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Abstract

Policy makers justify renewable energy promotion policies partly on the grounds that such policies have positive employment impacts. We apply a computable general equilibrium model to assess the labour market impacts of the feed-in tariff policy used by the Government of Ontario. We find that although the policy is successful at increasing the employment in the 'green' sectors of the economy, the policy is also likely to increase the rate of unemployment in the province, and to reduce overall labour force participation. We conclude that policies designed to promote renewable energy should be promoted for the sake of their environmental impacts, not for their labour market effects.

KEYWORDS: renewable energy, policy, climate change, employment, unemployment

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1 Introduction

Although renewable energy policies are promoted primarily for their environmental attributes, policy makers are increasingly embracing such policies based on their perceived strength as engines of job creation. For example, in the US, the Obama-Biden New Energy for America plan suggests that renewable energy and energy efficiency policies will "create millions of new green jobs",[1] and the Clean Energy Jobs and American Power Act of 2009 claims that "substantially increasing the investment in the clean energy future of the US will provide economic opportunities to millions of people and drive future economic growth".[2] In Europe, the European Commission projects that achieving a target of 20 percent of primary energy use from renewables would be associated with the creation of over 600,000 jobs in the EU.[3]

Given relatively high rates of unemployment in many countries, there is a clear allure to policies that could simultaneously achieve environmental and labour market goals. However, claims of substantial levels of job creation associated with renewable energy policies need to be carefully qualified. Because substantial support for renewable energy is likely to have general equilibrium effects, it is important to consider the net employment implications associated with such policies, rather than just the gross employment effects on one sector of the economy.

In this paper, we apply a computable general equilibrium model of the Canadian economy to examine the employment effects of renewable energy policies in the Canadian province of Ontario. Ontario provides a useful case study to examine the employment impacts of renewable energy policies for two reasons: first, it has recently implemented one of the strongest support regimes for renewable energy in the world using a feed-in tariff that we describe in more detail in the following section, and second, there is a provincial concern over unemployment levels and job losses in the manufacturing sector, which appears to be one justification for promoting renewable energy production as a potential job creation engine in the province.

Our simulation results indicate that feed-in tariffs are likely to stimulate significant direct job creation associated with manufacturing and operation of renewable electricity plants. However, we find that these job gains are more than offset by employment losses in other sectors of the economy, such that the net employment impacts of the policy are negative.

Our paper builds on a budding literature on the relationship between re-

[1] See http://change.gov/agenda/energy_and_environment_agenda/ .
[2] See http://www.opencongress.org/bill/111-s1733/text .
[3] See http://ec.europa.eu/europe2020/priorities/sustainable-growth/index_en.htm .

newable energy support policy and employment. Hillebrand et al. (2006) conduct an analysis of the German renewable support policy using an input-output model, and conclude that the policy is likely to generate a positive level of net employment in the near term, but a negative level in the medium- to long-term. Lehr et al. (2008) use a similar model, but supplement with a detailed survey to generate input-output coefficients specific to the renewable electricity sector. They find that the net effect of the renewable energy support policies in Germany will be positive, such that the policy lowers the long-run rate of unemployment. This conclusion is reinforced by Ragwitz et al. (2009), who estimate that EU-wide renewable energy support policies have generated a net positive impact on employment. Küster et al. (2007) uses a recursively dynamic computable general equilibrium model to estimate the impact of a 50 percent subsidy to the capital cost of renewable energy technologies throughout Europe. They find that such a policy increases the unemployment rate in all countries that adopt the policy.

Our paper also builds on an established theoretical literature that explores the link between environmental taxation and employment. For example, Bovenberg and de Mooij (1994) use a simple stylized general equilibrium framework with labour-leisure choice (but without involuntary unemployment) to explore analytically the impacts of a labour to dirty goods tax shift on employment and non-environmental welfare. They find that the relatively narrow base of the environmental tax implies that the dirty goods tax is more distorting than the labour tax, and results in a fall in the real wage, and consequently a reduction in employment. Schneider (1997) uses a similar model but includes involuntary unemployment, and concludes that a shift towards environmental taxation is likely to reduce unemployment (for caveats see Scholz (1998)). A series of papers by Bovenberg and van der Ploeg (1996); Bovenberg and Van der Ploeg (1998); Bovenberg and Van Der Ploeg (1998) as well as a summary by Bovenberg (1995) include various specifications for involuntary unemployment and consider the effect of mobile factors, substitution elasticities, initial tax rates, and factor shares. This literature generally concludes that shifting the tax burden from broadly-based income taxes to dirty goods taxes is unlikely to boost employment (Goulder, 1995).

The remainder of this paper is organized as follows. We first lay out the design of Ontario's feed-in tariff with a particular focus on its model-based implementation. We then describe the model we use to numerically simulate the impacts of the feed-in tariff policy. Finally, we explain the results of our modeling study, and offer some policy conclusions.

2 Ontario's feed-in tariff

In 2009, the Government of Ontario passed the *Green Energy and Green Economy Act*. The Act enabled the development of Ontario's current feed-in tariff program for renewable electricity, which is promoted as "North America's first comprehensive guaranteed pricing structure for renewable electricity production."[4]

The feed-in tariff was motivated by several concerns. First, Ontario's electricity generating infrastructure is aging, and much of it needs to be retrofitted or replaced in coming decades. In particular, Ontario has committed to eliminating its existing fleet of coal-fired power plants by 2014, and Ontario's nuclear power stations will need to be modernized and refurbished in the coming decade, which will result in a temporary, but substantial, loss in capacity. Coal (8.3 percent) and nuclear (55 percent) account for a significant share of Ontario's electricity supply.[5] Renewable sources of electricity, which can be built relatively quickly, are one way to fill these projected supply gaps.

Second, investment in renewable electricity helps to advance Ontario's environmental goals. The province has committed to reduce its emissions of greenhouse gases by 15 percent relative to 1990 levels by the year 2020. Additionally, coal-fired generating stations are responsible for a substantial amount of local air emissions in Ontario, and the province has committed to reducing such emissions as part of meeting the *Canada-wide Standards for Particulate Matter and Ozone*. Renewable electricity generation, which produces few emissions compared to conventional fossil fuel based power generation, helps to achieve these goals.

Third, the feed-in tariff was designed "to creat[e] thousands of jobs and economic prosperity" (Government of Ontario, 2009). Indeed, the 2007 Speech from the Throne claims that "we can grow our economy by making it greener. There are good, high-paying jobs that will go to the places that develop the most innovative green technologies." Specifically, the government estimates that the implementation of the *Green Energy and Green Economy Act* will create 50,000 jobs in its first three years.[6] Employment in Ontario's manufacturing sector last peaked in 2004, when the sector provided jobs to 1.1 million people. By 2010, the sector employed almost 30 percent fewer people, and the sectoral unemployment rate had increased from 3.3 percent in 2000 to 11.4 percent in 2009 before falling back to 6.8 percent in 2010.[7] Given the decline in

[4] See: http://fit.powerauthority.on.ca/what-feed-tariff-program .
[5] Values are for 2010. See http://www.ieso.ca/imoweb/media/md_supply.asp .
[6] See: http://www.mei.gov.on.ca/en/energy/gea/ .
[7] All data from Statistics Canada, Tables 282-0001 and 282-0008.

Ontario's manufacturing sector employment and the high unemployment rate in general, creation of new jobs has become an important government and public priority, and policies with positive employment spillovers for the manufacturing or construction industries are likely to be embraced in the province.

Under the feed-in tariff, generators of renewable electricity are provided with a 20-year contract that guarantees a fixed price for generated electricity,[8] and are provided with preferential access to the electricity grid. The pricing schedule for the feed-in tariff is given in Table 1.[9] For comparison, the Ontario Independent Electricity System Operator reports that the hourly-weighted average wholesale electricity price in Ontario has annually averaged between 3.15 and 7.21 ¢/ kWh during 2002 and 2011.[10] Recent contracts for nuclear power have ranged from 5.0 to 7.9 ¢/ kWh, and recent contracts for natural gas supply have ranged from 8.2 to 16.4 ¢/ kWh.[11] In the model, we assume that the cost of procuring new non-renewable power is 12.3 ¢/ kWh, the midpoint of recent contract prices for natural gas-fired generators. The feed-in tariff therefore provides a substantial subsidy for certain types of renewable electricity generating technologies.

The feed-in tariff has been calculated by program designers with the objective to cover the costs of renewable energy development as well as to provide a reasonable rate of return to investors. In addition, by providing a contractually guaranteed price for generated electricity, the feed-in tariff is structured to reduce the risk associated with renewable electricity projects, and therefore should reduce the cost of financing such projects. Similar features have led feed-in tariff programs in European countries to record substantial renewable electricity capacity additions (Mitchell et al., 2006; Butler and Neuhoff, 2008).

Ontario's program appears to be likewise successful in stimulating renewable electricity deployment. Table 2 shows that projects totaling 4,200 MW of capacity have already been offered contracts under the feed-in tariff program. A further 11,500 MW of projects is in pre-contract phase. Applying failure and attrition rates from the past year of operation, current applications will likely result in about 10,500 MW of total renewable energy capacity built.[12]

[8]Hydro-power developments receive a guaranteed 40-year contract.

[9]In addition to the prices listed in Table 1, some projects are eligible for 'adders' related to community and aboriginal participation in the project. These adders can amount to an additional to 3 ¢/ kWh on top of the prices shown in the table.

[10]See: http://www.ieso.ca/imoweb/siteShared/monthly_prices.asp?sid=ic .

[11]See Ontario Power Authority, "Cost disclosure - generation supply - detailed overview", available at: http://powerauthority.on.ca/sites/default/files/page/7977_Generation_Cost_Disclosure_-_Detailed_Overview.pdf .

[12]To calculate this, we use data from the Ontario Power Authority http://fit.powerauthority.on.ca/program-updates to classify renewable energy projects submitted to

Table 1: Feed-in tariff pricing. Source: Ontario Power Authority.

Technology	Size	Price
Solar		
Rooftop	$\leq$ 10 kW	80.2 ¢/kWh
Rooftop	$>$ 10 kW $\leq$ 250 kW	71.3 ¢/kWh
Rooftop	$>$ 250 kW $\leq$ 500 kW	63.5 ¢/kWh
Rooftop	$>$ 500 kW	53.9 ¢/kWh
Ground-mounted	$\leq$ 10 kW	64.2 ¢/kWh
Ground-mounted	$>$ 10 kW $\leq$ 10 MW	44.3 ¢/kWh
Bio-energy		
Biomass	$\leq$ 10 MW	13.8 ¢/kWh
Biomass	$>$ 10 MW	13.0 ¢/kWh
Biogas on-farm	$\leq$ 100 kW	19.5 ¢/kWh
Biogas on-farm	$>$ 100 kW $\leq$ 250 MW	18.5 ¢/kWh
Biogas	$\leq$ 500 kW	16.0 ¢/kWh
Biogas	$>$ 500 kW $\leq$ 10 MW	14.7 ¢/kWh
Biogas	$>$ 10 MW	10.4 ¢/kWh
Landfill gas	$\leq$ 10 MW	11.1 ¢/kWh
Landfill gas	$>$ 10 MW	10.3 ¢/kWh
Water power		
Water	$\leq$ 10 MW	13.1 ¢/kWh
Water	$>$ 10 MW $\leq$ 50MW	12.2 ¢/kWh
Wind power		
On-shore	any size	13.5 ¢/kWh

For reference, the Ontario electricity system draws on about 35,000 MW of capacity, and the Ontario long-term electricity plan envisages about 10,800 MW of renewable electricity capacity by 2018. The feed-in tariff appears on track to meet this ambitious goal, after only about 1 year of soliciting applications.

Table 2 also uses a projected capacity factor for each type of renewable electricity to determine the total amount of electricity that might be delivered to the grid, given our assumptions about future contracts. With eventual build-out of 10,500 MW of renewable energy capacity, as described above, it is projected that annual energy generation could total about 23.3 TWh. For comparison, Ontario's Long Term Energy Plan (Government of Ontario, 2011) projects a demand of roughly 150 TWh of electricity by 2020 (which is relatively unchanged from 2010). Thus, renewable sources are projected to represent about 15.5 percent of total Ontario electricity demand by 2020. We use this renewable energy supply forecast as a target variable in the model-based implementation of the feed-in tariff later in the paper.

By weighting the projected energy deliveries under the feed-in tariff with the appropriate feed-in tariff remuneration rates, we are able to calculate the average remuneration rate for projects covered by the program. Our estimate is that this rate falls in the range of 20.1 to 24.5 ¢/ kWh, where the range reflects the uncertainty about capacity of individual projects (which are not reported by the Ontario Power Authority). We use the mid-point between these values (22.3 ¢/ kWh) in our model simulations. In the model, we implement this as a subsidy on renewable electricity generation. The unsubsidized electricity generation price is given by the cost of conventional power, for which we adopt a value of 12.3 ¢/ kWh, as described above. The feed-in tariff therefore translates into a 81.3 percent subsidy rate for qualifying renewable electricity generation technologies.

Ontario's feed-in tariff is financed by electricity ratepayers, rather than by taxpayers, by means of a 'Global Adjustment' applied to the bills of electricity consumers in the province.[13] It thus increases the prices of electricity to

the feed-in tariff program into three mutually exclusive categories: $P_{ij} = 1$ if the project has not yet received a contract, $F_{ij} = 1$ if the project has been terminated, and $C_{ij} = 1$ if the project has succeeded in securing a contract. In each case, i indexes individual projects, and j indexes renewable energy types. Each project has a capacity in megawatts of Q_{ij}. The capacity-weighted failure rate of projects of type j is $f_j = \frac{\sum_i Q_{ij} F_{ij}}{\sum_i Q_{ij}(F_{ij}+C_{ij})}$. The total projected capacity assuming constant failure rates is $Y_j = \sum_i Q_{ij} C_{ij} + (1 - f_j) \sum_i Q_{ij} P_{ij}$.

[13] The Global Adjustment covers the difference between payments and revenues from contracted generators and for demand management services. Contracted generators include baseload nuclear and hydro plants, power producers under the feed-in tariff scheme, and conservation services procured by the Ontario Power Authority.

Table 2: Actual and projected Ontario feed-in tariff results

	Data		Projections		
	Pre-contract (MW)	Contract executed (MW)	Total projected (MW)	Capacity factor (%)	Energy delivered (GWh)
Biogas	17	20	33	75%	217
Biogas (on farm)	3	5	8	75%	49
Biomass	101	18	38	83%	273
Landfill	29	14	41	85%	306
PV Groundmount	4,479	928	3,266	14%	4,005
PV Rooftop	604	295	646	13%	735
Hydroelectric	152	188	323	52%	1,473
Wind on-shore	6,064	2,448	5,794	30%	15,228
Wind off-shore	-	300	300	37%	972
Total	11,449	4,217	10,449	25%	23,259

Source: Contract and pre-contract data from Ontario Power Authority July 8, 2011 program report. Total projected calculated by applying contract termination and failure rates from existing projects. Capacity factors from Ontario Power Authority (Proposed Feed-in Tariff Price Schedule, April 7, 2009). Delivered energy calculated by authors.

Table 3: Feed-in tariff domestic content requirements

	First 1-2 years[a]	Later years
Wind power > 10 kW	25%	50%
Solar power > 10 kW	50%	60%
Solar power ≤ 10 kW	40%	60%

[a] For wind power projects, lower content requirements (in the first column) apply until January 1, 2012. For solar power projects, lower content requirements apply until January 1, 2011.

consumers in the province.[14] We implement the Global Adjustment in the model by means of an endogenous tax on electricity sales, with the tax rate set such that the entire feed-in tariff subsidy is financed through the Global Adjustment mechanism.

Ontario's feed-in tariff also includes a domestic content requirement. This requirement specifies that a minimum portion of the generating equipment used must be sourced from Ontario-based suppliers in order for the project to qualify for remuneration under the feed-in tariff. Domestic content is a physical (rather than a value) measure, and is calculated according to detailed rules specified by the Ontario Power Authority.[15] For example, a wind turbine that has blades that have been cast in Ontario, and instrumentation within the blades that has been assembled in Ontario, is considered to have sourced 16 percent of its content domestically. Content requirements are only specified for wind and solar power, and values of the requirements are given in Table 3.

By weighting the content requirement by our forecast for delivered energy by energy type (Table 2), we are able to determine the average content requirement under the feed-in tariff program. Because we are concerned with the longer-run impacts of the program, we use the higher-level content requirements, in the last column of Table 3. The weighted average content requirement works out to 47 percent. We use this value in the model simu-

[14]Fischer and Preonas (2010) show that if the supply curve for natural gas-fired generation (which substitutes for renewables) is sufficiently steep relative to that for renewables, a feed-in tariff can lower consumer electricity prices. In our model, Ontario is a price-taker for natural gas, and so the feed-in tariff is guaranteed to increase electricity prices.

[15]See Exhibit D of the Feed-in Tariff Contract, http://fit.powerauthority.on.ca/what-feed-tariff-program .

lations. We describe implementation of the domestic content requirement in the model in the following section.

3 Model

We employ a multi-region (i.e., multi-province) static computable general equilibrium model of the Canadian economy to conduct the policy assessment. Because we use a static model, we do not model transitional dynamics associated with the feed-in tariff program, but instead focus on long-run impacts of the program. More specifically, the scenarios we consider assume full build-out of all renewable electricity projects proposed to the Ontario Power Authority under the feed-in tariff program by July 2011 (less failure and attrition). As we describe above, the Ontario government expects this to occur between about 2018 and 2020.

The following sub-sections describe the model; a complete algebraic description is left to the appendix. Data underlying the model parameterization is described in the subsequent section.

3.1 Production

All firms are assumed to operate at constant returns to scale in a perfectly competitive environment, and so make zero profits. We specify nested separable constant-elasticity-of-substitution (CES) production functions to characterize substitution possibilities between productive inputs. We characterize the production function for renewable energy firms slightly differently than for other firms.

For all firms except renewable energy producers, the production function consists of a CES aggregate of capital and labour nested within a CES aggregate of all other inputs. For renewable energy producers, we nest this aggregate within an additional CES nest, such that the entire capital-labour-energy-material nest is combined with a fixed factor input that represents limited availability of renewable energy sites. This model specification allows us to model upward-sloping renewable energy supply (to mimic the best sites being used up first - see e.g., Paltsev et al. (2005); Sue Wing (2008)). It is straightforward to calibrate CES supply functions for renewable energies to be consistent with exogenous estimates for supply elasticities (Rutherford, 2002). However, empirical evidence on supply elasticities for discrete renewable energy sources is scant and difficult to generalize from one regional energy market (e.g., Johnson, 2010) to another given substantial cross-country differences in market regulations and renewable energy availability. Since our main focus is on evaluating labour market impacts of Ontario's feed-in tariff we take a different approach: we adopt renewable energy supply elasticities in the model to match the supply estimates developed by the Ontario government as well as our own estimates, which are reported in Table 2. This allows us to focus on the general equilibrium and labour market impacts of the feed-in tariff policy.

We distinguish a separate domestic manufacturing sector that produces capital equipment for renewable energy generation (wind turbine blades, nacelles, solar panel and inverter manufacturers, etc.). Producers of renewable energy will choose to purchase outputs from this manufacturing sector, rather than purchasing imported renewable energy capital, when doing so is consistent with profit maximization. More precisely, since the feed-in tariff is contingent on generators achieving a minimum fraction of domestic content, generators will source this fraction from domestic suppliers when the cost of doing so does not exceed the subsidy value of the feed-in tariff.

We implement the domestic content requirement in the model by dividing renewable electricity generation into that produced using domestic equipment and that produced using foreign equipment, and using a pair of side-constraints. First, we use an endogenous tax on generation of renewable energy that is produced using foreign equipment. This tax is endogenously chosen such that the domestic content requirement (which we interpret as the fraction of generation using domestic equipment) is achieved. Second, we use an endogenous subsidy on renewable electricity generated with domestic equipment, with the rate set such that there is no net fiscal transfer resulting from the combination of the endogenous tax and subsidy.

3.2 Factor markets

Our model includes three factors of production: capital, labour, and specific resources. Capital is completely mobile between sectors and provincial borders. Fixed factors are associated with production of electricity from renewable sources. This factor is used uniquely in the production of renewable electricity, and is not mobile across borders. Labour is mobile between sectors within a province, but immobile between provinces.[16] Household labour supply is modeled using a choice between leisure and consumption to produce an uncompensated elasticity of labour supply of 0.15, consistent with econometric estimates (Ballard et al., 1985, provide a survey of such studies and adopt the

[16] We test the assumption of non-mobile labour between provinces in a sensitivity analysis that is reported later in the paper.

same value as a central estimate).

Our model also accounts for equilibrium unemployment, so not all labour supplied to the market is employed. Several theories have been used to explain the relationship between the real wage rate and the rate of unemployment. For example, Shapiro and Stiglitz (1984) and Solow (1979) consider that workers invest additional effort in working (to avoid being fired) when the value of employment is higher, which occurs when the probability of finding a job is low - i.e., unemployment is high - or when the wage rate is high relative to the reservation wage. When firms choose a wage rate to minimize unit labour costs, this results in a real wage offer schedule that is decreasing in the unemployment rate. Pissarides (2000) builds a relationship between the real wage rate and the unemployment rate by focusing on the matching process that takes place between firms looking for new workers and unemployed workers. With the recognition that heterogeneity (in firms and workers) and imperfect information generate real search costs, he develops a theory in which employed workers obtain a premium on their reservation wage. This premium is a function of the tightness of the labour market, which is itself a function of the unemployment rate. An alternative strategy to investigating equilibrium unemployment is taken by Blanchflower and Oswald (1990), who use data on wages and unemployment rates to infer an empirical relationship between the wage rate and the unemployment rate. Because of its simplicity and widespread empirical support, we include this reduced-form relationship in our model.[17] Specifically, we incorporate a 'wage curve' specification of equilibrium unemployment, where real wages are a decreasing function of the unemployment rate. Relying on empirical estimates by Blanchflower and Oswald (1990), we specify the real wage elasticity with respect to the unemployment rate at -0.1.

Figure 1 illustrates the structure of the labour market. The real wage is determined from the intersection of the labour demand curve (L^D) and the wage curve. This results in a labour demand of L_D. The equilibrium real wage is above the market clearing wage, however, because of the specification of the wage curve. The supply of labour to the market is determined by the intersection of the upward-sloping labour supply curve (L^S) and the real wage rate, and gives a labour supply of L_S. Unemployment is the difference between labour supplied and labour employed, $L_S - L_D$.

[17] Note that this type of wage curve can be analytically derived from union bargaining wage models as well as from efficiency wage models (Hutton and Ruocco, 1999).

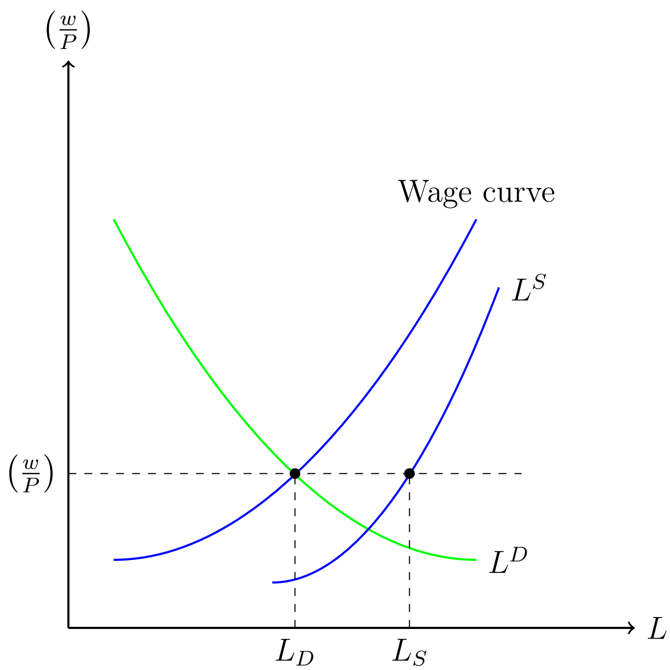

Figure 1: Labour market

3.3 Government and taxation

We represent a separate government agent in the model for each province or region. This agent collects taxes to finance the provision of a public good. We include in our model all existing indirect taxes, albeit at an aggregated level. In our equal-yield model simulations, we maintain government provision of the public good at benchmark levels in order to focus on the impact of the policy on the representative household.[18]

Tax rates on labour income are adjusted to maintain public goods provision at the initial level. In experiments involving subsidies, the tax rates need to be raised to fund the subsidies.

3.4 Investment demand

Investment demand is exogenously set at the benchmark level. Savings adjust in equilibrium such that this investment demand is met.

[18] We thus assume separability between public and private consumption.

3.5 Consumer demand

Since we are not focusing on distributional issues in this paper, we use a representative household to model consumer demand. Consumption is a constant elasticity of substitution aggregate over all consumer goods. Consumers exhaust their income, net of savings and taxation, on purchasing goods and services for consumption.

3.6 International and inter-provincial trade

The model includes bilateral trade flows between each province pair in addition to extra-Canadian trade. Export supply and import demand from outside Canada is assumed to be perfectly elastic, i.e. Canada is perceived as a price-taker on international markets (conversely, relative prices and thus terms of trade between provinces are endogenous).

For the purposes of modeling international and inter-provincial trade, we employ the Armington (1969) formulation, common in applied studies. The Armington aggregate good within a province is a CES function of goods from the rest of the world and those produced in Canada.[19] The latter is a CES aggregate of goods produced in the home province and those imported from other provinces.

In similar fashion, we specify an elasticity of transformation function, governing the destination of domestically produced goods. This elasticity governs the ease with which domestic producers can shift between serving the domestic and foreign markets as relative prices change.

The model is closed by maintaining a fixed balance of trade surplus or deficit in each province. Thus total foreign saving in Canada is also exogenously fixed at the benchmark level.

4 Data

As is customary in applied general equilibrium analysis, economic transactions in a benchmark year (quantities and prices) together with exogenous elasticities, determine the free parameters of the functional forms that characterize production technologies and consumer preferences. Our model is based on the symmetric provincial input-output tables compiled by Statistics Canada for the year 2005, coupled with data on inter-provincial and international trade

[19] A separate Armington good is specified for each commodity defined in the model.

flows.[20] The benchmark data set also includes production, intermediate use, final demands, sectoral capital earnings and sectoral expenditures on wages and salaries. Key aspects of the sectoral aggregation are briefly identified in Table 4.

The input-output data set that we use does not include data on renewable electricity supply technologies; rather the electricity sector in the benchmark data is an aggregate of existing renewable and conventional technologies. As a result, we parameterize the input requirements for the renewable electricity technology in our model based on additional data sources, allowing us to disaggregate the aggregate electricity sector into renewable and conventional sub-components, as in Sue Wing (2008) and Böhringer (1998). We conduct our disaggregation using data from the US Environmental Protection Agency that describes cost and technological characteristics of 18 distinct electricity generation technologies, compiled by Sue Wing (2008). This allows us to compile input cost shares for each technology. We weight these input cost shares according to our forecast of electricity generation by renewable energy technology (our forecast is given in Table 2) to generate an aggregate technology profile for the renewable energy sector. Using additional data on benchmark renewable (3 percent) and conventional (97 percent) shares of total electricity production from the Ontario Independent Electricity System Operator, we are thus able to separate the aggregate electricity generation sector into conventional and renewable sub-sectors. The input cost shares for each electricity generating technology are given in Table 5. Overall, the key differences between the two technologies are that the renewable energy technology is more capital intensive and less energy intensive than the conventional electricity generating technology. The renewable energy technology is also somewhat less labour-intensive than the conventional generating technology.

The renewable equipment manufacturing (turbines, inverters, etc.) sector has a similar cost structure as the broader manufacturing sector. In order to capture differences between the two sectors, we use detailed data from the more disaggregate national economic accounts.[21]

[20] Statistics Canada Tables 15-211-XCE and 15-F0002-XDB, respectively.

[21] To generate cost shares, we averaged national input-output data from the following four sectors:

3330 Machinery Manufacturing

3341 Computer and Peripheral Equipment Manufacturing

334A Electronic Product Manufacturing

335A Electrical Equipment and Component Manufacturing

The differences are reported in Table 6. Our data suggest that the renewable equipment manufacturing sector has a lower proportion of value added compared to the broader manufacturing sector. To reflect evidence that most renewable energy capital equipment would be supplied by foreign manufacturers in the absence of a specific policy dictating otherwise, we assume that the domestic renewable energy manufacturing industry initially operates at negative profit, and only becomes active when a policy is applied.[22]

We calibrate the functional forms described above using the benchmark data on economic transactions and exogenously specified parameters, given in Table 7.

5 Scenarios and results

5.1 The Ontario feed-in tariff

In our central case simulation of the Ontario feed-in tariff program we set the feed-in tariff at 22.3 ¢/ kWh, which corresponds to the average feed-in tariff weighted by our forecast of delivered energy by renewable power technology type. We apply a local content requirement of 47 percent, which is calculated from the technology-specific content requirement weighted by our forecast of delivered energy by technology type.

Our estimates of the impact of the Ontario feed-in tariff program are given in Table 8. As described above, we chose renewable energy supply elasticities to arrive at a renewable market share in line with projections from the Ontario government, and also from projections we constructed ourselves based on already-executed feed-in tariff contracts as well as those pending execution (Table 2). These both suggest a long-run renewable electricity market share under the feed-in tariff program of roughly 15 percent (measured in terms of energy, rather than capacity). As shown in Table 7, the elasticity of renewable energy supply consistent with these projections is 12.66. This is significantly higher than the only econometrically-estimated elasticity of which we are aware (Johnson (2010)); however, this study is for a different region, with a different market structure and different geographic conditions. We test the sensitivity of the model results to changes in this parameter later in the paper.

[22] We implement this by imposing a very small (<0.1 percent) efficiency penalty on the domestic renewable energy manufacturing sector. The penalty is too small to influence outcomes reported later other than to ensure that renewable energy capital is initially supplied by foreign firms. If the efficiency penalty of foreign firms is actually greater than the value we implement in the model, then welfare losses we estimate will be a conservative, and actual welfare losses associated with the domestic content requirement will be higher.

As a result of the feed-in tariff implementation, we estimate that electricity prices will increase by about 13 percent. This results in a decrease in total electricity demand of roughly 2.1 percent. Our analysis projects a welfare decrease, measured as the Hicksian equivalent variation in income, of $1.07 billion, or about 0.54 percent of Ontario household income. Importantly, this total does not include any environmental benefits that might accrue due to the program, and so cannot be used on its own to assess the desirability of the program. In fact, a government commissioned report suggests that the health benefits of shutting down coal-fired generating stations, at about $3 billion annually, would significantly exceed this amount (DSS Management Consultants, Inc and RWDI Air Inc, 2005).[23]

Table 9 provides impacts of the feed-in tariff on a sector-by-sector basis. Not surprisingly, we find the largest impact on the electricity sector. The model suggests a reduction in conventional electricity output of 20 percent, which is only partly made up for by the increase in output from renewable energy production. Electricity-intensive sectors, such as the mining and manufacturing sectors contract as a result of the transmission of higher electricity prices through the economy, and because the reduction in conventional electricity supply reduces demand for certain inputs. On the other hand, output of certain non-electricity intensive sectors increases.

Our main findings concern the labour market. We estimate that the feed-in tariff program does cause a substantial increase in the level of employment in the renewable energy (green) sector - in our calculations, we define the 'green' sector to include the generation of renewable electricity as well as the manufacturing of equipment for renewable electricity generation. Assuming an average salary of $50,600 per employee,[24] we find that the current Ontario feed-in tariff policy is likely to generate roughly 12,400 new jobs in the renewable energy generation and manufacturing sectors.[25] These 'green' jobs represent one of the primary desired outcomes of the policy, according to statements

[23]In abstracting from any environmental benefits from the policy, our model implicitly assumes that utility is separable in environmental quality, and that production is not impacted by changes in environmental quality. While these are standard assumptions in modeling the impact of policies, the assumptions may impact our results. For example, Carbone and Smith (2008) show that including non-separability of environmental quality in consumer utility can influence CGE assessment of environmental policies, and Ostro and Chestnut (1998) and Williams (2002) document several pathways through which particulate matter (a main by-product of coal-fired electricity generation) can reduce productivity and output.

[24]This is the average earnings per employee in Ontario's manufacturing sector in 2005, according to Statistics Canada 202-0107.

[25]As discussed previously, the Ontario government analysis projects 50,000 new jobs in these sectors as a result of the policy, so our finding suggests this may be an overstatement.

made by policy makers upon the release of the program.

However, we also estimate that the feed-in tariff has a detrimental impact on the broader labour market.[26] In particular, our analysis suggests that the unemployment rate in the province is likely to increase by 0.32 percentage points (or about 4 percent relative to a benchmark unemployment rate of 8 percent) as a result of the implementation of the feed-in tariff, and that the overall level of employment in the province is likely to decrease by about 0.3 percent. This occurs because the feed-in tariff increases consumer prices, and thus reduces the real wage. Because of the inverse relationship between real wages and the unemployment rate, this results in a new equilibrium with a higher unemployment rate. Likewise, because leisure is treated as a normal good, the reduction in the wage rate (price of leisure) results in an increase in leisure demand and thus a reduction in the labour force participation rate.[27]

Table 8 shows the losses in employment in non-renewable energy sectors per gain of employment in renewable energy sector. If employment was costlessly transferred from one sector to another as a result of the policy, we would expect a value of unity; that is, one job would be destroyed in the broader economy for each job created in the renewable energy sectors. If the feed-in tariff created net employment in the economy, we would expect a value of less than one; that is, less than one job would be destroyed in the broader economy for each job created in the renewable energy sectors. As Table 8 shows, we find a value of 1.97. This suggests that each new job created by the policy in 'green' sectors of the economy is likely to cause the loss of 1.97 jobs in other sectors of the economy.

5.2 Sensitivity analysis

We conduct sensitivity analysis to determine the impact of changing parameter values on the results of our analysis. We vary the Armington elasticity, the elasticity of substitution between intermediates and value added, the elasticity of substitution between goods in final demand, the elasticity of renewable energy supply, and our assumption regarding the immobility of labour between provinces.[28] In two cases where parameters have a theoretically and empiri-

[26] This is expected; consider for example a fixed labour supply, in which every job 'created' in one sector must be accompanied by job 'destruction' in another sector.

[27] Our results using a classical (downward rigid real wage) unemployment formulation lead to large increases in unemployment.

[28] We also vary the elasticity of substitution between capital and labour in production, the domestic-foreign elasticity of transformation, and the wage curve elasticity but do not report results of these sensitivity runs here for reasons of parsimony. The model is relatively

cally similar impact on results, we vary parameters together to condense the discussion. Since the elasticity of demand for electricity depends on the ease of substitution in both final and intermediate demand, we vary these parameters together. Similarly, we vary the Armington elasticities among domestic sources and between foreign and domestic goods together.

The results of the sensitivity analysis are reported in Table 10. When the ease of substitution between domestic and foreign goods is increased, the welfare impact of the feed-in tariff policy is slightly exacerbated, as are impacts on wage rates and unemployment. Decreasing the renewable electricity supply elasticity causes the output of renewable electricity to drop substantially, and thus causes the overall volume of subsidy payments to fall correspondingly, and the electricity price increase to be muted in proportion. As a result, the burden of the policy, measured as the change in unemployment or the change in welfare, is diminished relative to the reference case. This sensitivity scenario, however, results in a renewable energy market share that is inconsistent with current trends (see Table 2).

Increasing the elasticity of substitution between intermediates and value added in production, as well as between goods in consumer demand, allows increased renewable energy generation and raises electricity prices overall, but does not affect other outputs. Electricity demand falls when this elasticity is increased because consumers substitute other commodities for electricity in response to the greater elasticity of substitution.

In the final column of Table 10, we report an experiment where we relax the assumption that labour is interprovincially immobile. Here, we classify 10 percent of the benchmark labour force in each province as mobile between provinces (as well as sectors), and we use a constant elasticity of transformation function (with elasticity equal to unity) to allocate this mobile labour force between provinces such that it responds to changes in the relative real wage rate between provinces. This specification has little impact on the results: it results in a very slight reduction in the unemployment rate, real wage decrease, and welfare loss that result from the policy.

In all, our sensitivity analysis suggests that our key results are quite robust to parametric changes within a reasonable range. The main change occurs when we change the elasticity of supply for renewable electricity. However, large changes in this parameter are inconsistent with observed supply response of renewable energy generators, as shown in Table 2 above.

insensitive to variations in these parameters.

Table 4: Benchmark Data Sectoral Overview

	Output (% Share)	Emp. (% Share)	Electricity (% Share)
Agriculture and Forestry	1.2	0.6	2.0
Mining	0.7	0.6	3.5
Electric Power Generation	1.3	2.0	0.0
Renewable electricity sector	0.0	0.0	0.4
Other Utilities	0.2	0.3	0.4
Construction	5.6	6.1	0.1
Manufacturing	32.8	18.6	1.0
Wholesale and Retail Trade	9.0	13.2	0.9
Transportation and Warehousing	4.7	4.2	0.4
Information and Culture	3.3	3.2	0.3
Finance, Insurance, Real Estate	15.0	10.6	0.5
Professional Services	4.1	6.6	0.2
Administrative Services	2.1	3.7	0.3
Educational Services	0.1	0.2	0.9
Health Care Social Assistance	1.7	1.9	1.1
Arts, Entertainment, Recreation	0.7	0.9	1.2
Accommodation, Food Services	1.9	2.6	1.1
Other Services	3.4	2.0	0.5
Non-Profit Institutions	1.1	2.6	2.1
Government Sector	11.1	20.1	1.1

Output % Share denotes the sector's value share of provincial total GDP

Emp. % Share denotes the sector's share of provincial employment

Electricity % Share denotes the electricity cost share of the sector's total cost

Table 5: Benchmark cost shares for electricity generation

	Conventional	Renewable
Labour	0.21	0.15
Capital	0.41	0.65
Energy	0.18	0
Materials	0.19	0.14
Fixed factor (resource)	0	0.06
Total	1.00	1.00

Table 6: Cost shares for renewable equipment manufacturing and all other manufacturing

	Renewable equipment	Other manufacturing
Capital	0.08	0.26
Labour	0.26	0.38
Intermediates	0.66	0.36
Total	1.00	1.00

Table 7: Model Parameters

Parameter	Description	Value
σ_D	Elasticity of substitution between own-province and out-of-province goods	6.00
σ_F	Elasticity of substitution between goods from rest of world and Canada	3.00
σ_U	Elasticity of substitution between goods in final consumption	0.20
σ_V	Elasticity of substitution between capital and labour in production	0.70
σ_S	Elasticity of substitution between intermediate inputs and value added in production	0.10
η_R	Elasticity of supply for renewable energy production	4.00
σ_T	Elasticity of transformation between domestic goods and exports	1.00

Table 8: Impact of Ontario Feed-in Tariff

	OFIT
Renewable electricity market share (%)	15.54
Change in total electricity demand (%)	-2.09
Change in electricity price (%)	12.63
Change in unemployment rate	0.32
Change in employment (%)	-0.28
Change in green employment (thousand employees)	11.07
Jobs lost in other sectors per green job gained	1.97
Change in welfare (%)	-0.41
Change in welfare ($B)	-1.11
Real Wages (%)	-0.54

Table 9: Sectoral Detail OFIT (wagecurve)

	Emp (%)	Y (%)	X (%)	M (%)
Agriculture and Forestry	-0.8	-0.9	-1.1	0.0
Mining	-4.1	-4.3	-4.5	-1.2
Electric Power Generation	-20.6	-20.7	-20.5	67.3
Other Utilities	0.6	0.6	0.7	0.0
Construction	0.0	-0.1	0.1	-0.5
Manufacturing	-0.7	-0.7	-0.8	-0.3
Wholesale and Retail Trade	-0.1	-0.1	0.0	-0.9
Transportation and Warehousing	0.2	0.1	0.3	-0.6
Information and Culture	0.1	0.0	0.2	-0.7
Finance, Insurance, Real Estate	-0.2	-0.3	-0.2	-0.7
Professional Services	0.3	0.2	0.4	-1.0
Administrative Services	0.3	0.3	0.5	-1.0
Educational Services	0.5	0.5	0.6	0.0
Health Care, Social Assistance	-0.1	-0.2	-0.1	-0.5
Arts, Entertainment, Recreation	-0.1	-0.2	-0.1	-0.4
Accommodation, Food Services	-0.2	-0.3	-0.2	-0.5
Other Services	-0.2	-0.2	-0.1	-0.6
Non-Profit Institutions	-0.5	-0.5	-0.5	-0.7
Government Sector	0.0	0.0	0.1	-0.4
Renewable electricity†	6.9	7.7		
Domestic renewable electricity†	6.9	6.9		
Domestic renewable equipment†	0.3	0.1		

† Note that these sectors are reported as a share of the corresponding non-fossil sector in the benchmark. For the renewable elctricity sectors this is conventional electricity while for the domestic renewable equipment sector this is the remainder of manufacturing.

Table 10: Sensitivity Analysis

Parameters Used	Ref	Arm (-)	Arm (+)	Ren Sup (-)	Dem (-)	Dem (+)	Mob Lab
Renewable el. mkt share (%)	15.54	15.09	16.14	4.51	15.24	15.87	15.55
Electricity demand (%)	-2.09	-2.00	-2.18	-0.60	-0.45	-3.77	-2.11
Electricity price (%)	12.63	12.32	13.02	3.41	12.35	12.93	12.63
Change in unemployment rate	0.32	0.29	0.34	0.08	0.31	0.33	0.31
Green employment (thousand)	11.07	11.03	11.12	1.71	11.05	11.10	11.07
Jobs lost per green job	1.97	1.89	2.03	3.00	1.95	1.98	2.06
Welfare (%)	-0.41	-0.38	-0.45	-0.09	-0.41	-0.42	-0.40
Real Wages (%)	-0.54	-0.50	-0.58	-0.15	-0.53	-0.55	-0.53

Arm (-) Armington elasticities are 33 percent lower

Arm (+) Armington elasticities are 33 percent higher

Ren Sup (-) elasticity of supply of renewable electricity much lower (4)

Dem (-) elasticities of demand for electricity are zero

Dem (+) elasticity of demand for electricity are 100 percent higher

Mob Lab labour is inter-provincially mobile (see text)

5.3 Alternative policy designs

In this section, we consider several alternative policy designs to test the impact of policy design elements on the specific results that were presented above. In order to make our first set of policies comparable, we ensure that each attains the same resulting penetration of renewable electricity (as a percentage of total electricity generation). The policies we consider include (1) the feed-in tariff currently applied in Ontario as our reference scenario (labelled 'OFIT' in Table 11), (2) a feed-in tariff policy as applied in Ontario, but without the domestic content requirement (labelled 'ONDFIT'), (3) a subsidy policy financed by raising the personal income tax (rather than out of the Global Adjustment Mechanism, as described above) (labelled 'SUB'), and (4) a renewable portfolio standard with a domestic content requirement, that requires generators of conventional electricity to hold a renewable energy certificate that must be remitted with each unit of electricity generated (labelled 'DCRRPS'). These certificates are produced by renewable energy generators each time a unit of electricity is generated.

We further consider one policy alternative that, instead of targeting a similar penetration of renewable electricity, targets a similar increase in green employment as the OFIT experiment. This experiment, denoted WSAR provides an employment subsidy to all workers in all renewable sectors. This includes all renewable electricity production and the renewable equipment sector. As in the previous experiment involving a subsidy, we adjust labour income taxes in the same proportion in all other sectors to fund the subsidies paid out.

The removal of the content requirement (see 'ONDFIT' in Table 11 has the expected effect of making the feed-in tariff less distortionary, because it removes a binding constraint. Without the content requirement, the welfare cost of the policy is reduced by about 30 percent relative to the existing policy (which contains a content requirement). Furthermore, removing the content requirement means that less upward pressure is put on electricity prices as a result of the feed-in tariff. By requiring electricity generators to purchase domestic renewable electricity equipment, the content requirement imposes higher electricity costs throughout the economy. Comparing the results of the existing ('OFIT') policy with the same policy with no content requirement ('ONDFIT') shows that the content requirement as represented in our model has a long-run positive impact on 'green' sector employment: employment in this sector is about 30 percent higher with the content requirement than without. However, the higher electricity prices caused by the content requirement result in a reduced real wage, such that the overall unemployment rate increases more when the content requirement is applied in conjunction with the feed-in tariff than when the same policy is applied without the content requirement.

It is possible to determine the effective social cost of renewable energy job creation implied by the presence of the domestic content requirement, by comparing the feed-in tariff policy with and without the content requirement. Adding the content requirement increases the annual welfare cost of the policy by $340 million, and results in an additional 2,620 green jobs. We therefore calculate that the social cost of the domestic content requirement works out to $130,000 per job.

The alternative policy (‘SUB’) where the subsidy is raised through a broad personal income tax rather than a surcharge on electricity consumption does not raise the electricity price, and thus hardly impacts electricity demand. Consistent with theory, we find that the application of a broad tax (the personal income tax) is less distortionary than the narrow electricity tax, such that the welfare cost of the renewable electricity subsidy is estimated at 0.4 percent of consumer income compared to 0.54 percent in the case of the currently applied policy.[29] We also find that the subsidy policy (‘SUB’) produces a smaller impact on the labour market than the currently applied policy (‘OFIT’); unemployment increases by 0.23 percent rather than 0.33 percent under the existing policy.

The renewable portfolio standard policy (‘DCRRPS’) is implemented similarly to the existing Ontario feed-in tariff, except that, rather than fund the feed-in tariff using the Global Adjustment Mechanism (which is a surcharge on all electricity consumption), the renewable portfolio standard requires conventional electricity generators to hold certificates from clean electricity generators. This essentially narrows the funding base for the subsidies from all generation to just conventional generators. The narrowing of the tax base causes additional reductions in demand for conventional electricity, compared to the currently applied policy. As the model results show, however, the broader implications of the change in the funding base are limited, such that this policy is quite similar to the currently applied policy.[30]

[29] Under the subsidy program, more conventional electricity is generated relative to the currently applied policy. If externalities are produced during production of energy, then the net welfare cost of the current policy could actually be below the subsidy policy.

[30] Other differences that exist between renewable portfolio standards and a feed-in tariff (such as the transfer of risk away from generators to the purchaser of electricity in the feed-in tariff) are not modeled.

Table 11: Impact of Alternative Renewable Energy Policies

	OFIT	SUB	ONDFIT	DCRRPS	WSAR
Renewable electricity market share (%)	15.54	15.54	15.54	15.55	12.20
Change in total electricity demand (%)	-2.09	-0.32	-1.61	-2.07	-0.16
Change in electricity price (%)	12.63	0.01	9.73	12.50	0.01
Change in unemployment rate	0.32	0.31	0.25	0.32	0.11
Change in employment (%)	-0.28	-0.31	-0.24	-0.28	-0.07
Change in green employment (thousand employees)	11.07	9.39	8.45	11.03	11.01
Jobs lost in other sectors per green job gained	1.97	2.27	2.09	1.96	1.26
Change in welfare (%)	-0.41	-0.35	-0.29	-0.41	-0.18
Change in welfare ($B)	-1.11	-0.95	-0.77	-1.11	-0.47
Real Wages (%)	-0.54	-0.53	-0.42	-0.54	-0.19

Finally the employment subsidy to all renewable sectors (WSAR) was expected to achieve the green employment target of our reference policy OFIT at lower cost to the economy as a whole. This indeed turns out to be the case. The negative labour market effects of this policy are, less severe than any of the others. Overall employment and real wages fall less and the negative effects outside of the renewable sector are also smaller than any other. Finally, the welfare cost of this policy is also the least of the alternatives we considered. While this policy does not achieve as high a market share for renewable electricity, our analysis suggests that it generates the same increase in green employment at less than half the cost of the OFIT experiment.

6 Discussion and conclusions

In this paper, we have applied a standard computable general equilibrium framework with electricity market disaggregation and labour market detail to examine employment impacts associated with renewable energy support policies. Our study suggests that while these policies can stimulate new employment in 'green' sectors of the economy associated with the manufacture of equipment for renewable electricity generation and the generation of renewable electricity itself, the net impact of such policies on the labour market is likely to be negative. We examine several alternative designs of renewable energy promotion policies and find that all of them had undesirable impacts on labour market participation and unemployment rates.

Our analysis is conducted with a static model, so we do not incorporate potentially important dynamic elements of the policy or broader economic environment. In particular, a potential reason for supporting the manufacture of renewable energy equipment in a region relates to dynamics: if the world market for that equipment is likely to grow quickly over time, and if there are external economies associated with that manufacturing process, then early entrants to the market may gain an advantage over potential later entrants, and secure a lucrative export market. This first-mover advantage may partly explain Denmark's persistently high market-share in renewable equipment manufacturing.

Another potentially important dynamic missing from our static model is technical change. Global studies of renewable energy adoption and climate change mitigation often focus on learning-by-doing and research and development as key elements that reduce the long-run cost of environmental protection. Although these are absent from our model, we feel that they are less important omissions in a provincially-focused energy policy, given the global public good nature of the knowledge stock generated from either of these activities. Nevertheless, it is possible that their omission leads to upward biases in the long-run costs estimated by our model.

Our analysis should be placed in context. In particular, it does not necessarily suggest that renewable energy policies should not be employed: if environmental benefits from pursuing additional renewable electricity generation exceed costs, such a policy may still be socially desirable (albeit, in a second-best setting where more efficient policies like emission taxes are not considered). Instead, our analysis focuses on quantifying the broader labour market impacts of renewable energy promotion policies, and suggests that they may not create net new employment in an economy, contrary to the claims of some policy makers. In the absence of such positive employment benefits, broad market-based emission reduction policies such as cap and trade systems or carbon taxes are likely to reach environmental goals at much less overall cost to the economy.

A Model

This Appendix provides an algebraic summary of the model used for the analysis. A description of all sets, parameters, and variables included in the model is included in the tables that follow the algebraic model.

A.1 Zero-profit conditions

1. Production of goods excluding renewable electricity $(i \notin n, m)$

$$\begin{aligned}\Pi_{i,r} \;=\;& (1-t^Y_{i,r})\left(\theta^F_{i,r}(p_{FX})^{1-\sigma^T} + (1-\theta^F_{i,r})(p^Y_{i,r})^{1-\sigma^T}\right)^{\frac{1}{1-\sigma^T}} \\ & -\left(\theta^V_{i,r}\left(\left(\theta^K_{i,r} r^{1-\sigma^V} + (1-\theta^K_{i,r})(w_r)^{1-\sigma^V}\right)^{\frac{1}{1-\sigma^V}}\right)^{1-\sigma^S}\right. \\ & \left. +(\sum_j \theta^j_{i,r}((1+t^A_{i,j,r})p^A_{j,r})^{1-\sigma^S})\right)^{\frac{1}{1-\sigma^S}} \le 0\end{aligned}$$

2. Production of renewable electricity using domestic capital $(i \in d)$

$$\begin{aligned}\Pi_{i,r} = (1-t^Y_{i,r})(1+s^F_r)(1+s^{DM}_r)p^Y_{i,r} \\ -\Bigg(\theta^R_r(p^R_r)^{1-\sigma^R} \\ +(1-\theta^R_r)\Bigg(\Bigg(\theta^V_{i,r}\left(\left(\theta^K_{i,r}(P^Y_{m,r})^{1-\sigma^V} + (1-\theta^K_{i,r})(w_r)^{1-\sigma^V}\right)^{\frac{1}{1-\sigma^V}}\right)^{\rho^Z} \\ +(\sum_j \theta^j_{i,r}((1+t^A_{i,j,r})p^A_{j,r})^{1-\sigma^Z})\Bigg)^{\frac{1}{1-\sigma^R}}\Bigg)^{1-\sigma^R}\Bigg)^{\frac{1}{1-\sigma^R}} \le 0\end{aligned}$$

3. Production of renewable electricity using foreign capital ($i \in f$)

$$
\begin{aligned}
\Pi_{i,r} = (1 - t^Y_{i,r})(1 + s^F_r)(1 - t^{FM}_r)p^Y_{i,r} \\
- \Bigg(\theta^R_r (p^R_r)^{1-\sigma^R} \\
+ (1 - \theta^R_r) \Bigg(\Bigg(\theta^V_{i,r} \Bigg(\Bigg(\theta^K_{i,r} (P_{FX})^{1-\sigma^V} + (1 - \theta^K_{i,r})(w_r)^{1-\sigma^V} \Bigg)^{\frac{1}{1-\sigma^V}} \Bigg)^{\rho^Z} \\
+ (\sum_j \theta^j_{i,r}((1 + t^A_{i,j,r})p^A_{j,r})^{1-\sigma^Z}) \Bigg)^{\frac{1}{1-\sigma^R}} \Bigg)^{1-\sigma^R} \Bigg)^{\frac{1}{1-\sigma^R}} \leq 0
\end{aligned}
$$

4. Armington ($i \notin e$)

$$
\begin{aligned}
\Pi^A_{i,r} = \theta^{RX}_{i,r} P_{FX} + (1 - \theta^{RX}_{i,r}) P^A_{i,r} \\
- \left(\theta^{IM}_{i,r} (P_{FX})^{\rho^A} + (1 - \theta^{IM}_{i,r}) \left(\left(\sum_s \theta^P_{i,r,s} (P^Y_{i,s})^{\rho^P} \right)^{\frac{1}{\rho^P}} \right)^{\rho^A} \right)^{\frac{1}{\rho^A}} \leq 0
\end{aligned}
$$

5. Armington ($i \in e$)

$$
\begin{aligned}
\Pi^A_{i,r} = (1 - t^F_r) \left(\theta^{RX}_{i,r} P_{FX} + (1 - \theta^{RX}_{i,r}) P^A_{i,r} \right) \\
- \left(\theta^{IM}_{i,r} (P_{FX})^{\rho^A} + (1 - \theta^{IM}_{i,r}) \left(\left(\sum_s \theta^P_{i,r,s} (P^Y_{i,s})^{\rho^P} \right)^{\frac{1}{\rho^P}} \right)^{\rho^A} \right)^{\frac{1}{\rho^A}} \leq 0
\end{aligned}
$$

6. Household consumption aggregate

$$
\Pi^C_r = p^C_r - \left(\Pi_i \left(\theta^C_{i,r} \left(p^A_{i,r} (1 + t^C_{i,r}) \right)^{1-\sigma^C} \right) \right)^{\frac{1}{1-\sigma^C}} \leq 0
$$

7. Investment

$$
\Pi^I_r = p^I_r - \left(\Pi_i \left(\theta^I_{i,r} \left(p^A_{i,r} (1 + t^I_{i,r}) \right)^{1-\sigma^I} \right) \right)^{\frac{1}{1-\sigma^I}} \leq 0
$$

8. Government consumption

$$
\Pi^G_r = p^G_r - \left(\Pi_i \left(\theta^G_{i,r} \left(p^A_{i,r} (1 + t^G_{i,r}) \right)^{1-\sigma^G} \right) \right)^{\frac{1}{1-\sigma^G}} \leq 0
$$

A.2 Market clearance conditions

1. Labour

$$\bar{L}_r(1 - U_r) = \sum_i Y_{i,r} \frac{\partial \Pi^Y_{i,r}}{\partial w_r}$$

2. Capital

$$\sum_r \bar{K}_r = \sum_{r,i} Y_{i,r} \frac{\partial \Pi^Y_{i,r}}{\partial r}$$

3. Natural resources

$$\bar{R}_r = Y_{n,r} \frac{\partial \Pi^Y_{n,r}}{\partial p^R_r}$$

4. Foreign exchange

$$\bar{FS} + \sum_{r,i} Y_{i,r} \frac{\partial \Pi^Y_{i,r}}{\partial p_{FX}} = \sum_{r,i} A_{i,r} \frac{\partial \Pi^A_{i,r}}{\partial p_{FX}}$$

5. Output for domestic consumption

$$Y_{i,r} \frac{\partial \Pi^Y_{i,r}}{\partial p^Y_{i,r}} = A_{i,r} \frac{\partial \Pi^A_{i,r}}{\partial p^Y_{i,r}}$$

6. Armington aggregate commodity

$$A_{i,r} \frac{\partial \Pi^A_{i,r}}{\partial p^A_{i,r}} = Y_{i,r} \frac{\partial \Pi^Y_{i,r}}{\partial p^A_{i,r}} + C_r \frac{\partial \Pi^C_r}{\partial p^A_{i,r}} + \bar{I}_r \frac{\partial \Pi^I_r}{\partial p^A_{i,r}} + \bar{G}_r \frac{\partial \Pi^G_r}{\partial p^A_{i,r}}$$

A.3 Income balance

1. Household

$$
\begin{aligned}
C_r p_r^C &= w_r \bar{L}_r (1 - U_r) \\
&+ r \bar{K}_r \\
&+ p_r^R \bar{R}_r \\
&- \bar{I}_r p_r^I \\
&- \bar{G}_r p_r^G \\
&+ \bar{FS} p_{FX} \\
&+ \sum_i Y_{i,r} \left(\frac{\partial \Pi_{i,r}}{\partial p_{i,r}^Y} p_{i,r}^Y + \frac{\partial \Pi_{i,r}}{\partial p_{FX}} p_{FX} \right) t_{i,r}^Y \\
&+ \sum_{i,j} Y_{i,r} \left(\frac{\partial \Pi_{i,r}}{\partial p_{j,r}^A} p_{j,r}^A \right) t_{i,j,r}^A \\
&+ C_r \frac{\partial \Pi_r^C}{\partial p_{i,r}^A} p_{i,r}^A t_{i,r}^C \\
&+ I_r \frac{\partial \Pi_r^I}{\partial p_{i,r}^A} p_{i,r}^A t_{i,r}^I \\
&+ G_r \frac{\partial \Pi_r^G}{\partial p_{i,r}^A} p_{i,r}^A t_{i,r}^G
\end{aligned}
$$

A.4 Side constraints

1. Feed-in tariff revenue neutrality

$$
s_r^F \sum_n p_{n,r}^Y Y_{n,r} = A_{i,r} \frac{\partial \Pi_{e,r}^A}{\partial p_{e,r}^Y} p_{e,r}^Y t_r^F
$$

2. Domestic content requirement revenue neutrality

$$
s_r^{DM} p_{d,r}^Y Y_{d,r} = t_r^{FM} p_{f,r}^Y Y_{f,r}
$$

3. Domestic content requirement

$$
Y_{d,r}(1 - \zeta) \geq Y_{f,r} \zeta
$$

4. Unemployment

$$
\frac{w_r}{p_r^C} = \left(\frac{U_r}{U_r^0} \right)^{\psi}
$$

Table 12: Sets

Symbol	Description
i	Sector/commodity
j	Aliased with i
r	Region
s	Aliased with r
$n \in j$	Renewable electricity production
$d \in n$	Renewable electricity produced with domestic capital
$f \in n$	Renewable electricity produced with foreign capital
$m \in j$	Domestic renewable equipment manufacturing
$e \in i$	Electricity commodity

Table 13: Activity levels

Symbol	Description
$Y_{i,r}$	Production in sector i in region r
$A_{i,r}$	Armington aggregate for good i in region r
C_r	Household consumption in region r
$\bar{G}_r$	Government consumption in region r
$\bar{I}_r$	Investment consumption in region r
U_r	Unemployment rate in region r

Table 14: Prices and taxes

Symbol	Description
p_{FX}	Price of foreign exchange
$p^Y_{i,r}$	Output price of good from sector i in region r for domestic consumption
r	Price of capital services
w_r	Wage rate in region r
$p^A_{i,r}$	Price of Armington good i in region r
p^R_r	Rental price of non-fossil sites in region r
p^C_r	Aggregate household demand price in region r
p^I_r	Aggregate investment demand price in region r
p^G_r	Aggregate government demand price in region r
$t^Y_{i,r}$	Tax rate on outputs from sector i in region r
$t^A_{i,j,r}$	Tax rate on inputs of good j to sector i in region r
s^F_r	Feed-in tariff subsidy on renewable electricity generation in region r
t^F_r	Endogenous tax ('Global Adjustment') on electricity in region r
s^{DM}_r	Endogenous subsidy on renewable electricity with domestic capital in region r
t^{FM}_r	Endogenous tax on renewable electricity with foreign capital in region r

Table 15: Cost shares

Symbol	Description
$\theta^F_{i,r}$	Benchmark value share of output from sector i in region r that is exported
$\theta^V_{i,r}$	Benchmark value share of capital and labour in production for sector i in region r
$\theta^K_{i,r}$	Benchmark value share of capital in the value added nest for sector i in region r
$\theta^j_{i,r}$	Benchmark value share of intermediate input j in production for sector i in region r
θ^R_r	Benchmark value share of natural resource inputs in non-fossil energy in region r
θ^W_r	Benchmark value share of value added in total industry output less the remuneration to the fixed resource in the non-fossil energy sector in region r
$\theta^{RX}_{i,r}$	Benchmark value share of re-exports of commodity i in region r
$\theta^{IM}_{i,r}$	Benchmark value share of international imports in domestic consumption plus re-exports of commodity i in region r
$\theta^P_{i,r,s}$	Benchmark value share of output from province s in the domestic consumption by province r of good i

Table 16: Endowments

Symbol	Description
$\bar{FS}$	Foreign savings
$\bar{L}_r$	Labour supply in region r
$\bar{K}_r$	Capital endowment in region r
$\bar{R}_r$	Renewable resource sites endowment in region r
U^0_r	Benchmark unemployment rate in region r

References

Armington, P. (1969). A theory of demand for products distinguished by place of production. *IMF Staff papers 17*, 159–176.

Ballard, C., J. Shoven, and J. Whalley (1985). General equilibrium computations of the marginal welfare costs of taxes in the united states. *The American Economic Review 75*(1), 128–138.

Blanchflower, D. and A. Oswald (1990). *The wage curve*. The MIT Press.

Böhringer, C. (1998). The synthesis of bottom-up and top-down in energy policy modeling. *Energy economics 20*(3), 233–248.

Bovenberg, A. (1995). Environmental taxation and employment. *De Economist 143*(2), 111–140.

Bovenberg, A. and R. de Mooij (1994). Environmental levies and distortionary taxation. *The American Economic Review 84*(4), 1085–1089.

Bovenberg, A. and F. van der Ploeg (1996). Optimal taxation, public goods and environmental policy with involuntary unemployment. *Journal of Public Economics 62*(1-2), 59–83.

Bovenberg, A. and F. Van der Ploeg (1998). Consequences of environmental tax reform for unemployment and welfare. *Environmental and Resource Economics 12*(2), 137–150.

Bovenberg, A. and F. Van Der Ploeg (1998). Tax reform, structural unemployment and the environment. *Scandinavian Journal of Economics 100*(3), 593–610.

Butler, L. and K. Neuhoff (2008). Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. *Renewable Energy 33*(8), 1854–1867.

Carbone, J. and V. Smith (2008). Evaluating policy interventions with general equilibrium externalities. *Journal of Public Economics 92*(5), 1254–1274.

DSS Management Consultants, Inc and RWDI Air Inc (2005). Cost benefit analysis: Replacing Ontario's coal-fired electricity generation. Technical report, Ontario Ministry of Energy.

Fischer, C. and L. Preonas (2010). Combining policies for renewable energy: Is the whole less the sum of its parts. *International Review of 4*, 51–92.

Goulder, L. (1995). Environmental taxation and the double dividend: A reader's guide. *International Tax and Public Finance 2*(2), 157–183.

Government of Ontario (2009). Green Energy and Green Economy Act. Policy statement, Government of Ontario.

Government of Ontario (2011). Ontario's Long Term Energy Plan. Technical report, Government of Ontario.

Hillebrand, B., H. Buttermann, J. Behringer, and M. Bleuel (2006). The expansion of renewable energies and employment effects in Germany. *Energy Policy 34*(18), 3484–3494.

Hutton, J. and A. Ruocco (1999). Tax reform and employment in europe. *International Tax and Public Finance 6*(3), 263–287.

Johnson, E. (2010). The price elasticity of supply of renewable electricity generation: Evidence from state renewable portfolio standards. *University of Michigan Working Paper*.

Küster, R., I. Ellersdorfer, and U. Fahl (2007). A CGE analysis of energy policies considering labor market imperfections and technology specifications. Working Paper 73, Fondazione Eni Enrico Mattei.

Lehr, U., J. Nitsch, M. Kratzat, C. Lutz, and D. Edler (2008). Renewable energy and employment in Germany. *Energy Policy 36*(1), 108–117.

Mitchell, C., D. Bauknecht, and P. Connor (2006). Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany. *Energy Policy 34*(3), 297–305.

Ostro, B. and L. Chestnut (1998). Assessing the health benefits of reducing particulate matter air pollution in the United States. *Environmental Research 76*(2), 94–106.

Paltsev, S., J. Reilly, H. Jacoby, R. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian, and M. Babiker (2005). The MIT emissions prediction and policy analysis (EPPA) model: version 4. Technical report, MIT Joint Program on the Science and Policy of Global Change.

Pissarides, C. (2000). *Equilibrium unemployment theory*. the MIT press.

Ragwitz, M., W. Schade, B. Breitschopf, R. Walz, N. Helfrich, M. Rathmann, G. Resch, C. Panzer, T. Faber, and R. Haas (2009). The impact of renewable energy policy on economic growth and employment in the european union. *Brussels, Belgium: European Commission, DG Energy and Transport*.

Rutherford, T. (2002). Lecture notes on constant elasticity functions. *University of Colorado*.

Schneider, K. (1997). Involuntary unemployment and environmental policy: The double dividend hypothesis. *Scandinavian Journal of Economics 99*(1), 45–59.

Scholz, C. (1998). Involuntary unemployment and environmental policy: The double dividend hypothesis: A comment. *Scandinavian Journal of Economics 100*(3), 663–664.

Shapiro, C. and J. Stiglitz (1984). Equilibrium unemployment as a worker discipline device. *The American Economic Review 74*(3), 433–444.

Solow, R. (1979). Another possible source of wage stickiness. *Journal of Macroeconomics 1*(1), 79–82.

Sue Wing, I. (2008). The synthesis of bottom-up and top-down approaches to climate policy modeling: Electric power technology detail in a social accounting framework. *Energy Economics 30*(2), 547–573.

Williams, R. (2002). Environmental tax interactions when pollution affects health or productivity. *Journal of Environmental Economics and Management 44*(2), 261–270.