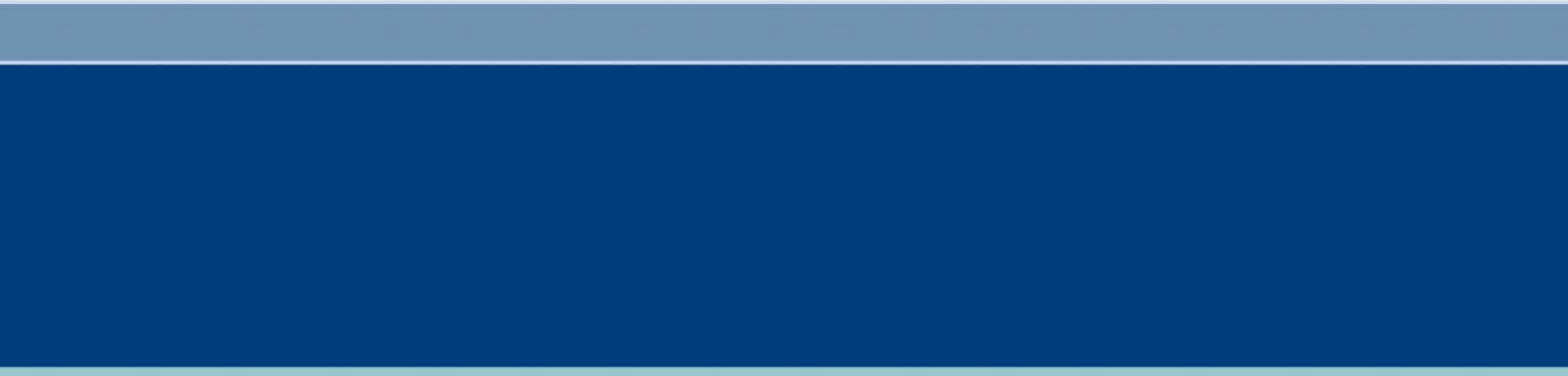**Figure 41: Effect on Real Wage, Alternate Target**

Figure 42 summarizes the comparison of the two targets by showing—for the economy-wide tax in 2050—the differences in GDP on the vertical axis and the reduction in emissions on horizontal axis. The looser target would reduce the impact of the policy on emissions and reduce the economic cost as well. In addition, as noted above it would delay the costs by allowing emissions to remain closer to the baseline until 2030.

37

Figure 42: Effects of Targets on 2050 GDP and Emissions

Comparison of Main and Alternate Targets