WPS8332

Policy Research Working Paper 8332

Effect of Climate Policies on Labor Markets in Developing Countries

Review of the Evidence and Directions for Future Research

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February 2018

Policy Research Working Paper 8332

Abstract

This study surveys one of the critical welfare aspects of contemplating climate policies in developing countries and their potential effect on workers and labor markets. The existing body of evidence finds that climate policies will likely cause a significant reduction of jobs in fossil-fuel industries. These industries make up a relatively small share of total employment, even in fossil-fuel-intensive countries. Therefore, the effect on aggregate employment will likely be small, especially over the long term, since there will be offsetting gains in other industries. However, most of the literature ignores the key features of developing country labor markets and may significantly misrepresent the dynamics of labor market adjustment to climate policies.

This paper is a product of the Environment and Energy Team, Development Research Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at jsteinbuks@worldbank.org.

Effect of Climate Policies on Labor Markets in Developing Countries: Review of the Evidence and Directions for Future Research[1]

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Keywords: climate policies, developing countries, employment, labor markets.
JEL: O13, Q52, Q54

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[1] The authors thank Steve Hammer and James Close for guiding and motivating us to write this paper, and Alvaro González and Mike Toman for helpful comments and suggestions. This paper is a part of a series of background papers produced by the Climate Change Group, World Bank. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent.
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1. Introduction

It is becoming increasingly clear that developed and developing nations will need to take significant efforts to address the challenge of climate change. For example, the recent Report of the High Level Commission on Carbon Prices argues that all countries will need to take substantive action, including significant carbon prices. Moreover, 191 countries have submitted national climate commitments, or Nationally Determined Contributions, to the United Nations under the Paris Agreement on climate change.

In designing and evaluating policies to address climate change, governments must consider not just the global effects of such policies, but also concerns about how such policies will affect the welfare of their citizens, at the national level and at narrower, more local levels such as individual industries or regions. One of the key issues is the question of how policy will affect workers and labor markets. This is important because it represents an important channel for effects on economically vulnerable households and these effects on workers strongly influence the political viability of any policy choice.

How will workers be affected? Will those who work in carbon-intensive industries lose their jobs as a result of mitigation policy? What new job opportunities will be created in clean energy and related fields? How will the effects ripple through other industries that are not directly energy-related? These and many other related questions will play important roles as governments make climate policy decisions.

This study reviews what is known about how climate policy will affect workers and labor markets, evaluates where the major gaps are in that knowledge, and discusses promising directions for future knowledge work. Although we are primarily interested in the effects on developing nation labor markets, much of the existing research on labor market effects of climate policy focuses on developed economies. Therefore, we include that research, along with a discussion of what those developed economy studies might say about effects in developing economies.

We focus on the effects of climate mitigation policies, not the effects of the climate change itself. Damages from climate change will likely also affect labor markets

– perhaps dramatically – but those effects are beyond the scope of this study. The effects of climate policies on labor markets are already challenging to measure, and the effects of damage caused by climate change are substantially more difficult to address. Thus, although such effects may well be very important, we focus exclusively on the effects of climate mitigation policies here.

Existing research falls into three broad categories: qualitative studies, which discuss channels through which climate policy can affect labor markets, but do not attempt to model or measure those effects explicitly; econometric studies, which attempt to measure statistically the effects of existing policies; and simulation studies, which attempt to model economic responses to climate policy, including effects on labor markets. Each type of study provides valuable insight. But each also has major limitations. Thus, although we can draw useful lessons from this prior research, major gaps remain and substantial new work is still needed.

The majority of econometric studies look at the labor market effects of only one or a small group of industries directly affected by regulation, such as, fossil fuel industries. This provides a useful measure of the changes in employment and/or wages in those industries. Greenstone (2002), for example, concludes that the Clean Air Act significantly reduced manufacturing jobs in the United States. In contrast, Morgenstern et al. (2002) find a small positive (but statistically insignificant) effect of environmental regulations on employment in heavily polluting industries.

However, these studies do not provide much insight about the labor market effects within the broader economy. Directly affected industries typically represent only a small share of the economy. Such studies thus miss much of the spillover effects, such as effects on downstream industries that buy inputs from regulated sectors, effects on industries that produce substitutes for the regulated products (e.g., renewable energy), and a range of subtler effects throughout the economy. Moreover, to the extent that such studies use the rest of the economy as a “control group” when looking at regulated industries, these broader effects may lead to mis-measurement even of the effects on the regulated industries, as pointed out by Hafstead and Williams (2016).

General equilibrium simulation modeling can look at those broader effects, measuring not just the effect on regulated industries, but also the spillover effects throughout the economy. But nearly all of the existing general equilibrium models assume full employment (i.e., they assume that demand always equals supply in the labor market, implying that every worker who wants a job gets one). For many questions, that is a useful simplifying assumption, but it has clear limitations when the goal is to evaluate labor market effects. Specifically, such models generally do a good job of identifying which industries will be most affected by climate policy and the rough magnitude of those effects, but are much less accurate in assessing overall effects on the broad labor market or economy as a whole. Moreover, these models ignore the possibility that climate policies may result in persistent unemployment in some carbon-intensive sectors, due to labor market search frictions or more fundamental structural reasons, such as mismatch of skills.

As an illustrative example, we look at results from the well-known Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) computable general equilibrium model (van der Mensbrugghe 2010). These results suggest that job losses in carbon-intensive industries will be a substantial fraction of employment in those industries. But because jobs in such industries only represent a small fraction of total employment (less than 1 percent in most countries, and less than 5 percent even in countries that supply fossil fuels), these job losses are small relative to the overall economy. The model results also indicate that job gains in less-carbon-intensive industries exactly offset those job losses (i.e., the lost jobs entirely represent a shift from more-carbon-intensive to less-carbon-intensive industries, with no net change in employment overall). But one should be skeptical of the latter result, because the model's assumptions necessarily imply that total employment will always remain fixed (and thus any job losses must be exactly offset by gains elsewhere). Moving away from that assumption is obviously crucial for looking at the aggregate effects on employment.

We go on to review a variety of alternative assumptions about the labor market that are used in general equilibrium simulation models, to move away from the fixed-labor assumption. The first of these, adding a labor-leisure decision, means that aggregate labor is no longer fixed, but still assumes that the labor market perfectly clears (i.e., every worker who wants a job has one, and every job is filled). Going further, wage rigidities, sector-specific labor, and search frictions each break the perfect labor market assumption. Each of these alternative models allows the economy to gain or lose jobs on net in response to climate policy. That is, additional employment in industries that gain jobs does not necessarily exactly offset job losses in other industries. Nonetheless, the studies using these alternative assumptions still find substantial job gains in less-polluting industries. As a result, nearly all the studies suggest that the net change in total employment caused by climate policy would be small.

Taken as a whole, the existing literature suggests that climate policy may cause a significant job shift, with fewer jobs in fossil fuels and related sectors offset by more jobs elsewhere in the economy, especially in renewable energy and relatively low-carbon-intensity sectors. Because of the offsetting effects, the overall effect on jobs – whether positive or negative – will be relatively small. Nonetheless, the shift could cause significant short-run disruptions in carbon-intensive sectors of the economy, especially if the transition is rapid. Labor market adjustment is likely to be slower – and thus the disruption will persist longer – in a developing economy than in a developed economy, because of the important role played by labor market segmentation.

We then evaluate directions for future knowledge work. We argue that the most promising direction is to incorporate a search model of employment into a general equilibrium simulation model, and calibrate it based on the empirical literature. Under this approach, unemployed workers must search for and match with an available job. This approach has been widely used in the macro-labor literature, but is relatively new to the literature on the employment effects of environmental policy. The few existing models that have taken this approach have all focused on developed economies. Thus, applying this approach in a developing country context would require the development of a new model or adaptation of an existing model.

In doing so, one would need to incorporate the key ways in which developing country labor markets differ from those in developed economies. For example, unemployment insurance is largely nonexistent in the developing world and informal labor markets are far more important. An even bigger difference is the persistent segmentation in developing country labor markets, which means that labor is far less mobile across sectors. It will be important to account explicitly for labor market segmentation in revising the existing general equilibrium models with labor market frictions.

In the near term, we recommend working with existing models. These could include full-employment models such as ENVISAGE. For such models, one needs to distinguish carefully between the types of questions these models can answer well and those they cannot. With somewhat more work, one could adapt an existing model, by adding employment search to an existing developing country model or taking an existing developed country model with employment search and recalibrating it to developing country data. The best long-run solution, however, would be to build a model specifically tailored for developing country labor market issues, so that it could be designed from the ground up to incorporate key features of those markets, especially labor market segmentation. Such a model would then need to be carefully parameterized based on the best available statistical evidence. It could also be useful to develop a more stylized model that could look at how climate policy uncertainty interacts with labor market frictions, to determine the extent to which clear signals about future policy could help to speed the transition.

2. Background on Labor Markets

This section provides a brief discussion of labor markets. It first summarizes reasons why the labor market does not clear perfectly (and thus we see unemployed workers and unfilled jobs). It then discusses key differences between developed and developing country labor markets, focusing specifically on the important role of labor market segmentation in developing countries.

A. Unemployment

Economic models often assume "market clearing": prices adjust until demand equals supply. For the labor market, market clearing would imply full employment: every worker who wants a job would have one, and every open job would be filled by a worker. In practice, however, labor markets do not clear perfectly, and we observe unfilled jobs and unemployed workers.

Traditional labor economics describes three types of unemployment. *Frictional unemployment* arises from the imperfect matching process between prospective employees looking for work and firms seeking to hire new workers. Often, it may take time for a worker to find a suitable job or a firm to find a suitable worker. Thus, workers may experience spells of unemployment between jobs and jobs may go unfilled for a period of time.

Structural unemployment occurs when there is a fundamental mismatch between workers and employers. A common example of mismatch is skills. Workers may not have the appropriate skills for a job and firms may find it hard to fill positions with qualified candidates. Locational mismatch is another example, with unemployed workers located too far from available jobs. Structural unemployment often occurs in the short run when economies undertake rapid expansion or change due to technology or policies but is much less of an issue in the long run. Over time, workers and firms can adjust to resolve mismatch: for example, workers can obtain new skills to solve skill mismatch and move to resolve locational mismatch.

Cyclical unemployment is the result of business cycle fluctuations. During boom times unemployment falls and during recessions unemployment increases. This is typically short-term in nature, although it is certainly possible to have a prolonged economic downturn and correspondingly prolonged period of elevated cyclical unemployment.

Climate policies may impact all three types of unemployment. If firms reduce hiring in response to climate policy, workers will find it harder to find jobs and experience longer employment spells, resulting in an increase in frictional unemployment. Structural unemployment may increase if, for example, climate policy causes firms to demand significantly more skilled workers than unskilled workers. Finally, cyclical unemployment may increase if the economy shrinks due to climate policy, perhaps because of changes in trade flows.

Unemployment has a variety of costs for an economy. It means that labor is not fully utilized, leading to lower aggregate economic output. Perhaps more importantly, it can have serious distributional consequences, because the economic cost is concentrated primarily on unemployed workers and their families, as well as on the surrounding communities. It is important to recognize that those costs are the fundamental issue, not jobs themselves, and that appropriately designed public policy can address some of those issues. Carbon pricing (a carbon tax or auctioned tradable carbon permits) generates revenues, some of which could be used to fund programs to cushion the impact on unemployed workers, their families, and communities, such as transfer payments or job retraining programs.

B. General Features of Developing Country Labor Markets

Labor markets in developing countries differ substantially from those in developed countries. Labor markets in developing countries are characterized by an excess supply of labor relative to capital, leading to high unemployment, low productivity of labor resources, and a large informal sector. This is complemented by the lack of (or weak) formal labor market institutions and regulations with limited coverage of social protection and insurance.

Fields (2011) compiles several features that characterize labor markets in most developing economies. The unemployment rate following the formal International Labour Organization definition is typically lower in developing countries than developed countries, illustrating the inadequacy of a general definition to capture the extent of the problem. The unemployment rates for Eastern European countries are on average around 8.4 percent, while those of East Asian and South Asian economies are around 4.4 percent. In most of Asia, Latin America, and Africa, wages are low and working hours are long. The problem of low wages is worsened by uncertain and irregular income flows. Women are disproportionately employed in the informal sector, in casual positions with lower earnings. Overall, the composition of employment in developing countries is different from that in developed countries, with a larger proportion of people engaged in agriculture, self-employment, and own-account work, and a smaller percentage employed in offices and factories. A high proportion of these workers are not covered by government-run job-security programs and therefore do not receive any form of protection from job loss.

Fields also recognizes that wage employment jobs are more coveted than self-employment jobs. Within wage employment jobs, regular wage jobs are preferred over casual jobs. The high incidence of self-employment is primarily driven by the fact that in most developing countries there are not enough wage employment opportunities available and the cost of waiting for a wage job is too high for most people. Thus, they prefer to set up their own business and create their own employment opportunities, despite the scarcity and high cost of capital. A section of those engaged in self-employment could also be doing so voluntarily, for example, women trying simultaneously to work and fulfill childcare responsibilities. Finally, developing country labor markets are highly segmented (as discussed below). In summary, Fields characterizes developing country labor markets as having "employment problems" rather than "unemployment problems." As we show in the subsequent sections, these developing country labor market features make households more vulnerable to climate change and reduce the effectiveness of climate mitigation policies.

C. Labor Market Segmentation

Labor markets in developing countries are characterized by different parts or segments that are qualitatively different from each other. However, the conditions in one segment affect and are affected by the conditions in others, and labor and firms are somewhat mobile across sectors. Different models label the sectors differently – urban vs. rural, agriculture vs. industry, formal vs. informal, wage employment vs. self-employment, and so forth. Whatever the name, the common underlying feature is that one sector has a higher prevailing wage than the other.

Fields (2009) reviews segmented labor market models in developing countries and places models into three categories based on the reason behind the wage differential: (i) models where the market-clearing wage in the formal sector is set by institutional forces, (ii) models where the market-clearing wage is set by efficiency wage theory, and (iii) models where the market-clearing wage is set through supply-side issues. The first category includes models involving (i) minimum wage policies that aim to ensure a minimum standard of living (prevalent in countries like Bangladesh; Côte d'Ivoire; India; the Republic of Korea; and Taiwan, China), (ii) trade unions that aim to entitle workers to a fair share of the fruits of their labor (prevalent in Ghana, Jamaica, Malaysia, and South Africa), (iii) public sector pay policies that result in higher wages in the government sector (prevalent in Costa Rica and some East Asian countries), (iv) multinational corporations that pay higher wages (prevalent in Sub-Saharan countries), and (v) labor codes that regulate hiring and firing and other benefits that firms provide their workers (prevalent is Panama, Bolivia, and Zimbabwe).

The second category of models involves efficiency wage theory, which postulates that firms will pay a wage rate that is higher than the prevailing market wage rate if and only if the gains from higher productivity associated with paying the workers a higher wage outweigh the costs associated with it. The third category, involving supply-side factors, models workers' behavior in a casual labor market where unemployed workers tend not to undercut the prevailing wage rate because the worker knows that he/she will earn more over the course of many days if he/she does not undercut wages.

3. Qualitative Research on Labor Market Effects of Climate Policy

This section reviews a handful of studies that do not explicitly model the labor market effects of climate policy. Instead, each provides a qualitative discussion of the key channels through which climate policy could affect jobs.

Fankhauser et.al. (2011) analyze the employment impact of climate change policy in three stages: (i) a short-term effect, (ii) a medium-term effect, and (iii) a long-term effect. The short-term effect is the direct employment effect where jobs are lost in the regulated sectors and new jobs are created in replacement sectors. The medium-term effect consists of bigger economywide effects where jobs are lost and created along the value chains of regulated industries. The long-term effect is the dynamic effect of the economy where innovation and development of new green technologies lead to further opportunities for investment and growth and job creation. This paper argues that renewable energy is more labor intensive than conventional energy, and thus switching to renewable energy will lead to net job creation. In the short run, the emerging renewable energy technologies are less likely to be cost-effective, for example because of steep learning curves, implying that per unit of output they would employ more than the efficient level of input (including labor). Additionally, labor is less mobile across the sectors of the economy in the short run, due to labor adjustment costs and short-term capital-labor complementarities, leading to structural and frictional unemployment.

In the medium run, the effects of the policy will spread through the economy, leading to more job losses and creations along the supply chains. Thus, the total economywide effects need to be studied using an input-output matrix (or a more sophisticated general equilibrium model). Three other factors – the stringency of climate policy (including unilateral and multilateral commitments to reduce carbon emissions), the size of the sectors in the economy that are affected by climate policies, and the level of international competition – will be crucial in assessing the total impacts. In the long run, the most important channel of job creation will be through innovation and development of new technology, leading to investment and growth. The paper argues that countries that move early in this context can develop a comparative advantage through export-related jobs.[3]

Olsen (2009) looks specifically at the effects of climate change in agriculture and tourism. These two industries are relatively understudied, but are potentially very important in the developing world, and may be especially affected by climate change and climate policy. Given that a large section of those employed in the two sectors are women and children, the paper also draws attention to the possible gendered nature of job losses resulting from climate change policies.

Agriculture provides the second largest source of employment, employing more than a billion people all over the world. Most of these jobs are in Asia (India and China) and Sub-Saharan Africa. Many of the jobs reflect a bad status quo of small-scale, labor-intensive, and low-productive activities, which lack job security and have low wages and poor working conditions. Without significant structural transformation of the agriculture sector in these countries toward modern, high-productivity commercial agriculture, climate change is likely to worsen this flawed status quo through changing sea levels, increased water salinity, greater heat stress, and other changing climate conditions.

Agriculture is also a major source of greenhouse gas emissions (GHGs) – if one takes into account non-carbon dioxide (CO_2) GHGs – which means it could be greatly affected by climate mitigation policy. Mitigation policies that would specifically target agriculture include improved management of crop and grazing practices to maintain soil fertility, and improved fertilizer and pesticide application techniques that will reduce the amount of GHG emissions.

The tourism industry employs a much smaller labor force, but is one of the fastest-growing industries globally. As with agriculture, women and children occupy a large share of employment in the tourism industry, and face low wages and difficult working conditions. Climate change is likely to influence the tourism industry as well.

[3] It is important to point out that if investments in renewable energy technologies are not sustained in the long run, the first-mover advantage may quickly erode, leaving the country locked in an older and inefficient low-carbon technology.

Many current tourist destinations could become less attractive, or even disappear, due to rising sea levels and related shifts. This could have a particularly devastating effect on the economies of small islands, like Maldives, whose gross domestic product (GDP) depends almost entirely on tourism.

Bowen (2012) provides a broad overview of the existing literature on climate change policies, “green jobs,” and the employment effects of these policies. He highlights the lack of a clear and widely accepted definition of “green jobs” or “green economy.” Some definitions focus on entire industries that are associated with producing goods that improve the environment, while other definitions are related to improving energy efficiency. The United Nations Environment Programme (UNEP) adopts a definition that incorporates the environmental aspects of job content as well as industry characteristics. Bowen’s discussion on the definition of green jobs ties in well with Olsen’s discussion of the relevance of labor standards in the process of defining green jobs.. This issue becomes especially pertinent in the context of developing countries where, for example, because of political economy reasons, job creation very often takes precedence over improving job quality (including raising environmental standards) and increasing labor productivity. Following UNEP, Bowen also makes the case for developing a “spectrum” or range for the definition of green jobs, by which jobs can be classified as being less green or more green based on the degree of carbon usage or energy efficiency achieved. The less-green jobs would be those with a net negative impact on the environment, such as mining, whereas more-green jobs would be those with a more positive impact on the environment, such as renewable energy. Jobs can also be classified based on whether they are proactive (preventive) or reactive (remedial) in dealing with environmental degradation.

One of the most important contributions of Bowen’s paper is his discussion of the various issues related to modeling labor markets in developing countries. The paper notes that the simple full-employment framework used in most studies of green jobs and green economy is often inadequate in dealing with labor markets in developing countries. Such models assume that any green jobs created in the economy will naturally displace jobs elsewhere. Developing economies are characterized by surplus labor (Lewis 1954; Harris and Todaro 1974) as well as segmentation between the formal and informal labor markets. Because of the presence of that surplus labor, Bowen argues that "crowding out" of jobs – when new jobs created by climate change policy divert workers who would otherwise have been employed elsewhere, thus leading to little or no net job gain – should be much less of a worry in developing economies than it would be in a developed economy.

Oral, Santos, and Zhang (2012) study the differentiated impact of climate policy on employment in countries in Eastern Europe and Central Asia (ECA). This paper is primarily a qualitative investigation into the effect of climate change policies on the labor market of ECA countries, and does not attempt to provide any estimate of the impacts. But it develops some useful concepts for looking at key ways in which countries may differ that will influence how those countries' labor markets would be affected by carbon mitigation policy.

Specifically, the paper develops the concepts of "vulnerability" (measured by the country's output and employment in energy-intensive sectors) and "adaptability" (measured by the country's capacity to relocate labor and shift production effectively to other, greener sectors), and uses these to look at how labor markets adjust on the intensive and extensive margins. They find that in the ECA region, significant shares of employment (around 30 percent) and value added (around 40 percent) are in energy-intensive industries. Naturally, any energy policy is likely to affect employment in these sectors. Moreover, the employment effect is likely to spill over to other sectors. An energy price shock is likely to affect the ability of energy-intensive sectors to generate further employment and boost aggregate demand, as well as other industries that use energy-intensive inputs.

Using principal component analysis, the authors classify the ECA countries into low-, medium-, and high-vulnerability groups. The countries that are highly vulnerable are naturally the largest oil producers, like Kazakhstan, Azerbaijan, and the Russian Federation. Similarly, the authors classify the countries into three groups by labor market flexibility, measured using indicators of employment protection legislation, taxes, minimum wage level, and maximum length of fixed contracts. The countries with the highest labor market flexibility are Albania, Azerbaijan, Bulgaria, Georgia, Russia, Kazakhstan, and the Slovak Republic. A more flexible labor market will generally respond to an energy price shock by adapting more quickly, with less unemployment and less lasting disruption. The paper also discusses the role of a government safety net, which can help ease the burden on displaced workers during the job market transition.

4. Econometric Research on Labor Market Effects of Climate Policy

Many studies have used empirical methods to investigate the relationship between environmental regulations and jobs. The initial studies largely focused on pollution control regulations, such as the Clean Air Act of the United States. As climate policies have been put into place over the past 10-15 years, newer studies have begun to estimate empirically the impacts of climate policy on jobs. Collectively, this empirical research provides mixed evidence on the environmental regulation/climate policy impact on jobs.

A. Micro-econometric Models

The majority of econometric studies on environmental regulation and jobs has used micro-econometric methods and data (i.e., data on individual workers, firms, or industries affected by regulation).

i. Effects on Employment

Micro-econometric estimates of environmental regulations and/or climate policy impacts on employment are generally focused on developed countries. First, developed countries are much more likely to have quality data on employment at the plant and industry levels. Second, developed countries have been far more ambitious in implementing environmental regulations and climate policies.

Morgenstern et al. (2002) find that environmental regulations, as measured by expenditures on environmental compliance activities, have a small positive, but statistically insignificant, impact on jobs in "four heavily polluting industries: pulp and paper mills, plastic manufacturers, petroleum refiners, and iron and steel mills." The study uses plant-level data from 1979–91 for a pooled cross-sectional estimation that essentially compares firms within an industry with each other: firms that spent more on environmental compliance had slightly more workers.

If environmental regulations and/or climate policies reduce the entire size of an industry, then the Morgenstern et al. method will not be able to capture these effects.

Using a difference-in-difference approach that compares firms in affected regions with those in nonaffected regions, Greenstone (2002) estimates that the 1972 Clean Air Act Amendments (CAAA) had large negative employment impacts in manufacturing industries in “nonattainment” counties, that is, counties that did not meet national air quality standards. His results showed that, relative to “attainment” counties that did meet national standards, the nonattainment counties lost approximately 590,000 jobs during the 1972–87. However, he emphasized that although the decline in manufacturing activity was substantial in nonattainment counties, it was modest compared with the size of the entire manufacturing sector. However, if firms shifted employment from the regulated region to the unregulated region, these results would overestimate the employment impacts of the CAAA.

Climate policies generally raise energy prices. There is a strand of literature that predicts the impact of potential climate policies on employment by estimating the historical relationship between energy prices and employment. Deschenes (2012) uses within-state variation in electricity prices in the U.S. economy from 1976 to 2007 to estimate the relationship between electricity prices and employment rates. Overall, he finds a weak negative correlation between electricity prices and employment rates: each period of higher than average electricity prices is accompanied by a lower than average level of employment. The sectors affected the most are agriculture; transportation; and finance, insurance, and real estate. Using the estimated cross-price elasticities, Deschenes predicts that the employment response to a 4 percent increase in the price of electricity would eliminate 335,000 to 510,000 jobs across the economy.

Although these estimates are sizable, they should be interpreted with caution. First, they are only short-run responses to the change in electricity prices. Second, the author notes that the results are likely to be “biased if there are omitted factors in the regression model that are correlated with both electricity prices and labor demand,” and discusses a range of such potential omitted factors (such as changes in regulator behavior and capacity constraints), adding that, “this bias is difficult to sign a priori.”

Gray, Linn, and Morgenstern (2016) study the effect of California's cap and trade on manufacturing industries by estimating the historical relationship between electricity costs and natural gas costs at the plant level. They then use the estimates to predict the impact of a price of $10/metric ton on CO_2 emissions on plant-level output and employment. Across industries, employment falls on average by 3.7 percent. In the long run, the affected industries rebound from the climate policy shock to some extent, and the impact on employment is smaller than the short-run impacts, with a 1.3 percent decrease in employment. Because of the inherent assumptions in their model, the long-run estimates should be interpreted with caution. Their data set does not have enough variation in historic energy prices, which renders many of their long-run estimates statistically insignificant. Further, the estimates are only for California; this model does not estimate the change in jobs in neighboring states due to changes in energy prices in California.

Outside the United States, researchers have estimated the impacts of climate policies on employment in Canada and Europe. Yamazaki (2017) examines the employment impact of British Columbia's revenue-neutral carbon tax, which was implemented in 2008. Using a methodology closely related to Greenstone (2002), Yamazaki finds that the output effect of the carbon tax negatively affects employment for all industries, but differently based on emission and trade intensity, while the redistribution effect positively affects employment for all industries. He shows that the most carbon-intensive and trade-sensitive industries saw employment fall with the tax, while clean service industries saw employment rise. For instance, at $10/ton CO_2 equivalent, the basic chemical manufacturing sector, one of the most emission-intensive and trade-exposed industries, experienced the largest decline in employment, of 37 percent. The health care service sector, which is one of the cleanest and most domestic industries, experienced the largest increase in employment, of 18 percent. Overall, by aggregating the employment effects across industries, he found the British Columbia's carbon tax generated, on average, a small but statistically significant annual increase in employment over 2007–13. These results illustrate how a revenue-neutral carbon tax could potentially boost employment.

Several studies have estimated the impact of the European Union (EU) Emissions Trading Scheme (ETS), which restricts emissions of CO_2 across a wide range of firms. Martin et al. (2016) provide an excellent review of the policy in general and summarize the evidence on employment effects, finding that some studies determined the EU ETS had no impact on employment, whereas others find statistically significant negative effects, with the effects varying based on the industries studied, time period covered, and source of data on employment. In general, all the studies suffer from similar limitations as those mentioned previously: most notably, they look only at the effects on regulated industries, and cannot capture spillover effects (positive or negative) elsewhere in the economy.

ii. Effects on Wages

Walker (2013) is the only study that investigates the effect of climate change policies, specifically the 1990 CAAA, on wages. He uses the confidential Longitudinal Employer Household Dynamics data set from the U.S. Census Bureau to follow workers across their jobs over time. This allows him to study two costs associated with environmental policy that have typically been ignored in the literature: long-run earnings loss for workers who leave a sector affected by climate change policy, and wage costs borne by workers who choose to remain in that sector.

Walker uses a difference-in-difference-in-difference technique to make within-sector comparisons before and after the implementation of regulatory policy. He finds that workers in sectors that were affected by the policy suffered persistent losses of more than 5 percent of their pre-regulated earnings in the three years after implementation of the legislation. These losses were borne mostly by workers who were displaced from regulated sectors, rather than those who remained in their jobs. He also calculates that a worker in a cohort experienced a present discounted wage loss of 20.2 percent of their pre-regulated wages (calculated at a 4 percent discount rate). This paper is particularly important not only because it looks into an economic outcome mostly overlooked by the literature, but also because it suggests the presence of long-term negative effects from climate change policies.

However, this study has a similar problem as the other difference-in-difference studies discussed previously. The study effectively uses workers outside regulated industries as a control group. To the extent that those workers benefit from climate policy, the difference-in-difference estimator will misinterpret that gain for the control group as a loss for workers in regulated industries.

B. Macro-econometric Models

Several studies use macro-econometric models to assess the macroeconomic effects of climate change policies, as well as other economic and environmental policies. Macro-econometric models use advanced statistical techniques to estimate the historical correlation between economic variables such as GDP, employment, and inflation. They then use those estimates to forecast the implications of climate policy scenarios. Unfortunately, these models rely on the assumption that past correlations can predict future outcomes, and most of these models rely on data that are not available in most developing countries.

Lehr et. al. (2012) analyze the labor market implications of a large-scale investment in the renewable energy sector in Germany. They use a sophisticated econometric simulation and forecasting model, PANTA-RHEI (which is an extension of the INFORGE forecasting model), for a set of scenarios and compare the resulting economic outcomes. All the parameters are estimated econometrically using time-series data from 1991 to 2008.

Three different types of economic scenarios are considered: (i) two price paths for international energy prices (low-price scenario and high-price scenario) following projections from the International Energy Agency, (ii) three forecasts for domestic investment in renewable energy (the lead scenario from the German government's annual updates, high investment in the photovoltaic sector, and low investment in the photovoltaic sector), and (iii) four export forecasts for renewable energy technology (minimum, slow, optimistic, and maximum). The PANTA-RHEI model calculates the corresponding labor market effects from each of these scenarios endogenously, with the reference scenario being that of a low-price path of international energy prices.

Another widely used global sectoral macro-econometric model, E3ME (the Energy-Environment-Economy Model at the global level), analyzes long-term energy and environment interactions within the global economy and evaluates the short- and long-term impacts of climate change policy. The model covers 59 global regions that include all major developing (e.g., Brazil, Mexico, India, and China) and developed (e.g., EU27 member states, the United States, and so forth) economies and 42 economic sectors, including a disaggregation of the energy sectors and 16 service sectors. It provides projections forward annually to 2050.[4]

Pollitt et al. (2015) expand on the modeling that was carried out for the official impact assessment of the European Union's proposed energy and climate targets for 2030. They provide a macroeconomic assessment of the potential effects on employment of the 2030 climate and energy package compared with a reference case based on current and planned policies to 2020. Using E3ME and drawing on results from the PRIMES energy systems model, in the first scenario, they conclude that a 40 percent reduction in GHG emissions (compared with 1990 levels) could lead to an increase in employment of up to 0.7 million jobs in Europe. In the second scenario, they combine the same GHG reduction target with a 30 percent target for renewables and stricter energy efficiency standards. The results show that the net increase in jobs is as high as 1.2 million. They also emphasize that the large investment stimulus needed to meet the combined targets leads to higher levels of GDP and employment, and suggests medium-term economic and social benefits from including all the targets combined in the future in an energy and climate package. Their additional sensitivity testing highlights that the ways in which the energy efficiency and renewable measures are funded are important factors in determining overall economic impact.

[4] Detailed information about the E3ME model is available in Cambridge Econometrics (2011) and at https://www.camecon.com/how/e3me-model/.

The major problem with such macro-econometric models is that they are subject to the well-known Lucas critique (Lucas 1976). The models are identified based on historical correlations in macroeconomic data, and because such correlations are not fundamental structural parameters, they may well change when policy changes. Thus, although such models can be useful for forecasting, especially in the short run, they are not well suited to analyzing the long-term effects of policy changes. Consequently, over the past few decades, there has been a strong movement in macroeconomics away from using such models for policy analysis.

5. Simulation Models

Computable General Equilibrium (CGE) simulation models are useful tools for evaluating the impacts of global or regional climate policies because they can analyze the direct effects on regulated industries, but also the spillover effects throughout the economy. However, most existing CGE models use simplifying assumptions related to the labor market that introduce limitations with respect to evaluating the labor market impacts of climate policy. In this section, we begin by using the ENVISAGE model (van der Mensbrugghe 2010) as a benchmark CGE model with perfect labor markets and fixed labor. We find that this type of model is useful in identifying those industries most affected by climate policy and general shifts in employment, but falls short in evaluating overall labor market impacts. We then look at how the CGE literature has attempted to build on the benchmark models by relaxing key labor market assumptions, and how employment estimates differ across models. With a few exceptions, we note that these extensions have only been applied to models for developed countries.

A. Fixed-Labor CGE Models and ENVISAGE

Most CGE models assume perfectly functioning labor markets. Wages are fully flexible, everyone who wants a job can have one (i.e. the full-employment assumption), and labor is perfectly mobile across sectors. Further, some models assume that the total level of labor supply is fixed; labor can move between sectors in response to climate policy, but by definition, these models predict changes no change in the overall level of employment. However, the results on changes in labor demand across industries are commonly reported as employment. In this section, we utilize the full-employment CGE model ENVISAGE to demonstrate the strengths and limitations of such an approach. With 40 sectors, 15 regions, and two types of labor (skilled and unskilled), ENVISAGE is a powerful tool to analyze the impacts of climate policies, but maintains the simplifying labor market assumptions described above.

A World Bank Group (2017) utilizes the ENVISAGE model to analyze the opportunities for employment in "green" or low-carbon sectors in response to global and regional climate policies and technological change. The study examines several scenarios that are relevant to understanding climate policy–induced shifts in employment. Here, we utilize simulation results from the global carbon tax scenario. Figure 1 displays the time-path for the global carbon tax, rising from $8 to $151 over time.

Figure 1: Global Carbon Tax Time-Path

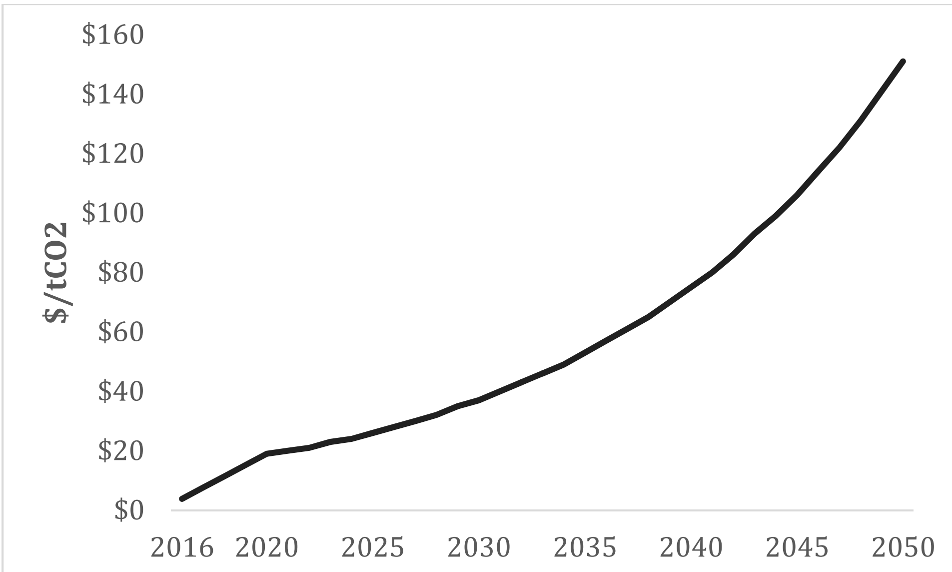

Table 1 reports the distribution of unskilled and skilled employment across 26 sectors in 2020 in three types of emitter countries under business as usual.[5] The global economy is divided into large emitters (LEs), swing emitters (SEs), and carbon dependent countries (CDCs). Employment in traditional dirty industries (fossil fuel producers, coal, or gas-based electricity) and traditional clean industries (biodiesel, wind, solar power, and so forth) is small in all regions. For example, in carbon dependent countries, dirty industries (coal, oil, natural gas, refined oil, coal-based power, and gas-based power) employ only about 4 percent of unskilled workers; in SEs and LEs, the same industries employ only 1.1 and 0.7 percent of unskilled workers, respectively. Therefore, even if climate policy produces large changes in employment in these industries, we expect climate policy–induced job shifts to be a relatively small share of total employment.

[5] The 40 sectors are aggregated into 26 sectors for the sake of presentation. Here, we use the standard technology reference case.

Table 2 reports the change in employment in each region in 2030 in response to the global carbon tax. For each region and skill type, the first column reports the percent change in employment for that skill type in each industry. The second column reports the change in employment as a fraction of total employment. The results from the full-employment ENVISAGE model are consistent with our priors. Sectors such as coal, natural gas, coal-based power, gas-based power, and refined oil products all display sharp declines in employment. Sectors such as ethanol, bio-diesel, wind power, and carbon capture and storage (CCS) electricity display sharp increases in employment. However, because these industries are small, the change in employment as a fraction of all workers is relatively small: gross job flows (the absolute value of job gains and losses) represent only 0.60 percent of global unskilled employment and 0.36 percent of global skilled employment. In CDCs, where job shifts from a global carbon tax are expected to be relatively high, relative job flows represent only 1.06 percent of unskilled employment and 0.69 percent of skilled employment in countries that are dependent on supplying fossil fuels.

ENVISAGE can also look at developed and developing countries separately within each of the three emission categories (although we do not report those results here). The pattern of job changes is strikingly similar between developed and developing countries, with large job losses (relative to initial employment) in carbon-intensive industries, and large job gains in green industries (again, relative to initial employment). The magnitudes of within-industry job changes vary: SE developing countries experience larger relative job decreases in carbon-intensive industries than SE developed countries, but CDC developing countries experience smaller relative job decreases in carbon-intensive industries than CDC developed countries. Overall, however, the total gross job flows are not significantly different across developed and developing countries. The flows reflect a small share of total employment in developed and developing countries across all three regions.

Table 1: Regional Distribution of Employment by Sector (ENVISAGE simulations)

	Large Emitters			Swing Emitters			Carbon Dependent Countries		
Sector	Unskilled Labor	Skilled Labor	Ratio of Unskilled to Skilled Labor	Unskilled Labor	Skilled Labor	Ratio of Unskilled to Skilled Labor	Unskilled Labor	Skilled Labor	Ratio of Unskilled to Skilled Labor
Agriculture	4.1%	0.7%	5.02	12.1%	0.8%	14.99	15.3%	1.1%	18.72
Coal	0.2%	0.1%	3.36	0.2%	0.1%	1.48	0.3%	0.2%	2.11
Oil	0.2%	0.1%	1.31	0.4%	0.4%	1.13	2.2%	3.2%	0.92
Natural gas	0.1%	0.1%	1.04	0.2%	0.1%	1.16	0.9%	1.1%	1.13
Other mining	0.5%	0.2%	2.98	1.1%	0.7%	1.38	1.3%	0.8%	2.09
Nondurable manufacturing	10.6%	5.4%	1.72	9.1%	6.9%	1.25	11.1%	6.4%	2.27
Refined oil	0.1%	0.1%	1.77	0.1%	0.1%	1.11	0.5%	0.2%	3.03
Ethanol	0.0%	0.0%	2.69	0.1%	0.0%	4.02	0.0%	0.0%	4.27
Bio-diesel	0.0%	0.0%	1.02	0.0%	0.0%	1.02	0.0%	0.0%	1.06
Durable manufacturing	16.1%	8.1%	1.73	7.1%	5.8%	1.16	9.9%	5.0%	2.57
Nuclear power	0.1%	0.1%	0.62	0.1%	0.2%	0.88	0.0%	0.0%	1.09
Coal-base power	0.1%	0.0%	1.76	0.1%	0.2%	0.60	0.1%	0.1%	1.56
Gas-base power	0.0%	0.0%	1.13	0.0%	0.0%	0.65	0.0%	0.1%	0.93
Wind power	0.0%	0.0%	0.95	0.0%	0.0%	0.35	0.0%	0.0%	0.76
Hydro power	0.1%	0.0%	1.85	0.1%	0.1%	0.91	0.1%	0.1%	0.99
Oil-base power	0.0%	0.0%	0.63	0.0%	0.0%	0.73	0.0%	0.0%	0.75
Other power	0.0%	0.0%	1.29	0.0%	0.0%	1.04	0.0%	0.0%	1.57
Solar power	0.0%	0.0%	0.68	0.0%	0.0%	0.51	0.0%	0.0%	0.93
Coal based CCS	0.0%	0.0%	1.65	0.0%	0.0%	0.62	0.0%	0.0%	1.57
Gas based CCS	0.0%	0.0%	1.03	0.0%	0.0%	0.68	0.0%	0.0%	0.92
Advanced nuclear	0.0%	0.0%	0.58	0.0%	0.0%	0.89	0.0%	0.0%	1.14
Electricity distribution and transmission	0.2%	0.4%	0.52	0.3%	0.8%	0.32	0.2%	0.5%	0.56
Construction	13.6%	3.2%	3.76	14.5%	4.7%	2.90	12.7%	4.5%	3.67
Trade	15.1%	9.2%	1.43	17.2%	11.1%	1.46	16.4%	6.7%	3.18
Transportation	4.2%	2.8%	1.28	6.4%	3.4%	1.78	5.2%	4.3%	1.57
Other services	34.7%	69.3%	0.44	30.8%	64.5%	0.45	23.7%	65.8%	0.47

Table 2: Regional Shifts in Employment by Sector (ENVISAGE Simulations)

	Large Emitters				Swing Emitters				Carbon Dependent Countries			
	Unskilled Labor		Skilled Labor		Unskilled Labor		Skilled Labor		Unskilled Labor		Skilled Labor	
Sector	Pct Change in Industry Employment	Change as Pct of Total Employment	Pct Change in Industry Employment	Change as Pct of Total Employment	Pct Change in Industry Employment	Change as Pct of Total Employment	Pct Change in Industry Employment	Change as Pct of Total Employment	Pct Change in Industry Employment	Change as Pct of Total Employment	Pct Change in Industry Employment	Change as Pct of Total Employment
Agriculture	-0.31%	-0.012%	-0.08%	-0.001%	0.27%	0.031%	0.30%	0.002%	0.53%	0.075%	0.84%	0.008%
Coal	-29.16%	-0.047%	-24.83%	-0.012%	-29.10%	-0.049%	-26.23%	-0.029%	-31.48%	-0.071%	-31.32%	-0.042%
Oil	-2.21%	-0.003%	-2.43%	-0.003%	-2.63%	-0.010%	-2.91%	-0.010%	-1.88%	-0.036%	-1.86%	-0.051%
Natural gas	-22.17%	-0.016%	-21.42%	-0.014%	-25.19%	-0.043%	-26.22%	-0.037%	-10.20%	-0.084%	-9.00%	-0.086%
Other mining	0.73%	0.003%	0.73%	0.001%	0.02%	0.000%	0.50%	0.004%	0.76%	0.010%	1.06%	0.008%
Nondurable manufacturing	0.68%	0.066%	0.54%	0.026%	0.72%	0.062%	0.71%	0.044%	1.14%	0.123%	1.32%	0.078%
Refined oil	-0.90%	-0.001%	-1.13%	-0.001%	-2.71%	-0.002%	-3.58%	-0.003%	-3.88%	-0.015%	-3.82%	-0.006%
Ethanol	8.83%	0.000%	9.48%	0.000%	4.25%	0.003%	4.24%	0.001%	14.86%	0.000%	15.17%	0.000%
Bio-diesel	6.43%	0.000%	6.39%	0.000%	6.97%	0.000%	6.90%	0.000%	21.17%	0.000%	21.64%	0.000%
Durable manufacturing	0.46%	0.068%	0.37%	0.027%	0.80%	0.054%	0.89%	0.049%	1.72%	0.164%	2.02%	0.092%
Nuclear power	9.94%	0.009%	7.80%	0.010%	10.10%	0.014%	10.97%	0.016%	16.60%	0.001%	16.10%	0.001%
Coal-base power	-35.28%	-0.029%	-29.25%	-0.012%	-35.40%	-0.040%	-40.03%	-0.073%	-49.53%	-0.031%	-49.10%	-0.026%
Gas-base power	-11.39%	-0.002%	-10.38%	-0.002%	-15.90%	-0.004%	-13.69%	-0.005%	-25.02%	-0.011%	-25.18%	-0.016%
Wind power	13.75%	0.004%	8.37%	0.002%	12.53%	0.002%	14.66%	0.007%	22.48%	0.001%	22.40%	0.001%
Hydro power	8.46%	0.007%	5.37%	0.002%	4.10%	0.005%	4.94%	0.006%	8.96%	0.007%	8.89%	0.009%
Oil-base power	2.86%	0.000%	1.44%	0.000%	-1.99%	0.000%	1.51%	0.000%	-1.01%	0.000%	-1.14%	0.000%
Other power	11.30%	0.004%	6.59%	0.001%	5.86%	0.003%	8.63%	0.004%	13.86%	0.002%	13.36%	0.002%
Solar power	8.26%	0.001%	6.68%	0.001%	12.92%	0.000%	14.24%	0.001%	24.14%	0.000%	24.06%	0.000%
Coal based CCS	38.51%	0.007%	30.67%	0.003%	40.85%	0.009%	47.74%	0.016%	69.01%	0.007%	68.39%	0.005%
Gas based CCS	20.77%	0.001%	16.83%	0.001%	22.32%	0.001%	23.02%	0.001%	43.74%	0.003%	43.64%	0.005%
Advanced nuclear	10.92%	0.001%	8.52%	0.001%	11.37%	0.001%	12.22%	0.001%	19.94%	0.000%	19.55%	0.000%
Electricity distribution and transmission	-14.47%	-0.036%	-8.32%	-0.035%	-7.86%	-0.021%	-10.95%	-0.087%	-16.35%	-0.040%	-15.00%	-0.086%
Construction	-0.34%	-0.047%	-0.21%	-0.007%	-0.56%	-0.087%	-0.37%	-0.017%	-1.02%	-0.133%	-0.73%	-0.032%
Trade	0.02%	0.003%	0.12%	0.011%	-0.15%	-0.026%	-0.05%	-0.006%	-0.26%	-0.043%	0.01%	0.001%
Transportation	1.93%	0.072%	1.73%	0.043%	2.10%	0.119%	2.35%	0.069%	2.97%	0.137%	3.23%	0.117%
Other services	-0.14%	-0.052%	-0.06%	-0.044%	-0.06%	-0.020%	0.07%	0.047%	-0.25%	-0.066%	0.03%	0.020%

The ENVISAGE results suggest job flows in response to a global carbon tax are small relative to overall employment. This is primarily because industries that experience large job shifts employ a relatively small proportion of workers, which is a data fact, not dependent on perfect labor market assumptions. However, the fixed labor assumption implies that all workers who are displaced in a dirty industry find jobs in clean industries. Further, the model does not explicitly consider any of the differences between developing country and developed country labor markets. This may be part of why the pattern of job changes is so similar between developing and developed countries. Next we explore alternative labor market assumptions.

B. Labor/Leisure Choice

Models that introduce labor-leisure choices allow for changes in aggregate labor supply by allowing households to consume more leisure in response to climate policies. Goettle and Fawcett (2009) provide an example. They employ the Inter-temporal General Equilibrium Model to evaluate the U.S. economy's reaction to cap-and-trade programs with three different caps (287, 203, and 167 gross tons of CO_2) over 2012–50. Since mitigation policies increase the overall price of goods and services in the economy, consumption becomes more expensive overall compared with leisure. This causes the representative household to consume more leisure and fewer goods and services. Thus, total labor supply decreases.

NewERA is another full-employment model that uses a labor-leisure choice. NERA (2017) analyzes the impacts of regulating industrial greenhouse gas emissions.[6] The findings indicate that the decline in sectoral output reduces labor demand, depresses wages, and therefore leads to a shift into leisure and a reduction in labor supply. The study then interprets this reduction in labor supply as a loss of employment, indicating that the industrial sector job loss would exceed 1 million in 2025 relative to the baseline total industrial employment of 24 million, and the manufacturing sector alone would see

[6] The study claims that the emissions reductions path is consistent with the 2025 U.S. emissions targets announced as part of the Paris Agreement. However, a major flaw in this study is that the emissions reduction path assumes a vast majority of the reductions come from the industrial sector, ignoring low-cost emissions reductions in other sectors, such as the power sector.

a reduction of about 440,000 jobs in 2025 relative to the baseline employment of about 12 million.[7]

This approach is flawed for (at least) two reasons. First, it assumes that all changes in labor supply are voluntary: employment decreases because the household chooses to work less. Second, the representative labor supply represents aggregate hours worked, not the total number of employed workers, and the calculation therefore assumes no change in the number of hours worked per worker, which directly contradicts the labor-leisure decision of the representative household in the model. This approach also ignores climate policy impacts on carbon-intensive leisure decisions.[8]

C. Wage Rigidities

Models with perfect labor markets assume that wages adjust such that total labor supply (either fixed or endogenous) equals total labor demand. Given the evidence that labor markets do not perfectly clear in the real world, the CGE literature began to explore how wage-setting assumptions may introduce unemployment into these equilibrium models. Specifically, if wages were rigid and inflexible in response to climate policy, then markets may not clear. The literature has explored many options for introducing wage rigidities: economywide minimum wages, urban-rural divides with minimum wages in urban areas, and wage-unemployment curves. Here we explore each of these in greater detail.

i. Economywide Minimum Wage

One way to introduce unemployment into a general equilibrium model is to assume an economywide minimum wage, which could represent a minimum wage law or the effect of strong labor unions. If this wage is set above the market-clearing level, then it will lead to unemployment. One example of this type of model is Bovenberg and van der Ploeg (1996). This approach is very simple and tractable, but more recent work has

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[7] These numbers were cited by President Trump on June 3, 2017 as a key reason for pulling the United States out of the Paris Agreement.
[8] Carbon Trust (2006) estimates recreation and leisure as the most carbon-intensive consumption, largely due to large amount of time spent on travel.

tended toward more sophisticated models in which wage rigidities vary across sectors of the economy.

ii. Urban-Rural Divide

Several studies in the existing literature have extended the framework provided by the Harris and Todaro(H-T) (1970) model of rural-urban migration to investigate the impact of environmental policies on the urban unemployment and the welfare.[9]

Chao et al. (2000) explore the cost impacts of environmental protection on sectoral unemployment and welfare under a closed and an open economy in a standard H-T model. The model consists of an agricultural sector and a processing sector (having upstream and downstream firms). Agricultural products and upstream raw materials (the use of which causes environmental damage) are produced in the rural area, while processed downstream goods are produced in the urban area by using labor and raw materials. Chao et al. find that in a closed economy, environmental preservation necessitates a reduction in the supply of resources available for the downstream industry use and hence could cause unemployment. They suggest that the optimal preservation policy for a closed economy is to tax the gainers and use the tax revenue to pay affected workers. Moreover, for a small open economy, foreign resources could be imported to cover the shortage of domestic supply. Thus, free trade in resources could eliminate the shortage problem of domestic productive resources, and thereby lead to a higher optimal level of environmental preservation. They also highlighted that the preservation of raw materials does not result in additional urban unemployment for a small open economy.

In a closed economy version of the H-T model, Daitoh (2003) examines whether or not an environmental policy could create employment and decrease the urban unemployment rate. He analyzes a rise in urban pollution tax and shows that the

[9]For more details, refer to Harris and Todaro (1970). In their original framework, unemployment occurs endogenously in the dualistic economy, and the wage rate in the urban area is fixed and higher than that in the rural area. Labor migrates between the urban area and the rural area according to a comparison of the expected wage, while taking account of unemployment with wages in the rural area. Labor has no incentive to migrate to another area when the expected wage in the urban area is equal to that in the rural area.

condition for an increase in manufacturing employment depends on the relative price elasticity of demand for manufactured goods. A rise in the pollution tax rate pushes up the manufacturing firms' unit cost of production, and hence, the price of their product. Since the relative demand for it declines, the manufacturing firms lower their output level, and thus, labor employment tends to decrease by the scale effect while it tends to increase by the substitution effect between labor and the dirty input. If the demand for the manufactured good does not decrease much, the manufacturing employment would expand. Moreover, in the case in which rural-to-urban migration is promoted, urban unemployment would shrink if and only if agricultural technology exhibits sufficiently strong diminishing returns. More importantly, Daitoh demonstrates that there exists a range of welfare improving pollution tax rates, and the pollution tax rate would unambiguously improve social welfare if it is initially set in a sufficiently low range.

Barbier and Hochard (2017) consider a different aspect of the migration issue, looking at the behavior of households residing in remote, less-favored agricultural lands in developing economies. Using a theoretical model, they demonstrate that compared with a household located on favorable agricultural land, a poor household located on less favorable remote agricultural land is caught in a poverty-environment trap characterized by a steady-state level of low per capita output and capital stock. This occurs when the household is too poor to migrate out of the area and can engage only in agriculture. This is especially pertinent considering the World Bank (2003) study that estimates that about one-fifth of the world's population lives on less favorable agricultural land, and their number has doubled since 1950. These people are especially susceptible to loss of income and employment due to climate change. Since their agricultural land holdings are underproductive, these households are often motivated to seek other sources of income, often through exploitation of the surrounding natural resources.

iii. Wage-Unemployment Curves

An alternative approach is to assume a wage-unemployment curve, in which higher unemployment goes together with lower wages. This could potentially be rationalized as an outcome of efficiency wages (setting a wage above the market-clearing level to provide an incentive for employees not to shirk), with high unemployment providing a disincentive to shirk that reduces the need for higher wages. Or it could be rationalized as a bargaining outcome, in which workers (or unions) are willing to accept a lower wage when unemployment is high. But these models do not explicitly model the wage-setting mechanism. Instead, they use a reduced-form version, with an assumed functional form (typically a constant-elasticity function) for the wage curve as a function of unemployment.

Guivarch et al. (2011) use such a model, and emphasize the crucial role of labor market rigidities in the cost analysis of climate policies. Using a dynamic recursive energy-economy model, IMACLIM-R,[10] they examine two scenarios: first, a "reference" scenario, that is, without climate policies, and second a "550 parts per million" CO_2 target scenario with climate policies, over 2010 to 2050, represented by carbon pricing. They account for rigidity of real wages in their model through an aggregate regional wage curve linking real wage levels to the unemployment rate, assuming the wage curve elasticity at -0.1 for all regions. The low values of the wage curve elasticity (-0.1) signify very rigid labor markets; high values closer to -7 represent perfect labor markets. Their results show that the global real GDP loss, over 2010–50, between the "550 parts per million" scenario and the "reference" scenario to vary from 0.35 percent with a wage curve elasticity of -7 to around 3.5 perecent with an elasticity equal to -0.1. Thus, when labor markets are highly flexible, the mitigation costs are limited in the model, which indicates a significant impact of labor market rigidities on mitigation costs. The authors also emphasize that these results were based on unrealistic values of the elasticity of the wage curve (especially for downward flexibility). They note that with the use of more realistic values for this elasticity, the mitigation costs could be higher than this current assessment. They highlight that achieving emissions reductions at a reasonable macroeconomic cost would require the adoption of parallel policies in the labor market viz. labor subsidies, to reduce the existing labor market imperfections.

[10] IMACLIM-R is a hybrid recursive general equilibrium model of the world economy split into 12 regions and 12 sectors.

Another study, by Dissou and Sun (2013), assesses the employment implications of carbon mitigation policies with labor market rigidity in the Canadian economy. They use tradable permits as policy instruments to reduce emissions and analyze the effects of different revenue-recycling options. They represent real-wage rigidity in the labor market using a wage curve and consider low-skilled and high-skilled workers, with the real wage rates of both types of workers being rigid. Using a CGE model, they assess the welfare and employment dividends of reducing CO_2 through a cap-and-trade system.[11] They examine four alternative simulation scenarios of recycling the permit revenue: revenue is recycled as a lump-sum transfer to households; revenue is used to reduce payroll tax rates on skilled labor alone; revenue is used to reduce payroll tax rates of unskilled labor alone; and revenue is used to reduce payroll tax rates of both types of labor. By pairing welfare and employment dividends from all recycling schemes by higher wage rigidity, their results suggest that higher labor market rigidity leads to a stronger negative effect on the economy in terms of welfare and employment. The authors find that carbon policies are costlier in the presence of labor market imperfections and the negative effects of those policies could be offset with an appropriate revenue-recycling scheme that reduces wage taxes. They highlight that the use of permit revenue to reduce payroll taxes is better than a direct transfer of that revenue to households, as the former option has a positive effect on the employment level and makes it possible for households to enjoy higher welfare.

D. Sectoral Rigidities

Sectoral rigidities have been used to prevent sudden reallocation across sectors in response to mitigation policies in CGE models. Babiker and Eckaus (2006), using the MIT Emissions Prediction and Policy Analysis [12] model, based on the GTAP data set, is a prime example. The sectoral immobility of labor is characterized in the following ways. First, it is assumed that there exists an exogenously determined amount of sector-specific labor that is unable to leave the sector in the same period in which the demand for that

[11] They consider a cap-and-trade system where CO_2 emissions are reduced by 20 percent in comparison to the benchmark, and where all emitters are required to buy emissions permits and the cost of the permits increases the user price of fossil fuel.
[12] For a more detailed description of the MIT Emissions Prediction and Policy Analysis model, see Babiker et al. (2001) and Paltsev et al. (2005).

good has fallen. Second, there is a time lag in labor adjustment through wages in response to a fall in labor demand. Similarly, this model also considers variations of the model with rigid wages.

Using this model, four types of models are compared: (i) conventional assumptions of mobile labor and flexible wages, (ii) sector-specific labor and flexible wages, (iii) mobile labor and rigid wages, and (iv) both sector-specific labor and rigid wages. These four models are evaluated under the following three conditions: (i) the absence of any GHG emissions policy (the reference condition); (ii) restrictions following the Kyoto protocol are imposed but without any offsetting policies; and (iii) restrictions following the Kyoto protocol are imposed but with labor subsidies to offset the unemployment effects of the restrictions.

First, the authors find that, in the absence of emissions restrictions, the aforementioned labor market distortions, which are more likely to apply in developing countries, increase unemployment in the reference case compared with the model with flexible wages and mobile labor. Second, in the emission restrictions scenario, countries with large sectoral labor frictions experience smaller changes in employment with respect to mitigation policies than countries with low sectoral labor market frictions. Third, the authors show that it is theoretically possible to combine labor subsidies with mitigation policy to eliminate completely unemployment generated due to emissions restrictions in models with sector-specific labor by causing labor to be allocated more efficiently across sectors. In practice, an effective offsetting policy would be much more difficult to design.

E. Search Frictions

Hafstead and Williams (2016) introduce frictional unemployment into developed country CGE models with a search friction as in Mortenson and Pissarides (1994). Their simple two-sector model demonstrates a tractable framework for incorporating frictional unemployment into CGE models. Their results show that, as in full-employment models, pollution taxes are characterized by employment shifts between sectors with small net impacts on unemployment.

In a preliminary paper, Hafstead, Williams, and Chen (2017) compare a more detailed and sophisticated CGE model with search friction with an otherwise equivalent full-employment model with a labor-leisure choice. They find that the implied change in net job losses from a carbon tax in the full-employment model is more than two times greater than the job losses in the search-CGE model. The carbon tax exacerbates the search friction, but reductions in hours per worker in the search-CGE model reduce the need for firms to eliminate jobs in response to the climate policy.

These qualitative results would most likely apply to a developing country context, but future work on search frictions in developing countries is necessary to provide more quantitative results on how incorporating such a friction impacts the employment effects of climate policies in developing countries. A key step in that work will be to look carefully at interactions between search frictions and the labor market segmentation that is an important characteristic of developing economies.

F. Policy Uncertainty

There is substantial uncertainty about future climate policy. Although it seems highly likely that countries around the world will take substantive action to address climate change at some point, exactly when any given nation will take that action, what form it will take, and how stringent it will be are all still quite uncertain. This policy uncertainty has potentially important implications for how economies will react.

In particular, uncertainty creates an incentive to defer making any irreversible (or costly to reverse) investment. This is well-known for major capital investments.[13] For example, if a low-carbon energy project will be profitable only under a relatively high carbon price, and the future carbon price is uncertain, that creates an incentive to wait for

[13] See, for example, Dixit (1992).

further information about the future carbon price before making any investment.[14] Thus, having a clear and reliable signal of future policy promotes investments that will be consistent with that policy – and, conversely, uncertainty about future policy retards investment.

This same principle applies for other less-tangible forms of investment. To the extent that labor market adaptation to a low-carbon economy requires former coal miners to acquire new skills, or to move from coal-mining regions to areas where new jobs are being created, those are also potentially risky (and difficult-to-reverse) investments. So uncertainty about future policy will retard those types of investment as well.

Thus, policy uncertainty interacts with labor market frictions, especially labor market segmentation, in a way that likely impedes the economy from adjusting to policy changes. Again, this means there is value to providing a clear signal of future policy. It also suggests a need for economic modeling that recognizes the effect of policy uncertainty. This represents a gap in the existing literature. Studies have looked at option value in environmental policy (e.g., Fisher 2000) without considering the labor market, and have looked at policy uncertainty and the labor market (e.g., Baker, Bloom, and Davis 2012) in a non-environmental context, but to our knowledge no work has brought together all these issues (policy uncertainty, environmental policy, and labor markets).

[14] The same is true for a high-carbon energy project that would be profitable only under a relatively low carbon price.

Conclusions

This section addresses two key concluding questions. Based on evidence from the literature, what can we conclude about the employment effects of climate policy in developing countries? And what are the most promising directions for future knowledge work to fill the important gaps in what we know?

A. What Do We Know about Employment Effects of Climate Policy?

Tables 3-5 provide an overview of surveyed methods that have been used for the analysis and understanding of the general economic effects, developing country effects, and policy questions that relate to the interplay of labor markets and climate policies.

Unfortunately, none of the various strands of research gives an ideal answer to the question of how climate policy affects employment. Micro-econometric studies provide useful information about effects on regulated industries, but cannot address broader effects (even worse, for studies that use unregulated industries as a "control group," those broader effects may bias estimates for the regulated industries). Macro-econometric studies attempt to measure aggregate effects, but it is hard to have any confidence in those estimates, because the correlations they study may well change in the presence of new policies.

General equilibrium simulation models address these problems. They incorporate direct effects and broader spillovers, and because they are based on more fundamental models of the structure of the economy, they should be much more robust to policy changes. But most of these models assume that the labor market clears perfectly, implying that there are no unfilled jobs or involuntarily unemployed workers. Models that relax this assumption show great promise, especially those that explicitly incorporate search frictions, but these search-friction models are very new to the literature on employment effects of regulation and have not yet been widely deployed.

Focusing specifically on developing countries, the evidence is still thinner. For a variety of reasons – with data availability being likely the most important – a large majority of studies of employment effects of environmental regulation have focused on developed countries, in the econometric and simulation-modeling sections of the literature. It is unclear how well the results from such studies would apply in a developing country context.

Nonetheless, one can draw some tentative conclusions by pulling together evidence from various strands of the literature. The ENVISAGE model results for carbon mitigation policy indicate that highly carbon-intensive sectors of the economy (fossil fuel extraction and fossil fuel–based power generation) will see drops in employment that are large relative to existing employment in those sectors (e.g., a loss of roughly one-third of coal-sector jobs), in developing and developed economies. But such industries make up a very small share of total employment, even in fossil fuel–producing nations, so those employment drops are small relative to the overall economy. And they are offset by gains in other industries: big employment increases in clean-energy industries (relative to existing employment in those industries), but also smaller gains across a broad range of other sectors.

The major limitation of the ENVISAGE model is that it assumes that total labor is fixed. So it cannot look at effects on aggregate employment. And the result that fossil fuel industry job losses are exactly offset by job gains elsewhere is also dubious, because it comes directly from the fixed-labor assumption. And we do not have a good example from the literature of a developing country model that realistically addresses involuntary unemployment. Nonetheless, results from developed country models (notably Hafstead, Williams, and Chen 2017) suggest that the sector-level results from full-employment CGE models typically correspond relatively closely to those from search-friction models (which have more realistic assumptions about the labor market); that is, although full-employment models are not well-suited to looking at aggregate employment changes, they pick up sector-level shifts relatively well. If that holds true for developing countries – as we expect it would – then ENVISAGE would do relatively well in identifying which sectors will see employment gains, which will see employment losses, and the rough magnitude of those changes.

Results from these developed country models also suggest that the aggregate employment changes are relatively small. The ENVISAGE result of zero net employment change obviously will not hold up. But because fossil fuel industries represent a relatively small share of overall employment, and because there are substantial gains in other industries, the net change in employment is small. Again, it seems likely that this qualitative result would translate to developing countries.

Although the aggregate changes are small, the substantial effects on particular sectors will be disruptive, especially if policy is implemented relatively quickly. Workers in fossil fuel industries, and locations with high concentrations of such jobs, will be harmed to some extent by that shift. Policy makers will likely need to address that, providing some form of compensation and/or retraining to ease the transition. Carbon pricing (such as a carbon tax or auctioned tradable carbon permits) could provide revenue to fund those transition policies. The design of such policies, however, requires understanding the dynamics of that shift. And unfortunately, those dynamics are probably the piece of this issue that we understand least well, based on the existing literature. Labor market segmentation will cause that transition to be slower – and thus the adjustment more persistent – in a developing economy than it would be in a developed economy. However, how much slower the adjustment would be remains an open question.

Although these qualitative conclusions seem robust, and the sector-specific quantitative results should be reasonably accurate, the results should be taken with substantial caution, because we are extrapolating from models that are not directly suited to the question at hand.

B. Recommendations for Future Knowledge Work

Given the major limitations of the conclusions that can be drawn from prior work, there is a clear need for future work that will provide more solid evidence. In this section, we provide some suggestions for promising directions that such knowledge work could take. In the near term, the easiest approach will be to adapt and modify existing models. But new models built specifically to address this question will provide a better answer. That will require more time and effort, but is the most promising longer-run solution.

i. Near-Term (Use and Adaptation of Existing Models)

In the near term, the simplest approach for getting more solid evidence will be to adapt an existing model (or models) to make it better suited to looking at the employment effects of climate policy in developing countries. There are two logical directions this could proceed: modifying an existing full-employment model that includes developing countries to give it a more realistic treatment of labor market imperfections, or re-calibrating an existing developed country model of employment effects of environmental regulation to fit a developing country.

An existing full-employment model that includes developing countries (such as ENVISAGE) could be modified in a variety of ways, roughly corresponding to the different labor market assumptions discussed in section 5. Modifying such a model to include a labor-leisure decision or some form of wage rigidities (such as a fixed wage, either economywide or in particular sectors) would be relatively straightforward, and it would be useful to see how the model's results would change under these alternative assumptions. But implementing search frictions in such a model would be a substantially larger effort and incorporating key features of developing country labor markets would be more difficult still.

Alternatively, one could take an existing developed country model of employment effects of regulation (such as the model from Hafstead, Williams, and Chen, 2017), and recalibrate it to fit a developing country (or multiple developing countries). Given the necessary data, this would be very straightforward. And the bulk of the necessary data – industry-level inputs and outputs – is certainly available (and has been used for models like ENVISAGE). The biggest potential difficulty here is the availability of labor market data (such as job turnover by industry), although in the absence of such data, one could certainly extrapolate from the data that are available (and try a range of different extrapolations to see how robust the model's conclusions are).

ii. Longer-Term (Development of New Models)

The best answer would come from a model specifically built to address the job effects of climate policy in developing countries. Such a model would include not just search frictions, but also some representation of key features that make developing country labor markets different from those in developed countries, especially labor market segmentation. That segmentation could include explicit modeling of the informal sector and/or a rural-urban split. We know that such segmentation slows an economy's adjustment to new policy and leads to substantial divergence in how different industries, occupations, and regions are affected. A good model could provide useful information about how big those effects are, and will help to evaluate policies, which could address the resulting divergence in economic outcomes. The major challenge here will be to capture key features of the market, while still keeping the model simple enough to be tractable and easily understood.

To the extent possible, it would be useful to parameterize such a model to match developing country–specific empirical evidence about the labor market effects of policy. This could be taken from existing studies, or could represent new empirical work.

Building such a model will take substantially more time and effort than making straightforward modifications to an existing model. Thus, this would be more of a long-term effort. But it would provide substantially better quantitative results than what we currently have.

It could also be useful to develop a more stylized model that could look at how climate policy uncertainty interacts with labor market frictions. This would help to evaluate the extent to which policy uncertainty causes workers to defer costly adjustments (such as learning new skills or moving to a region with more jobs), and thus help to judge the importance of sending clear signals about future policy.

Table 3: General Economic Effects

GENERAL ECONOMIC IMPACTS	Case studies	micro-econ. Studies	macro-econ. Studies	Simulation Modeling: fixed employment	Simulation Modeling: full employment	Simulation Modeling: non-full employment
Direct impacts on industry	1	1	1	1	1	1,2
How is the coal industry affected by climate policy?						
Indirect impacts on industry	1	1,2	1	1,2	1,2	1,2
How is manufacturing affected by increased energy prices?						
Non-carbon-intensive non-energy-intensive industry impacts			1	1,2	1,2	1,2
How is the service sector affected?						
Aggregate effects			1			1,2
How would a carbon tax affect the unemployment rate?						
Short-run vs. Long-run impacts			1			2,3
How quickly does the economy adjust to climate policy?						
Effects on household welfare				1,2	1,2	1,2
Which households are made worse off by climate policy? How does this vary by income/skill/location?						
Unemployment and household welfare		1,2				2,3
How much are households harmed by unemployment? How does this vary by income/skill level?						
Wage impacts		1,2		1	1	1,2
How are wages affected by climate policy? Does the impact vary by industry? Skill level?						

Table 4: Developing Country Specific Effects

				Simulation Modeling		
DEVELOPING COUNTRY SPECIFIC IMPACTS	**Case studies**	**Micro-econ. Studies**	**Macro-econ. Studies**	**Fixed employment**	**Full employment**	**Non-full employment**
Developing country labor markets	1,2	1,2				
What characteristics typify developing country labor markets? Rural-urban? Informal labor markets?						
Developing country labor market institutions	1,2					1,2
How does the lack of unemployment insurance affect developing country labor markets?						
Climate policy - developing country labor market interactions			1	1		2,3
How do climate policies affect labor markets in developing countries?						
Do climate policies mitigate or exacerbate developing country labor market distortions?						

Table 5: Policy Questions

POLICY QUESTIONS	Case studies	Micro-econ. Studies	Macro-econ. Studies	Simulation Modeling		
				Fixed employment	**Full employment**	**Non-full employment**
<u>Can policies be designed to mitigate costs associated with labor adjustment?</u>	1,2	1,2				2,3
Which policies lead to smaller employment shifts among industries?		1,2		1,2	1,2	1,2
<u>Which policies lead to smaller effects on unemployment?</u>						1,2
<u>Is there a role for training programs to mitigate labor adjustment costs?</u>	1,2	1,2				
How do we design policy to compensate industries harmed by climate policy?				1,2	1,2	1,2
How do we design policy to compensate households harmed by climate policy?		1,2				
<u>How do we design policy to compensate workers who lose their jobs due to climate policy?</u>						2,3

LEGEND

Normal text = topic addressed and generally well-understood.

Italic text = adequately addressed and/or adequately understood, room for improvement.

<u>Underlined text</u> = not addressed and/or not well understood.

1 = method has been used answer this question

2 = this is a good method to answer this question

3 = this method could be used to answer this question

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