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**Article (Published version)  
(Refereed)**

**Original citation:** Kuralbayeva, Karlygash (2018) *Unemployment, rural-urban migration and environmental regulation*. [Review of Development Economics](#), 22 (2). pp. 507-539. ISSN 1363-6669  
DOI: [10.1111/rode.12360](https://doi.org/10.1111/rode.12360)

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**REGULAR ARTICLE**

# Unemployment, rural–urban migration and environmental regulation

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**Funding information**

Financial support by the Global Green Growth Institute (GGGI), the Grantham Foundation for the Protection of the Environment and the UK Economic and Social Research Council (ESRC) through the Centre for Climate Change Economics and Policy

**Abstract**

This paper develops a general equilibrium model that incorporates specific features pertaining to developing countries: a large informal sector and rural–urban migration. A calibrated version of the model is used to study the effects of energy tax changes and a reduction in agricultural-sector energy subsidies on labor market outcomes. The results indicate that the incidence of energy taxes is partly shifted on to the rural sector through rural–urban migration. The results thus highlight the importance of modeling the features particular to developing countries and the economic general equilibrium effects when assessing the impact of environmental taxation in those countries.

## 1 | INTRODUCTION

A large number of studies have analyzed the incidence of carbon taxes in developed countries, and a subset of these studies have looked at how carbon tax policies affect unemployment. Nonetheless, general equilibrium studies of environmental taxation, based on unique institutional and economic characteristics of developing countries, are limited. Special features of developing economies, which include “dual” economies with modern and traditional sectors, or three-sector economies with a traditional rural sector and an urban sector (characterized by both a formal and informal sector), suggest that models from studies of developed countries are not appropriate to examine the employment and wage impacts of green tax policies. The policy guidelines derived from existing studies in developed countries are likely to be misleading for developing countries, as they do not take into account economic conditions that are specific to developing countries.

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This paper develops a dual economy model, which is an extension of Satchi and Temple (2009) to analyze the effects of energy taxes in general equilibrium. The model features three sectors: urban formal, urban informal,<sup>1</sup> and rural agricultural. The search and matching frictions following Pissarides (2000) form a distinction between formal, or “regulated,” jobs and informal, or “unregulated,” jobs. This entails that workers in the informal sector search for jobs in the formal sector, with the unemployment rate being defined as the proportion of the population that is self-employed in the informal sector. The income of the unemployed comprises unemployment benefits and income from self-employment in the informal sector.

I solve the model numerically and choose parameter values to match some key aspects of labor markets in Mexico. I find that modeling key features of developing countries, namely rural–urban migration, can lead to qualitatively different conclusions about the incidence of higher energy taxation on poverty in developing countries. As in the simplified version of the main model, even though agricultural workers do not pay energy or labor taxes, they still bear the burden of environmental taxation through reduced wages. A potential explanation for this wage reduction is as follows: (a) when unemployment benefits and income from self-employment in the informal sector are fixed in real terms, the urban sector reduces demand for labor due to higher energy taxes and the agricultural sector absorbs some of the increased number of unemployed people; or (b) when unemployment benefits are proportional to the after-tax income of urban workers and labor taxes are evaded in informal sector, as environmental taxation imposes a heavy tax burden on the unemployed, the unemployed try to escape the brunt of higher taxation by either searching for jobs more intensively or migrating into the urban area, which pushes wages down in the rural area.

I also find that fixing the energy tax in the agricultural sector while increasing the energy tax imposed in the urban area results in a higher reduction in the earnings of rural-sector workers than when energy taxes change universally in the economy. This is because the former policy is associated with a relatively higher burden on the urban sector than the latter, resulting in a higher outflow of labor into the rural area, which leads to a higher decline in the earnings of workers in the agricultural sector. Furthermore, simulations of the model with energy subsidies in the agricultural sector also suggest that higher energy subsidies to protect the incomes of rural workers from the adverse effects of environmental taxation in the urban area can be counter-productive. Specifically, a higher level of energy subsidy provision to the rural sector is associated with a larger decline in earnings of rural workers when the urban sector is subject to environmental regulation. Intuitively, larger subsidies create more budgetary pressure and less room for the government to reduce payroll taxes, which ultimately determines whether such a reduction in labor taxes can offset the adverse effects of higher energy taxes on labor productivity and thus lead to a reduction in unemployment. If unemployment is reduced by less, more people migrate to the rural area, pushing wages down and increasing the incidence of poverty.

Finally, the results indicate that the energy intensity of the urban sector is important for the size of the potential double-dividend effects, and consequently for how rural sector wages are affected by environmental regulation. If the urban sector is highly labor-intensive, declines in energy demand due to higher energy taxes impose a smaller tax burden and the effects of environmental regulation are less pronounced. As a result, the prospects for a sizable reduction in unemployment are much lower in the economy, resulting in a larger inflow of workers into the rural area and therefore a larger decline in agricultural wages. Conversely, with a lower energy intensity of the agricultural sector and relatively higher energy intensity of the manufacturing (urban) sector, environmental regulation is associated with a higher reduction in payroll taxes and consequently higher employment, leading to lower migration and a decline in rural sector wages.

This paper makes two main contributions. First, it demonstrates the importance of modeling special features of developing countries when analyzing the tax incidence of carbon taxes in developing

countries. Looking only at the effects of environmental regulation on the sector that is subject to regulation would underestimate the potential adverse spillover effects on other sectors of the economy through migration patterns. For instance, the reduction in agricultural-sector wages due to urban-sector taxation can be sizable and comparable with the effects of regulation on incomes of the unemployed. Simulations of the benchmark model under the assumptions that incomes of the unemployed are proportional to the after-tax urban wage and that labor taxes are evaded in the informal sector suggest that a doubling of the energy tax rate from its baseline value reduces the income of the unemployed by 4.48 percent and rural-sector incomes by 2.77 percent. Therefore, the effects of environmental regulation in developing countries have to be analyzed using a different theoretical framework than conventional models suggest. Even though the focus of this paper is on the effects of energy taxes, similar issues arise with analyzing other tax incidences in developing countries.

Second, the paper develops a tractable framework that incorporates features that are specific to developing countries. This framework highlights an important rural–urban migration channel through which environmental regulation can yield other dividends that are important in assessing the overall welfare effects of regulation in developing countries. For instance, in many developing countries facing large rural–urban migration, the inability of city authorities to offer housing and basic public services to these migrants leads to the formation of slums, deterioration of living conditions, congestion, and environmental risks. In such circumstances, a larger rural population associated with higher energy taxes could be beneficial and could offset the costs of environmental taxation in terms of lower rural wages. I do not perform welfare analysis in this paper, but this simple framework can be extended to study the welfare effects of green tax reforms in developing countries by taking these general equilibrium effects into account. Another potential extension of the model could be to allow workers to have different productivity levels, which would facilitate studying the distributional implications of green tax policies.

The rest of the paper is organized as follows. Section 2 presents the structure of the model. Section 3 explains the parameterization of the model. Section 4 discusses the simulation results. In Section 5, I test the sensitivity of the baseline results to changes in the values of some parameters, as well as the functional form of the production function. Section 6 considers three extensions to the core model: the first allows payroll taxes paid by employees; the second makes an explicit distinction between the unemployed and the self-employed in the urban sector; and the third endogenizes the job destruction rate. Section 7 concludes.

## 2 | MODEL

The paper develops a general equilibrium search model in the style of Diamond, Mortensen and Pissarides (DMP: Diamond, 1971; Mortensen and Pissarides, 1994), with a large informal sector and potential for rural–urban migration, in a setting with a polluting production factor and environmental taxes.<sup>2</sup> The economy comprises two regions/sectors: urban and rural/agricultural, denoted by  $m$  and  $a$ , respectively. The urban sector is characterized by search and matching frictions, which mean that unemployment exists in equilibrium.<sup>3</sup> This in turn partitions the urban sector into informal (unregistered, assumed to be self-employed) and formal (registered) production activities, and I use the term “unemployed” to refer to self-employment in the informal sector. The size of the population is normalized to 1 and can be decomposed as follows:

$$L_a + (1 - u)L_m + uL_m = 1, \quad (1)$$

where  $L_a$  and  $L_m$  are the sizes of agricultural and urban sectors respectively, and  $u$  is the fraction of informal-sector workers in the urban labor force. There is scope for migration between urban and rural areas, so that workers can allocate themselves between the two sectors. Once workers migrate from rural areas, they first enter the informal urban sector, from which they search for jobs in the formal sector.

There are two types of firms: agricultural-sector firms and registered urban-sector firms. Firms operating in rural areas produce goods for consumption in that region. The rural (agricultural) sector is assumed to be perfectly competitive and is characterized by full employment. I assume that the economy imports both energy and capital at given world prices and that both are inputs into registered production activities. In the informal sector, workers are assumed to be self-employed and engage in low-productivity labor-intensive tasks. Goods from formal and informal production activities are assumed to be perfect substitutes.

Consistent with the Harris–Todaro model (Harris and Todaro, (1970), I assume that all workers are risk neutral. Finally, I assume that revenues collected from taxing energy and labor are used to provide general government goods and transfers to the unemployed.

The model uses the DMP framework of wage bargaining, instead of the Burdett and Judd (1983) and Burdett and Mortensen (1998) framework for equilibrium labor market search, which is based on the wage posting theory of wage determination. I use the DMP approach as opposed to the Burdett–Mortensen approach as I aim to understand how environmental policies affect labor market flows and unemployment, and the DMP matching framework is an appropriate framework for this analysis. In addition, I exploit the fact that environmental taxes affect the outside option of the bargainers (which is key in the Nash bargaining process) differently than other taxes. And finally, some evidence suggests that developing countries have a long tradition of determining wages and working arrangements through collective bargaining (Lamarche, 2015), despite considerable heterogeneity in terms of the coverage rates. For instance, in the 1970 and 1980s, industry-wide collective bargaining was widespread in Latin American countries such as Argentina, Mexico, and Venezuela, but currently bargaining is shifting towards decentralization, allowing negotiations at the firm level. Collective bargaining agreements affect less than 15 percent of workers in Brazil, Chile, Colombia, and Peru and more than 70 percent in Argentina, Bolivia, and Uruguay.

## 2.1 | Agricultural sector

Agricultural output is produced using capital (land), labor, and energy,

$$Y_a = A_a K_a^{\gamma_1} L_a^{\gamma_2} E_a^{1-\gamma_1-\gamma_2}, \quad (2)$$

and production per worker is given by

$$g_a(k_a, e_a) = \frac{Y_a}{L_a} = A_a k_a^{\gamma_1} e_a^{1-\gamma_1-\gamma_2}. \quad (3)$$

Agricultural workers are paid a wage  $w_a$ , and derive positive utility from living in a rural area,  $\chi_a > 0$ . The firms import energy at given international energy prices (the small open economy assumption) and pay taxes according to their energy use. The agricultural sector is assumed to be perfectly competitive, which implies that

$$w_a = g(k_a, e_a) - r_a k_a - p_E(1 + \tau_E)e_a, \quad (4)$$

with return on fixed capital given by

$$r_a = g'_{k_a}(k_a, e_a), \quad (5)$$

in which the demand for energy in the agricultural sector is

$$g'_{e_a}(k_a, e_a) = p_E(1 + \tau_E). \quad (6)$$

I assume there are no search frictions in the agricultural sector. Even though it may seem strong, there are several arguments based on features of agricultural unemployment in developing countries that support this assumption. Firstly, agriculture in developing countries is still very labor-intensive, so there is high demand for labor in agricultural production compared to other sectors. Commercial agriculture (agricultural production by firms for domestic or foreign markets) often requires both a long-term stable workforce and temporary labor (seasonal, subcontracted, and/or migrant). Mass recruitment of workers is much more common than individual job postings and occurs in designated areas known to the workers (e.g. hiring casual labor from marketplaces or other local gathering places). These factors make it relatively easy for workers from other sectors to find jobs in the agricultural sector, at little cost (per vacancy) to the firm (Cheong and Jansen, 2013). Also, agricultural jobs in developing countries tend to require fewer specific skills and qualifications compared to formal sector jobs. Although jobs in commercial agriculture are becoming more specialized due to mechanization, the nature of the tasks involved (e.g. tilling, planting, and harvesting) means that training happens on the job. Therefore, search frictions due to a mismatch in skills required for the job and the skills that job-seekers possess are unlikely (Cheong and Jansen, 2013).

## 2.2 | The urban labor market

Urban sector goods can be produced either from formal or informal activities. Labor market search and matching frictions form the distinction between production activities of formal and informal goods. The production process in the formal sector uses labor, (imported) capital and (imported) energy, while in the informal sector workers are engaged into low-productivity, labor-intensive tasks.

### 2.2.1 | Matching, flow equilibrium and Beveridge curve

In formal labor markets, the number of new matches between job searchers and vacancies is represented by the constant returns to scale matching function:

$$m = m(suL_m, vL_m, M) = M(suL_m)^\gamma (vL_m)^{1-\gamma}, \quad (7)$$

where  $uL_m$  denotes the number of unemployed workers,  $s$  is the average search intensity,  $vL_m$  is the number of open vacancies, and  $M$  denotes matching efficiency. The probability of a vacancy being filled is

$$q \equiv \frac{m}{vL_m} = M \left( \frac{su}{v} \right)^\gamma = M\theta^{-\gamma}, \quad (8)$$

where

$$\theta = \frac{v}{su} \quad (9)$$

measures labor market tightness and  $1/q$  the expected duration of the vacancy. Note that  $q(\theta)$  is a decreasing function of  $\theta$ , and I define  $\varepsilon_\theta \equiv -q'(\theta)\theta/q > 0$ . I assume that the match between worker and firm in the formal sector is destroyed with an exogenous Poisson rate  $\lambda$ . Thus the law of motion for the number of unemployed satisfies

$$u\dot{L}_M = L_m(\lambda(1-u) - su\theta q(\theta)), \quad (10)$$

where  $L_m\lambda(1-u)$  is the number of separations and  $L_msu\theta q(\theta)$  is the number of hires. In the steady state, the inflows and outflows of employment in the informal sector must balance:

$$\lambda(1-u) = su\theta q(\theta), \quad (11)$$

which determines the relationship between the unemployment rate and the rate of vacancies (labor market tightness), that is, the Beveridge curve.

## 2.2.2 | Workers' expected gains

In the informal sector, each worker receives  $z+b-\sigma(s;z)$ , where  $z$  denotes the labor productivity (output) of each worker,<sup>4</sup>  $b$  denotes unemployment benefits, and  $\sigma(s;z)$  represents formal job search costs which depend on search intensity  $s$  and labor productivity  $z$ . I distinguish between different arrangements concerning the taxation of unemployment benefits and the characteristics of the informal labor market, and discuss the specification of  $b$  and  $z$  in Section 2.2.5.

$U$  and  $W$  denote the value to the worker of being unemployed (and searching for a formal job) and being employed in a formal job, respectively. There is an incentive to search for jobs in the formal segment of the urban sector, as the *ex post* value of working in formal jobs is the highest. Informal sector workers decide how actively they search for a formal sector job. As discussed in Pissarides (2000), different levels of search intensity alter the probability of being matched with a vacancy. In particular, a worker  $i$ , who searches for a job with intensity  $s_i$ , when all other workers search with the same level of intensity  $s$ , has a matching rate proportional to his relative search intensity  $s_i/s$ :

$$\bar{q}_i = \frac{s_i}{suL_m} m(suL_m, vL_m) = s_i q \theta = s_i M \theta^{1-\gamma}. \quad (12)$$

Following Satchi and Temple (2009), I determine the optimal level of search intensity for worker  $i$  by equating the worker's marginal search costs ( $\sigma_{s_i}$ ) to the expected benefits  $d\bar{q}_i/ds_i(W - U_i)$  of job search, and then by imposing symmetry:

$$\sigma'_s(s; z) = \theta q(W - U), \quad (13)$$

with  $sq\theta$  the probability of finding a job for every job searcher.

A worker's expected utility of being unemployed and employed in a formal job can be defined as

$$rU = z + b - \sigma + sq\theta(W - U), \quad (14)$$

$$rW = w_m + \lambda(U - W + P), \quad (15)$$

where  $P$  is a severance payment paid by the firm to the departing employee.

### 2.2.3 | Firms and labor demand

I denote by  $V$  and  $J$  the value to the firm of holding a vacancy and a filled job, respectively. Each firm pays a flow cost  $c$  to post a vacancy. Once it is filled, the firm employs one worker paid the wage  $w_m$ , rents capital  $k_m$  from international capital markets, and imports the polluting production factor energy  $e_m$  at an exogenously given price  $p_E$ . Firms are liable to energy and payroll taxes. Jobs are destroyed each period at an exogenous rate  $\lambda$ , at which point the worker returns to the informal sector. The firm makes a severance payment  $P$  to the departing employee, which is an important feature of labor markets in developing countries such as Mexico.

Each firm produces the output  $A_m f(k_m, e_m)$ , where  $A_m$  is a total factor productivity parameter and  $f(k_m, e_m)$  is the intensive form of production technology, with capital,  $k_m$ , and energy utilized per worker,  $e_m$ . Under these assumptions,

$$rJ = A_m f(k_m, e_m) - (1 + \tau_L)w_m - r_m k_m - p_E(1 + \tau_{e,m})e_m - \lambda(J + P - V), \quad (16)$$

$$rV = -c + q(J - V). \quad (17)$$

The first-order conditions for the capital–labor ratio and energy–labor ratio are

$$A_m f'_k(k_m, e_m) = r_m, \quad A_m f'_e(k_m, e_m) = p_E(1 + \tau_{e,m}), \quad (18)$$

which imply that

$$rJ = y(k_m, e_m) - (1 + \tau_L)w_m - \lambda(J + P - V), \quad (19)$$

where

$$y(k_m, e_m) \equiv A_m f(k_m, e_m) - r_m k_m - p_E(1 + \tau_{e,m})e_m.$$

Free entry into the creation of vacancies implies  $V = 0$ , and states that in equilibrium, the expected profit from a job has to cover the expected cost of a vacancy:

$$J = \frac{c}{q}. \quad (20)$$

By combining equations (19) and (20) to eliminate  $J$ , and by assuming that hiring costs are a fixed proportion  $\nu$  of the producer wage in the formal sector,  $c = \nu(1 + \tau_L)w_m$ , we obtain the following equation:

$$y(k_m, e_m) = (1 + \tau_L)w_m \left[ 1 + (\lambda + r) \frac{\nu}{q} \right] + \lambda P, \quad (21)$$

which states that output per worker net of capital and energy costs equals total labor costs (including wage costs), the expected capitalized value of hiring costs, and expected severance payments.

### 2.2.4 | Wage determination

Search and matching frictions in the formal urban sector imply that each match gives rise to a surplus that is shared between the firm and its worker through a generalized Nash bargaining process.



Using the parameter  $\beta$  to index the worker's bargaining power, a wage bargain in the formal sector determines wages for formal urban jobs according to

$$w_m = \arg \max (W - U)^\beta (J - V)^{1-\beta}, \quad (22)$$

which yields the first-order condition

$$(1 - \beta)(1 + \tau_L)(W - U) = \beta J. \quad (23)$$

Using (14), (15) and (20) to eliminate  $W - U$  and  $J$  from (23), we obtain the following expression for the wage rate:

$$\frac{w_m - (z + b - \sigma)}{w_m} + \frac{\lambda P}{w_m} = \frac{\beta}{1 - \beta} v \left( \frac{r + \lambda}{q} + s\theta \right). \quad (24)$$

The higher the bargaining power of workers ( $\beta$ ), the larger is formal sector income (including expected severance pay). A higher interest rate ( $r$ ), a larger separation rate ( $\lambda$ ), or a tighter labor market ( $\theta$ ) raises the rents from a job match and thus raises the wage.

We can also rewrite the equation that determines the optimal level of search intensity, using (13), (20) and (23):

$$\sigma'_s = \frac{\beta}{1 - \beta} \theta v w_m. \quad (25)$$

## 2.2.5 | Unemployment benefits and informal sector labor productivity

A large number of different models have been developed to examine the potential for a double dividend. The existing literature suggests that in models with involuntary unemployment, the tax burden has to be shifted away from workers to other groups in society (e.g. recipients of income transfers) for a double dividend in employment to potentially arise.<sup>5</sup> Within the context of a search model, the outside option of the workers (the income of the unemployed) affects the bargaining position of workers and thus the equilibrium wages. This in turn impacts hiring decisions and determines the equilibrium unemployment in the economy. Therefore the effect of environmental taxation on the income of the unemployed can influence the scope for a double dividend (see, for example, Koskela and Schob, 1999; Bovenberg and van der Ploeg, 1998).

Following Bovenberg and van der Ploeg (1998), I consider two different assumptions on the income of the unemployed: fixed benefits and fixed informal-sector income ( $b = \bar{b}$  and  $z = \bar{z}$ ); and unemployment benefits and informal-sector income represent some fraction of formal sector earnings, such that  $b = \pi_b w_m$  and  $z = \pi_z (1 + \tau_L) w_m$ . The latter indexation rule suggests that labor taxes are evaded in the informal sector, but energy taxes are not. This is a plausible assumption, since pre-existing taxes such as taxes on labor tend to be easier to evade than certain forms of environmental taxes, as I discuss below in the context of Mexico. For the discussion of the simulation results, I refer to the first assumption on the income of the unemployed as 'fixed UI' and to the second assumption as 'proportional UI'. Proportional UI and fixed UI are empirically plausible, as they are broadly supported by stylized facts on benefit indexation schemes currently present in some Latin American countries, as discussed in the next section. There are potentially many other indexation schemes (see, for example, Koskela and Schob, 1999; Bovenberg and van der Ploeg, 1994), with environmental (or other) tax reforms exerting different impacts on the income from unemployment. The cases chosen represent two opposing scenarios: when green tax reform cannot affect the income from unemployment, and when it can shift the brunt of the tax burden on the unemployed, respectively.

## 2.2.6 | Summary of energy tax evasion arguments, with specific applications to Mexico

I first briefly discuss the structure of energy taxation in Mexico, and then present an outline of arguments in support of the theoretical assumption that energy taxes are harder to evade than other taxes, such as value-added tax (VAT) or income taxes.

The Mexican government sets energy product prices for gasoline, diesel, and liquefied petroleum gas (LPG), but only taxes gasoline and diesel. Natural gas, coal, LPG, and electricity are not directly taxed, although electricity may be indirectly taxed if diesel is used for electricity production (OECD, 2013). Almost all oil products (aside from some petrochemicals) are produced and sold by the state-owned oil company, *Petróleos Mexicanos* (Pemex).

The legislation that governs taxes on gasoline and diesel is called the IEPS (*Ley del Impuesto Especial sobre Producción y Servicios*). Under these laws, taxes are levied directly on the gasoline and diesel sold by Pemex to retailers. The government does not directly tax the sales of gasoline/diesel to final consumers. The IEPS tax has two components: one variable and one fixed.<sup>6</sup> The variable component allows the government to maintain retail prices of gasoline and diesel despite fluctuations in the international price of oil. The government adjusts this component according to the difference between domestic prices (set by the government) and Pemex's production costs (which mainly depend on international gasoline and diesel prices). If domestic prices are below production costs, the government provides a subsidy to Pemex by giving a tax credit on its VAT and ordinary hydrocarbon fee obligations (the variable component is negative). If domestic prices are above production costs, the government levies a positive tax on Pemex (the variable component is positive). The IEPS variable component is calculated monthly and differs according to the kind of fuel (regular or premium in the case of gasoline: automotive, industrial, or marine in the case of diesel). The second component of the IEPS tax is a fixed positive tax that depends on the type of energy (unleaded gasoline, 0.36 MXN per liter; premium gasoline, 0.4392 MXN per liter; diesel, 0.2988 MXN per liter). Tax credits equal to the entire variable component are given to diesel oil used in agriculture or industry (except mining), or for shipping and fishing purposes.

Energy taxes in Mexico are more difficult to evade than other taxes for the following reasons (Liu, 2013; OECD, 2013). First, it is easy to measure and monitor energy consumption at the supplier level, either by directly monitoring centralized points of infrastructure (e.g. electricity grid, pipelines, and storage tanks) or by indirect methods such as air pollution signatures. The Mexican government would find measuring and monitoring especially easy because almost all oil products are produced by one company (Pemex), which is also state-owned.

Second, energy prices have well-established prices and more transparent marketplaces, so are usually easier to assess than prices of other taxable goods. In Mexico, energy taxes depend on international prices and Pemex's production costs, both of which can be observed and verified. Although reported production costs can be manipulated to some extent, such manipulations would only affect the variable component of the energy tax and Pemex still has to pay the fixed component. Hence it is relatively difficult to completely evade energy taxes in Mexico. Third, the chemical structure of energy sources is fixed, so there is little room to manipulate the composition of energy sources to evade taxes.

Finally, government data support the intuition that environmental taxes are harder to evade than other taxes in both developed and developing countries. The Mexican government taxes gasoline and diesel in accordance with the IEPS. The estimates shown in Table 1 are the tax gap<sup>7</sup> as a percentage of the theoretical tax revenue, according to the type of tax: sales tax (similar to VAT), payroll taxes, taxes

**TABLE 1** Tax Evasion Estimates, Mexico (% by Type of Tax)

Year	Sales	Payroll	Rental income	Business income	Corporate tax	IEPS taxes
2004	34.9	19.6	88.7	70.0	55.0	7.9
2005	31.7	18.2	90.1	71.9	42.8	9.0
2006	25.5	17.0	90.4	71.9	41.2	8.9
2007	27.0	16.1	90.5	58.9	29.7	10.4
2008	24.3	15.9	87.2	68.2	24.1	12.3
2009	26.3	16.6	86.2	73.7	25.6	6.6
2010	27.0	12.6	86.0	84.2	23.7	10.4
2011	29.5	16.4	86.0	84.9	22.1	9.2
2012	24.3	15.5	85.7	83.4	31.4	6.1

*Notes:* The percentages represent the tax gap as a proportion of the theoretical tax liability (defined as the tax gap plus the actual amount of tax received). Source: OECD (2015).

**TABLE 2** Tax Evasion Estimates, UK (% by Type of Tax)

Year	VAT	Excise duties	Income	Corporate	Other
2005	14.7	7.8	5.6	13.7	5.6
2006	12.9	7.9	5.3	11.5	6.4
2007	11.7	7.3	5.8	10.2	6.2
2008	14.7	7.1	4.6	10.8	5.7
2009	12.6	6.6	5.3	11.3	6.6
2010	11.2	6	5.5	9.3	5.6
2011	11.7	4.9	5.1	6.4	5.1
2012	11.9	4.7	4.9	7.1	5.4
2013	11.1	5.2	5	6.7	5.6

*Notes:* The percentages represent the tax gap as a proportion of the theoretical tax liability (defined as the tax gap plus the actual amount of tax received). Source: HM Revenue and Customs (2015).

on rental income, taxes on business income (income earned by individuals from business activity, e.g. self-employment), corporate tax, and IEPS taxes (excise taxes on specific goods produced and sold within Mexico). Although gasoline and diesel taxes belong to the IEPS taxes category, gasoline and diesel were subsidized from 2005 onwards (OECD, 2013), so they are not included in the IEPS tax gaps reported in this table. However, the much lower tax gap for IEPS taxes suggests that these taxes are generally much harder to evade than taxes based mostly on taxpayers' self-reports (e.g. firm income or income from self-employment).

Table 2 shows similar tax gap statistics for the UK, where environmental taxes are part of the category 'other' (along with inheritance tax, petroleum revenue tax, and insurance premium tax, all of which make up a relatively small proportion of this category). Compared to the UK, Mexico's percentage tax gaps are much higher for all similar categories except 'other', where the IEPS tax gap is only slightly larger than the 'other' tax gap. Based on these government statistics, it is likely that the level of energy tax evasion in Mexico is both relatively low and similar to that of developed countries.

### 2.2.7 | Unemployment insurance systems in Latin American countries: A short overview

By looking at a sample of Latin American countries,<sup>8</sup> I broadly group unemployment benefits into two categories, summarized in Table 6 in the online appendix.

In most countries, unemployment benefits are tied to earnings, with minimum and maximum thresholds. Argentina, Uruguay, Venezuela, and Brazil are among the countries with top and bottom boundaries. In Argentina, benefits decrease once they have been granted for 4 months (there is no declining scheme for shorter-term benefits); a similar declining pattern is also in place in Chile and Uruguay. In Ecuador, the unemployed receive a one-off lump-sum payment upon losing employment.

Mexico does not have a nationwide UI scheme. However, there is a social security system in place that allows registered workers to withdraw a maximum of 30 days' worth of their pension savings from their individual account in the event of unemployment, once every 5 years.<sup>9</sup> Moreover, temporary employment programs are in place for workers from rural areas (with benefits being set at 99 percent of the local minimum wage) and in order to deal with the weak coverage (less than 50 percent) of the official social security system, a program named Seguro Popular (SP) was introduced in 2002 providing workers with health but not employment benefits. To complete the scattered coverage, Mexico City launched its own unemployment benefit scheme in 2007 (Programa Seguro de Desempleo del Distrito Federal). Benefits are restricted to 6 months, and the monthly benefit is worth 30 days of minimum wage. The existing Mexican programs have features that resemble flat-rate systems.

As such, the stylized facts presented in Table 6 in the online appendix provide evidence that supports the flat-rate system and earnings-related indexation scheme of benefits used in this model.

### 2.3 | Rural–urban migration

Like Satchi and Temple (2009), I allow for rural–urban migration and assume that rural migrants initially enter the urban informal sector. Migration involves a cost  $\phi_f|f|$ , where  $\phi_f$  represents the congestion effect caused by migration intensity<sup>10</sup> and  $f$  represents migration flows from the agricultural sector to the city (a negative sign would imply a migration flow in the opposite direction). The migration equilibrium condition is that the discounted value of being employed in the agricultural (rural) sector must be equal to the workers' expected utility from entering the urban informal sector:

$$w_a + \chi_a + r\phi_f f = rU. \quad (26)$$

In the steady state, migration flows cease ( $f = 0$ ) so, using (14) and (13), the above migration equation can be rewritten as

$$w_a + \chi_a = z + b + \sigma[\varepsilon_\sigma - 1], \quad (27)$$

where  $\varepsilon_\sigma = s\sigma'(s)/\sigma$  is the elasticity of search costs with respect to  $s$ . Equation (26) implies that in the steady state, workers are indifferent between staying in agriculture and moving to the informal urban sector. It implies that an increase in unemployment benefits and income in the informal sector attracts more labor from the agricultural sector to the informal sector, thus driving up wages in the agricultural sector. An increase in search intensity naturally entails a rise in search costs but also increases the probability of finding a job in the formal sector. Thus, when the expected benefits from search ( $\sigma\varepsilon_\sigma = s\sigma'(s)$ ) exceed the costs ( $\sigma(s)$ ), workers migrate from the agricultural to the informal sector, causing an increase in rural wages.

## 2.4 | The government's budget constraint

I assume that the government's main commitments are the provision of public goods  $G$  and transfers to the unemployed:

$$G + uL_m b = \tau_L w_m (1 - u)L_m \left( 1 + v \frac{r + \lambda}{q} \right) + \tau_{e,m} p_E e_m (1 - u)L_m + \tau_a p_E e_a L_a. \quad (28)$$

Government consumption expenditures are not assumed to have a productive role in this model. Government revenue includes revenues from taxing energy in the formal sector ( $\tau_{e,m} p_E e_m (1 - u)L_m$ ) and the agricultural sector ( $\tau_a p_E e_a L_a$ ), total payroll taxes paid by employees in the formal sector ( $\tau_L w_m (1 - u)L_m$ ), and taxing capitalized recruitment costs ( $\tau_L w_m (1 - u)L_m v(r + \lambda)/q$ ). When  $\tau_a < 0$ , the government provides energy subsidies to the agricultural sector. Throughout this paper, I consider green tax policies under which government spending remains constant.

## 2.5 | Key features of developing countries and environmental policies

In this section I discuss the key features of labor markets in developing countries that are important to model in order to study the implications of environmental policies for labor markets in developing countries. First, there is a high share of informal employment (self-employment or household/family business employment), especially in low-income countries, partially due to the importance of agriculture in their economies (Cho et al., 2012). Second, there are low female participation rates, especially in middle- and upper middle-income countries where less than half of females are in the labor force (45 and 49 percent on average, respectively). In low-income countries, female participation is higher because minimal household earnings force women to enter the workforce. Third, most of the labor force does not work for large firms (Ayyagari et al., 2011), and most new jobs are created by new establishments of existing firms and small new firms (Haltiwanger et al., 2010). Finally, there is a limited access to social security systems such as UI. Only 35 percent of developing countries have unemployment benefits as part of their social insurance system, while the rest rely on severance pay, which generally involves long legal or administrative processes. In upper middle-income countries, on average only 30 percent of the workforce is covered by UI. In middle-income countries, UI coverage varies across time for individuals, as they frequently transition between formal and informal employment, and also change employment status (Levy, 2008). The much lower coverage rate compared to developed countries is partly because social security laws exclude those in informal employment (e.g. self-employed or household workers) and agricultural workers.

This information supports the three-sector model set up with perfectly competitive firms in urban areas because informal and agricultural employment are still significant in developing countries (relative to developed countries), and there is generally a lack of UI (and few beneficiaries/low coverage even when there are UI systems).

## 3 | PARAMETERIZATION

I select parameter values that enable the theoretical model to produce reasonable figures for labor market characteristics such as the size of the informal sector, agricultural employment, and average employment duration for the case of Mexico.<sup>11</sup> I assign values to structural parameters using the

latest available official data, with reference to similar existing studies that analyze labor market policies in Mexico or Latin American countries that share many similar labor characteristics with Mexico. The baseline parameter values are summarized in Table 3, and Table 4 reports the characteristics of the labor market implied by the theoretical model, as well as the corresponding values from actual Mexican data. The time period is assumed to be 1 month.

### 3.1 | Matching and labor market parameters

I assume that the matching function is a Cobb–Douglas function ( $m(sv,u) = M(su)^\gamma v^{1-\gamma}$ ), and set the value of  $\gamma$  equal to 0.5, which is a commonly accepted value in the literature.<sup>12</sup>  $M$  and  $s$  are chosen to yield a plausible value for the duration of employment (see Table 4), and are set at 0.1 and 0.5, respectively. I set the value of  $\beta$  at 0.5 as it is again accepted by most of the literature.<sup>13</sup> The value of parameter  $v$  in the cost of posting a vacancy ( $c = v(1+\tau_L)w_m$ ) is set at 0.4; for comparison, Satchi and Temple (2009) sets the ratio  $c/w_m$  equal to 0.4. Following Satchi and Temple (2009), I assume that the average severance payment  $P$  is four times the wage which, along with the assumption that  $P = z_p(1+\tau_L)w_m$ , yields a value of  $z_p = 3.36$ .

**TABLE 3** Baseline Parameter Values

Parameter	Cobb–Douglas pr.f.	CES pr.f.
Search model parameters		
$v$ parameter of vacancy posting cost	0.40	0.4
$s$ search intensity	0.5	0.5
$\phi$ search cost elasticity	2.00	2
$\beta$ bargaining strength of workers	0.5	0.5
$M$ matching function efficiency	0.1	0.1
$z_p$ indexation of severance pay to wage	3.36	3.36
$\pi$ search intensity parameter	3.14	3.14
$\gamma$ matching function elasticity	0.50	0.50
$\lambda$ monthly job separation rate	0.04	0.04
Other parameters		
$\tau_e$ energy tax rate	0.15	0.15
$r$ monthly interest rate	0.04/12	0.04/12
$r_m$ return on capital	0.04/12	0.04/12
$\alpha_1$ share of capital in formal sector production	0.269	–
$\gamma_1$ share of capital in agricultural sector	0.63	0.63
$\alpha_2$ share of labor in formal sector production	0.5	–
$\gamma_2$ share of labor in agricultural sector	0.22	–
$\alpha$ share of labor in formal sector production	–	0.3
$\gamma_2$ share parameter in the nested CES function	–	0.1
$\varepsilon$ elasticity of substitution btw capital/labor & energy	–	0.05
$A_a$ productivity in agricultural sector	1	1
$A_m$ productivity in urban sector	2	5.2
$A^E$ fossil energy-augmenting technology	–	5.2

**TABLE 4** Labor Market Characteristics: Data versus Model

Labor market characteristics	Model $\tau_{e,m}=0.15$ $\tau_a=0.15$	Model $\tau_{e,m}=0.15$ $\tau_a=-0.15$	Data	Source
Agricultural employment share, $L_a$	0.13	0.13	0.13	Mexico 2010, World Bank (SL.AGR.EMPL.ZS)
Unemployment (informal sector share), $u$	30.94%	30.7%	34.1%	Mexico 2009, LABORSTA, ILO
Payroll tax rate, $\tau_L$	0.25	0.25	0.19, 0.27	Mexico (2013), OECD
Average employment duration	17.85 mths	18.06 mths	12–27 mths <sup>a</sup>	Mexico (1992, 1993) Gong and van Soest (2002)

<sup>a</sup>Respectively for men women and men.

The annual interest rate and return on capital ( $r$  and  $r_m$ , respectively) are set to 4 percent, which is the value used in the literature (Satchi and Temple, 2009; Albrecht et al., 2009). The monthly job separation rate,  $\lambda$ , is set at 0.04. For reference, Gerard and Gonzaga (2012) base their estimate on monthly data for Brazil and report a monthly separation rate of 0.04, and Satchi and Temple (2009), using quarterly estimates from Gong and van Soest (2002), calibrate  $\lambda$  at 0.06. I decided to set  $\lambda$  at 0.04, which allows me to match the labor data statistics better. This parameterization yields an unemployment rate of about 31 percent, which is very close to the official estimate of 34.1 percent for Mexico (2009Q2), of the number of people employed in the informal sector as a share of non-agricultural employment.<sup>14</sup>

### 3.2 | Search intensity, labor income, and government

Following Satchi and Temple (2009), I use a simple power function for the cost of search intensity:

$$\sigma(s) = \pi z s^\phi. \quad (29)$$

I assume that  $\phi = 2$  in line with Satchi and Temple (2009), and the value of the parameter  $\pi$  is chosen to generate plausible values for both productivity in the informal sector and the total income of the unemployed. The agricultural employment share,  $L_a$ , is set to 0.13, which matches the data for Mexico in 2010.<sup>15</sup> The value of  $\chi_a$  is then computed from the model's migration equation (26).

The payroll tax rate,  $\tau_L$ , is set at 0.25. OECD data suggest that the average labor income tax (tax wedge) faced by Mexican workers in 2013 is 19.0 percent, with an average compulsory payment wedge of 26.9 percent.<sup>16</sup> At the same time, payroll taxes may make up a maximum 35 percent of the payroll in Mexico (see International Business Publications, 2012). The values for the payroll tax rate used in the literature differ considerably: while Satchi and Temple (2009) use a value of 0.1, Albrecht et al. (2009) use a value of 0.5. The baseline tax on energy,  $\tau_{e,m} = \tau_a$ , is set at 0.15, which together with other parameters allows me to match the share of public consumption in GDP quite well. Specifically, I assume that government spending accounts for 10 percent of GDP ( $\psi = 0.1$ ), which is consistent with the empirical evidence for Mexico. In particular, the average share of general government final consumption expenditure in GDP is 11.4 percent during the period 1991–2013, while the average share is 10 percent for the period 2004–2008.<sup>17</sup> The baseline value of energy subsidies in agricultural sector is set at  $-0.15$ .

### 3.3 | Urban sector production function

The baseline specification of the formal urban-sector production function is assumed to be Cobb–Douglas:

$$Y_m = A_m K_m^{\alpha_1} ((1 - u)L_m)^{\alpha_2} E_m^{1-\alpha_1-\alpha_2}, \quad (30)$$

which in intensive form is given by

$$A_m f(k_m, e_m) = A_m k_m^{\alpha_1} e_m^{1-\alpha_1-\alpha_2}. \quad (31)$$

Cobb–Douglas technology has been widely used – see Golosov et al. (2014) as well as Barrage (2012) and references therein – and, as argued by Hassler et al. (2012), seems to be a reasonable representation of energy input use with a longer time horizon.

As I consider the case of an open capital account<sup>18</sup> for developing countries, this version of the model can be seen as capturing long-run adjustment, making the Cobb–Douglas specification a suitable choice. For the baseline Cobb–Douglas technology specification (33), I set the values of the parameters at  $\alpha_1 = 0.269$ ,  $\alpha_2 = 0.5$ , and  $\gamma_1 = 0.63$  (Satchi and Temple, 2009). These shares yield a value of the baseline share of energy costs in total production of 23.1 percent, which is broadly consistent with some evidence for developing countries. For instance, the energy intensity of the Chinese industry has been estimated at 40.7 percent (Yuan et al. (2009)). The estimates of 35 and 17 percent are the values of energy input per unit of value added in non-metallic mineral products and paper and in paper products, respectively, across developing countries (Upadhyaya, 2010). However, much lower values for the expenditure share of energy, such as  $1 - \alpha_1 - \alpha_2 = 0.03$ , have also been used in recent macroeconomic models of climate change (see, for example, Golosov et al., 2014; Barrage, 2012). To accommodate these estimates, I perform a sensitivity analysis on my results.

I also test how sensitive results are to a constant elasticity of substitution (CES) production function specification, which is considered to be a better representation of energy demand in the short and medium term (e.g. Hassler et al., 2012) than a Cobb–Douglas production function – that is, formal sector production is instead given by

$$Y_t = [(1 - \gamma_2)[A_t K_t^\alpha ((1 - u)L_t)^{1-\alpha}]^{\frac{\varepsilon-1}{\varepsilon}} + \gamma_2 [A_t^E E_t]^{\frac{\varepsilon-1}{\varepsilon}}]^{\frac{\varepsilon}{\varepsilon-1}}, \quad (32)$$

where  $L$  is labor,  $A_t$  the capital/labor-augmenting technology (later called  $A_m$ ),  $A^E$  fossil energy-augmenting technology,  $\varepsilon$  the elasticity of substitution between capital/labor and fossil energy, and  $\gamma_2$  a share parameter.

For the nested CES production function (32), I set the values of the parameters of the production function at  $\alpha = 0.3$ ,  $\varepsilon = 0.05$ ,<sup>19</sup> and  $\gamma_2 = 0.1$ .<sup>20</sup> The values of the exogenous price of energy and augmenting technology are chosen to match the labor data statistics so that the baseline values for both production function specifications are the same.

Finally, the small open economy and open capital account assumptions imply that the return to capital is equal to the world interest rate. In addition, given that the price of energy is determined internationally by the world markets, equations (18) imply that both  $k_m$  and  $e_m$  are exogenously given.

### 3.4 | Agricultural production

As for the formal sector, the baseline specification of the agricultural-sector production function is assumed to be Cobb–Douglas:



$$Y_a = A_a K_a^{\gamma_1} L_a^{\gamma_2} E_a^{1-\gamma_1-\gamma_2}, \quad (33)$$

which in intensive form is given by

$$g(k_a) = A_a k_a^{\gamma_1} e_a^{1-\gamma_1-\gamma_2}. \quad (34)$$

Energy usage is a considerable part of agricultural production, as it is used for fossil fuel, chemical fertilizers, pesticides, and machinery, as well as electricity for production processes such as land preparation, irrigation, intercultural operation, threshing, harvesting, transportation, and packaging. For the USA, energy and energy-intensive inputs account for a significant share of agricultural production costs. For example, corn, sorghum, and rice farmers allocated over 30 percent of total production expenditures to energy inputs in 2011. Direct and indirect energy-related expenses represented an average of more than 13 percent of total farm production expenses in 2005–8 – direct energy use averaged about 6.7 percent of total production expenses in the sector, while fertilizer expenses represented another 6.6 percent (Beckman et al., 2013). According to British Institute of Energy Economics (BIEE) reports, energy intensity in Argentina, Brazil, and Uruguay is around 0.15, so I set the value of energy intensity in the agricultural sector ( $1 - \gamma_1 - \gamma_2$ ) at 0.15. Since I choose the value of  $\gamma_1$  at 0.63 as in Satchi and Temple (2009), the expenditure share of labor stands at 0.22.

As  $K_a$  represents a fixed factor in agricultural production I can normalize its value to unity without loss of generality. In choosing the values of productivity parameters  $A_m$  and  $A_a$ , I draw on a recent study by Gollin et al. (2014), who undertake a thorough development accounting exercise using high-quality micro-data from household surveys to find that the rural–urban or agricultural–manufacturing productivity gap is at least a factor of 2. Accordingly, I normalize the value of  $A_a$  at 1, and set the value of  $A_m$  at 2.

### 3.5 | Other parameters

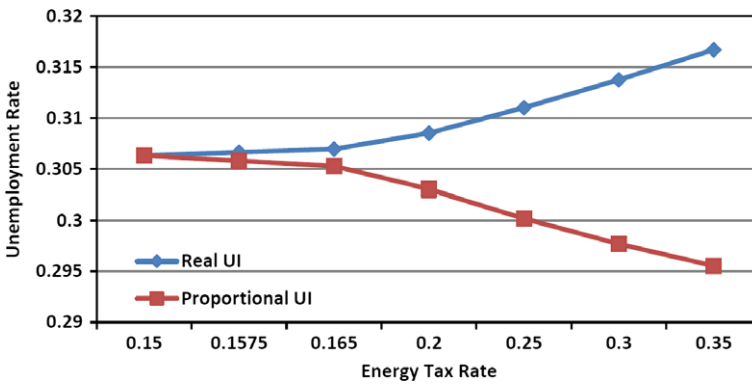
Finally, apart from matching some of the data statistics, this parameterization is consistent with all of the model's assumptions. In particular, I have verified that the following conditions of the model hold:  $w_m + \lambda P > z + b - \sigma$ ; and  $P < w_m / \lambda$ . The first condition implies that workers will only engage in job search if it is worthwhile, that is, the expected return from a formal job is greater than the return from being in the informal sector and searching for a formal job. The second condition implies that the (expected) severance payment  $P$  accounts for less than half of expected labor income from employment.

## 4 | DISCUSSION OF THE RESULTS

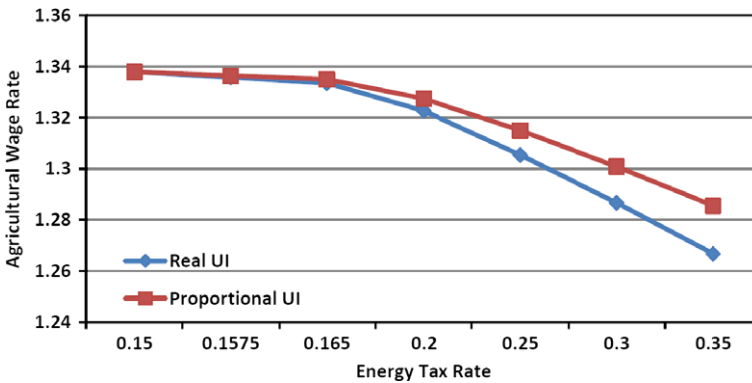
In my analysis, I utilize two versions of the aforementioned model. I refer to the model outlined in Section 2 as the 'core model', and to its simplified version (in which the agricultural sector does not use energy as an input into a production process), as the 'benchmark model'.

### 4.1 | Unemployment

Figure 1 depicts the effects of green tax reforms, in terms of increasing carbon taxes, on the level of unemployment (i.e. the size of the informal sector) in the benchmark economy under two different unemployment benefit indexation schemes.<sup>21</sup> It confirms the findings of previous studies that



**FIGURE 1** Benchmark Model: Aggregate Unemployment and Income of the Unemployed [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



**FIGURE 2** Benchmark Model: Agricultural-Sector Earnings [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

in models with involuntary unemployment, the double dividend (a decline in the unemployment rate) arises when the unemployed bear the burden of higher energy taxation. The intuition for this result is clear and discussed in the literature (see, for example, Koskela and Schob, 1999; Bovenberg and van der Ploeg, 1998). When unemployment benefits are fixed in real terms, the outside option available to workers remains unaffected by a green tax policy. This effectively raises the bargaining power of workers, who resist *large* cuts in after-tax wages, increasing labor costs and harming formal-sector employment. Conversely, with indexation of unemployment benefits and informal sector earnings to after-tax urban wages, the unemployed now share the cost of a cleaner environment, but a shift from labor taxes toward carbon taxes has a heavier impact on the income of the unemployed from informal activities ( $z$ ). Since the income from informal activities represents the bulk of the income from unemployment, this implies a much larger decline in the value of the outside option of workers. This weakens the bargaining strength of workers, prompting them to accept lower wages. This boosts labor demand and reduces unemployment.

## 4.2 | Earnings in the agricultural sector

Figure 2 displays the effects of carbon tax increases on wages of workers in the agricultural sector in the benchmark economy under two different assumptions about the income of the unemployed.

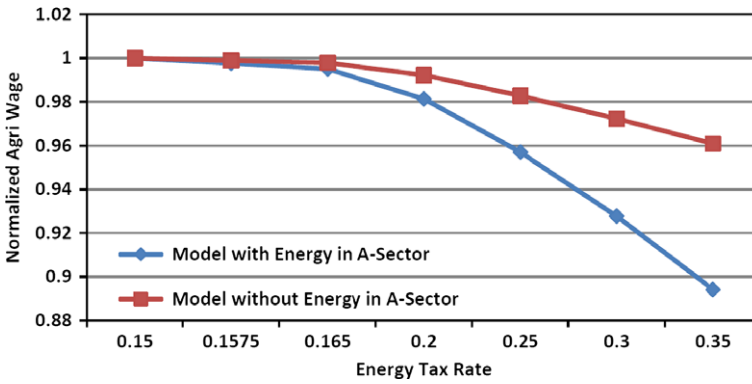
The figure shows that the income of agricultural workers decreases even though they pay neither energy nor labor taxes. Carbon taxation indirectly affects the income of workers in the agricultural sector through rural–urban migration. This illustrates that the traditional model used to analyze tax incidence in a developed country without rural–urban migration – as in Koskela and Schob (1999) and Bovenberg and van der Ploeg (1998) – is not appropriate in this context. Applying such a model to study the impacts of carbon taxes will underestimate the incidence of carbon taxes and wrongly estimate the potential costs of environmental regulation. The figure therefore shows some of the reasons why a multi-sectoral model with rural–urban migration is important for studying the effects of carbon taxes within the context of developing countries.<sup>22</sup>

Specifically, when unemployment benefits are fixed in real terms, a decrease in formal-sector employment is partially absorbed by the agricultural sector as the urban sector shrinks. The inflow of labor into rural areas pushes down wages in the agricultural sector not only in absolute terms, but also relative to formal-sector wages so that the incidence of poverty, measured by wages, is higher. If, however, unemployment benefits are proportional to after-tax urban wages, the unemployed now share the tax burden of higher energy taxes. Moreover, labor taxes and energy taxes have different impacts on income from unemployment. The specification of the income of the unemployed generated in the informal sector implies that payroll taxes do not affect productivity in the informal sector, and so the unemployed can escape some of the additional tax burden on labor. In contrast, the energy tax decreases both unemployment benefits and productivity in the informal sector, with income generated in the informal sector declining by more than unemployment benefits: a 100 percent increase in the energy tax rate from a baseline value of 0.15 leads to a 0.72 percent decrease in unemployment benefits and a decrease in income for those in self-employment by 5.45 percent, with the decline in total income of the unemployed constituting 4.48 percent.

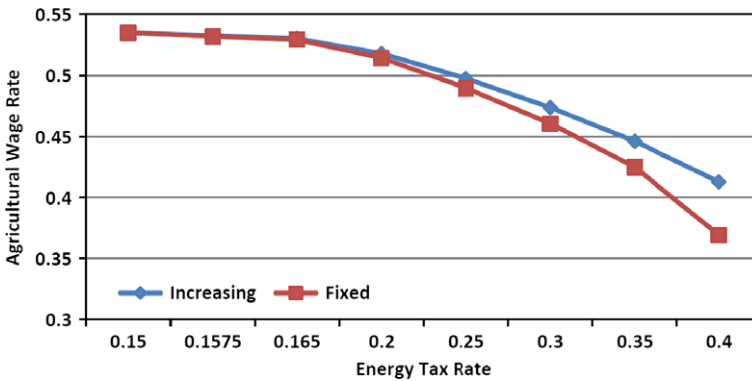
Therefore, a green tax policy involves replacing payroll taxes with energy taxes that impose a heavier burden of taxation on the unemployed, through its effect on income from self-employment. As such, the unemployed try to escape the brunt of taxation by searching for a job in the formal sector or by migrating into rural areas. In fact, the search intensity of the unemployed  $s$  increases. Since not all workers are able to find a job in the formal sector, some of them migrate into the rural area. As before, an inflow of labor into the agricultural sector pushes wages down.

### 4.3 | Energy use in the agricultural sector and the effects of green tax reforms

Thus far, I have considered the benchmark model of the economy, which does not use energy in the agricultural sector. As we saw in the previous sections, agricultural-sector workers still cannot avoid the burden of higher energy taxes through the migration channel. However, the different energy intensities of rural living versus urban living can further impact the migration channel and could also represent another channel through which green tax policies affect various sectors of the economy. Figure 3 shows the effect on earnings in the agricultural sector by model (benchmark and core), with proportional UI and with the same energy tax levied across both sectors of the economy, that is,  $\tau_{e,m} = \tau_a$ . The decline in the earnings of agricultural-sector workers is larger in the core model for the following reasons. Real earnings generally fall in response to higher carbon taxes in each sector, particularly in the agricultural sector. This is because higher emission taxes reduce the demand for energy, which in turn reduces labor productivity and consequently the demand for labor. Furthermore, payroll taxes are imposed on urban-sector incomes only, implying



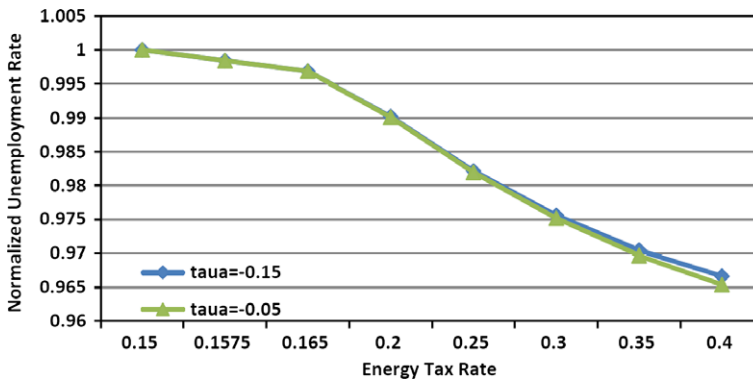
**FIGURE 3** Earnings in the Agricultural Sector, by Model [Colour figure can be viewed at wileyonlinelibrary.com]



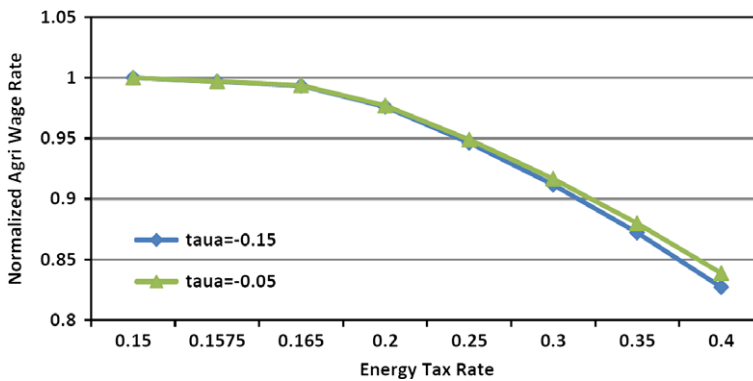
**FIGURE 4** Agricultural Sector: Earnings and Energy Tax [Colour figure can be viewed at wileyonlinelibrary.com]

that the government cannot offset the adverse effects of pollution tax on agricultural workers, so that the overall tax burden on those workers tends to rise. In addition, the rural–urban migration effect discussed above exacerbates the adverse effect of a pollution tax, further pushing down earnings in the rural area.

Above, I considered the situation in which pollution taxes are imposed universally and uniformly across the economy. However, there are also circumstances when carbon taxes are levied at various rates across different sectors. Next, I consider in turn two different assumptions on the pollution tax in the agricultural sector: a fixed energy tax versus a tax rate that varies alongside urban-sector energy taxes (i.e.  $\tau_{e,m} = \tau_a$ ). Figure 4 shows how earnings in the agricultural sector vary according to these assumptions, with unemployment benefits being fixed in real terms. Similar results go through for the case when unemployment benefits are proportional to after-tax urban wages. This figure demonstrates that fixing energy taxes in the agricultural sector results in a higher drop in the income of agricultural workers than when carbon taxes are levied at the same rate across sectors. Intuitively, when carbon taxes are fixed in the agricultural sector, urban-sector workers are subject to relatively higher energy taxation and they distribute this *higher* burden of taxation to workers in both agricultural and informal sectors through *larger* migration and *larger* informal-sector employment. Larger migration pushes down agricultural-sector wages by more compared with the situation when energy taxes are levied universally in the economy.



**FIGURE 5** Aggregate Unemployment and Energy Subsidies [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

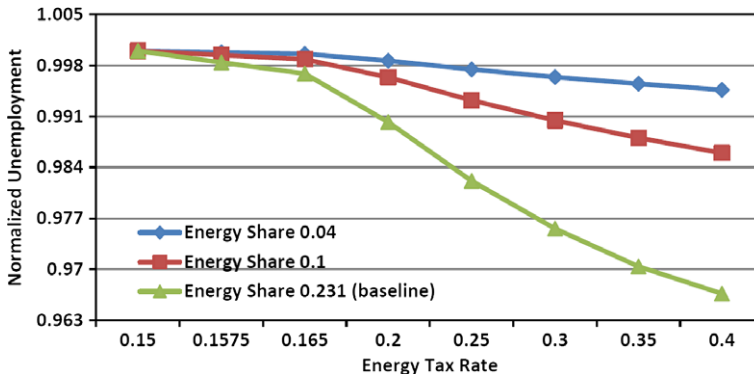


**FIGURE 6** Agricultural-Sector Earnings and Energy Subsidies [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

#### 4.4 | Energy subsidies and income of agricultural workers

The pervasiveness of energy subsidies in developing countries, particularly in the agricultural sector, is well documented. In this section, I consider an economy in which energy use in the agricultural sector is subsidized. I analyze an energy tax reform comprising increases in urban-area carbon taxes (manufacturing sector) and a reduction in agricultural-sector energy subsidies. Figure 5 presents the effects of a carbon tax on unemployment in the model with different values of the subsidies (scaled relative to the baseline values), under proportional UI: the blue line corresponds to the case with the subsidy imposed at the baseline value of  $-0.15$ . A lower subsidy is associated with a larger decrease in the unemployment rate (even though the differences are very small). Intuitively, larger subsidies create more budgetary pressure and less room for the government to reduce payroll taxes. As the government is unable to reduce labor taxes sufficiently to compensate for the large tax burden associated with higher energy taxes, the reduction in unemployment is less pronounced.

Figure 6 is the counterpart to Figure 5 and displays the impact of the energy tax reform on earnings (scaled relative to the baseline values) in the agricultural sector under different values of energy subsidies. As expected, a lower level of energy subsidies in the agricultural sector is associated with a lower decline in earnings of workers in that sector. As discussed earlier, unemployment is reduced by less under the presence of larger subsidies, so that higher migration to the rural area results in a larger decline in wages in that sector.



**FIGURE 7** Aggregate Unemployment by Energy Intensity, Urban Sector [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

## 5 | SENSITIVITY ANALYSIS

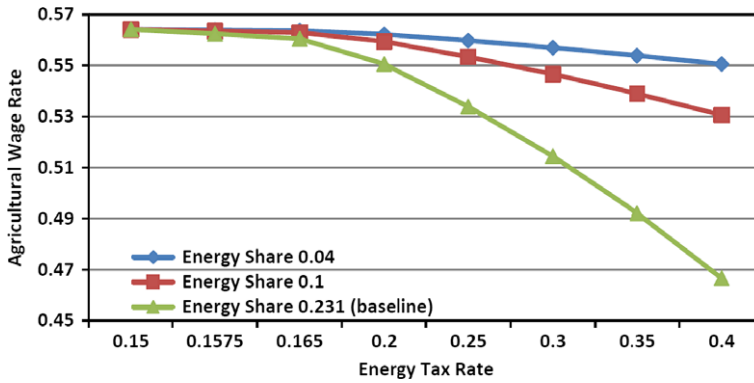
In this section I examine the robustness of the baseline results from Section 4. I start by varying the value of the expenditure share of energy in production. Next, I examine how the value of the parameter  $\phi$ , the elasticity of search costs with respect to search intensity, affects the baseline results. I also analyze how sensitive results are to the assumption that labor taxes are evaded in the informal sector by introducing a new parameter  $\zeta$ , which captures the degree of labor tax evasion. Then, I vary the value of parameter  $\beta$  that governs the workers' bargaining power. Finally, I explore the sensitivity of the baseline results to the choice of functional form for the production process, by considering a CES specification instead of a Cobb–Douglas specification for the production function.

### 5.1 | Varying the energy intensity of the formal sector

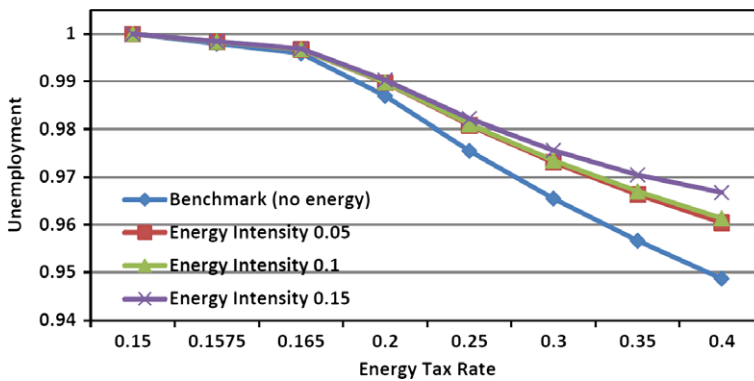
I first investigate how the results presented in the previous section change if I vary the value of the expenditure share of energy in production. The baseline expenditure share of energy in the urban area is  $\omega_E = 0.231$ , which, as discussed in Section 3, is consistent with some estimates of energy intensity in the manufacturing sub-sectors across developing countries, but is much higher than the values of energy expenditure shares used in recent macroeconomic models of climate change (0.04). To accommodate these differences in estimates, I consider alternative values of the expenditure share of energy ( $1 - \alpha_1 - \alpha_2 \equiv \omega_E$ ) ranging between 0.04 and 0.1, while keeping the value of  $\alpha_1$  (the expenditure share of capital) at its baseline value of 0.269. Similarly, the baseline expenditure share of energy in the rural area is  $\phi_E = 1 - \gamma_1 - \gamma_2 = 0.15$ . Alternative values of the energy share in the agricultural sector range from 0.05 to 0.1, and these are considered while keeping the value of  $\gamma_1$  (expenditure share of capital) at its baseline value of 0.63.

Figures 7 and 8 display the effects of increasing the carbon tax in the urban sector on aggregate unemployment and wages in the agricultural sector when unemployment benefits are proportional to the urban wage and when the level of subsidies in the agricultural sector is fixed at  $\tau_a = -0.15$ ,<sup>23</sup> under alternative values of  $\omega_E$ . These figures show that aggregate unemployment and wages in the agricultural sector vary by much less when the production process of the urban sector is more labor-intensive.

Intuitively, with a smaller share of energy in urban production, declines in energy demand due to higher energy taxes impose a smaller tax burden and the effects of environmental taxation are



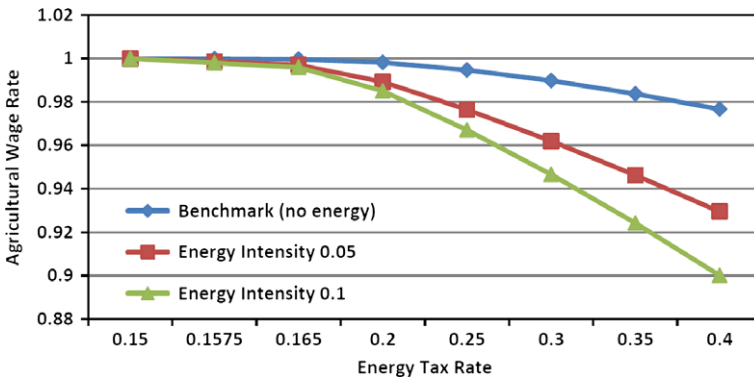
**FIGURE 8** Agricultural-Sector Earnings by Energy Intensity, Urban Sector [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



**FIGURE 9** Aggregate Unemployment by Energy Intensity, Agricultural Sector [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

less pronounced. Although payroll taxes have a wider tax base, there are also less energy tax revenues to be recycled, and as such, payroll taxes are cut by less. The unemployment rate is reduced but the effect is rather small compared to the situation when the urban area has a higher energy share in its production. Therefore, the size of the double dividend is sensitive to the energy intensity of the industry, subject to environmental regulation. If it is highly labor-intensive, the prospects for reduction in unemployment are much lower in the economy. Consequently, even more unemployed people migrate to the rural area, resulting in a higher decline in earnings in that sector, as shown in Figure 5.

In order to understand how the parameterization of energy intensity in the agricultural sector affects these results, Figures 9 and 10 display the change in aggregate unemployment and agricultural-sector wages. The figures depict the results in the benchmark model and in the core model under alternative energy intensities of the agricultural sector, when the energy tax in the agricultural sector is fixed at  $\tau_a = 0.15$ . The figures show that the lower the energy intensity of the agricultural sector (and consequently, a relatively higher energy intensity of the manufacturing/urban sector), the higher is the decline in unemployment, with a lower reduction in agricultural-sector wages. Payroll taxes and unemployment decrease by more when the energy intensity of agricultural sector is lower. This implies less migration to the rural area and consequently a lower reduction in real wages in that sector.



**FIGURE 10** Earnings in the Agricultural Sector by Energy Intensity, Agricultural Sector [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

### 5.2 | The elasticity of search costs to search intensity

In the baseline model, the elasticity of the search costs,  $\sigma(s) = \pi_z s^\phi$ , with respect to the search efforts is represented by the parameter  $\phi$  set at 2 as in Satchi and Temple (2009). There are two channels at work through which the value of the elasticity parameter  $\phi$  affects migration decisions. An increase in search intensity raises search costs but also increases the probability of finding a job. If the value of  $\phi$  exceeds unity, then the expected benefits from search,  $s\sigma'(s)$ , exceed the costs,  $\sigma(s)$ . This encourages workers to stay in the city rather than migrating back to the rural area, as the equilibrium migration condition suggests:

$$w_a + \chi_a = z + b + \sigma[\varepsilon_\sigma - 1]. \tag{35}$$

In this way, the income of rural workers is affected. Thus, by varying the value of  $\phi$ , I examine how the elasticity of search costs influences the energy tax incidence on rural workers. I consider two alternative values:  $\phi = 1.5$  and  $\phi = 3$ . I assume that energy taxes in agricultural sector are fixed at the baseline value of 0.15 and consider the proportional UI scheme. Table 8 in the online appendix presents the results for different values of  $\phi$  and demonstrates that lower values of  $\phi$  are associated with larger city sizes and consequently a lower rural population. The changing value of  $\phi$  affects (through general equilibrium) all other variables of the model, most importantly the income of the unemployed  $z$  and unemployment benefits  $b$ , which jointly with  $\sigma[\varepsilon_\sigma - 1]$  impact the amount of migration to the rural area. Under the given parameterization, with larger returns to migration (the right-hand side of the above equation), people tend to migrate to the city, increasing the income of agricultural workers.

### 5.3 | Degree of labor tax evasion

I introduce a new parameter,  $0 \leq \zeta \leq 1$ , into the proportional UI indexation scheme such that  $b = \pi_b w_m$  and  $z = \pi_z (1 + \tau_L \zeta) w_m$ . It is clear that if  $\zeta = 1$ , then the indexation scheme nests the baseline indexation scheme (proportional UI); if  $\zeta = 0$ , then the indexation scheme implies that labor taxes are not evaded in the informal sector and the income of the unemployed moves in line with that of the employed. The parameter  $\zeta$  thus captures the degree of labor tax evasion in the informal sector. I examine the effects on the baseline results by considering two alternative values:  $\zeta = 0$



and  $\zeta = 0.5$ . Table 9 in the online appendix presents the effects of varying  $\zeta$  on key variables of the model. The key result is that the results under  $\zeta = 0$  are quantitatively different from those with  $\zeta = 1$  and  $\zeta = 0.5$ , which both exhibit similar qualitative patterns. In particular, unemployment increases under the former and decreases under the latter scenarios.

These results provide insights in addition to the baseline results on the potential of double dividends in employment, which happen, as discussed in Section 4.1, when the unemployed share the brunt of higher energy taxation. The results in Table 9 in the online appendix further illustrate this point. When  $\zeta = 0$ , both the employed and the unemployed share the costs of a cleaner environment equally. Both formal-sector wages and the total income of the unemployed fall by the same amount (2.1 percent) when carbon taxes are increased from 15 percent to 30 percent. In contrast, when  $\zeta = 0.5$  and  $\zeta = 1$ , the tax burden is heavier on the unemployed, with their income falling by 3.3 percent and 4.4 percent compared with a reduction in formal-sector wages by 1.7 percent and 1.3 percent, respectively.

## 5.4 | Workers' bargaining power

As discussed above, the scope for a double dividend depends on how environmental taxation affects the income of the unemployed,  $z$  and  $b$ . If environmental regulation influences the outside option of workers so that the unemployed share the higher burden of energy taxation, as under proportional UI considered earlier, then a double dividend can arise. If, however, environmental policy does not affect the income of the unemployed, as under fixed UI, then the double dividend does not occur (as previously shown). However, under Nash bargaining, the equilibrium wages are also influenced by the bargaining power of workers. So, in this section, I explore the effects on the baseline results of varying the workers' bargaining power,  $\beta$ , by considering two alternative values:  $\beta = 0.25$  and  $\beta = 0.05$ . The baseline value of  $\beta$  is set at 0.5. I assume proportional UI in the core model, with  $\tau_a = 0.15$ . Table 10 in the online appendix presents the simulation results of effects of environmental regulation on unemployment under these different assumptions on  $\beta$ . The table suggests a nonlinear relationship between unemployment rate and workers' bargaining power. On one hand, with higher bargaining power, workers resist larger cuts in after-tax wages, increasing labor costs and reducing employment in the formal sector. So, higher bargaining power must be associated with a higher unemployment rate. This is the case of  $\beta = 0.5$  compared to the case when  $\beta = 0.25$ . On the other hand, if the workers' bargaining power is too low so that firms dominate the bargaining process (i.e.  $\beta \rightarrow 0$ ), then from equation (23) it follows that  $W \rightarrow U$ , that is, the formal-sector wages become equal to the workers' reservation wage. In that case, it is not possible to shift the higher burden of energy taxation on informal-sector workers and thus the unemployment rate falls by less. This is what I observe by comparing the baseline case  $\beta = 0.5$  with the case when  $\beta = 0.05$ .

## 5.5 | A nested CES production function

As discussed in Section 3, a Cobb–Douglas specification for the production process is a reasonable representation of energy input with a longer time horizon, while a CES specification is a better representation of energy demand in the short and medium term. Even though the baseline model assumed the case of an open capital account and thus implies the case of a longer-term horizon, some developing countries are more integrated with financial capital markets and thus it would be important to investigate how the baseline results change within the context of those countries. As such, I repeat the simulations of the benchmark model under the previous two assumptions about the unemployment benefits and income of the unemployed, and with the formal-sector production

**TABLE 5** Benchmark Model with CES Production Function, Proportional UI

Taxes									
$\tau_{e,m}$	$\tau_L$	$\theta$	$u$	$w_m/w_a$	$w_m$	$z$	$b$	$s$	$v$
0.15	0.2500	3.5449	0.2982	1.7838	2.3865	1.0771	0.0856	0.5000	0.5285
0.1575	0.2487	3.5446	0.2980	1.7847	2.3854	1.0755	0.0856	0.5005	0.5287
0.165	0.2473	3.5443	0.2978	1.7855	2.3847	1.0740	0.0856	0.5010	0.5288
0.2	0.2411	3.5428	0.2969	1.7898	2.3800	1.0665	0.0854	0.5033	0.5294
0.25	0.2321	3.5405	0.2956	1.7955	2.3741	1.0562	0.0852	0.5066	0.5302
0.3	0.2231	3.5381	0.2943	1.8012	2.3686	1.0461	0.0850	0.5100	0.5310
0.35	0.2141	3.5356	0.2930	1.8068	2.3634	1.0361	0.0848	0.5134	0.5318
0.4	0.2051	3.5329	0.2916	1.8123	2.3584	1.0262	0.0846	0.5169	0.5326

function assumed to be a nested CES production function. I report the results for the case with proportional UI<sup>24</sup> in Table 5.

In all model simulations, the effects on all variables are less pronounced, since with a lower elasticity of substitution between labor and energy, imposing a carbon tax has a smaller impact on the relative cost of labor, and thus on labor demand and overall labor market outcomes.

The low elasticity of substitution between labor and energy results in a small reduction in payroll taxes, which slightly compensates for the higher tax burden associated with higher energy taxes, leading to a small reduction in unemployment. For comparison, under the benchmark model with a Cobb–Douglas production function, an increase in energy taxes from the baseline by 5 percent lowers the payroll taxes by 1.7 percent, whilst under the same model with a CES production function in the urban area, payroll taxes are reduced by a mere 0.52 percent.

The results indicate that reducing emissions is a harder task under a lower elasticity of substitution, since there is a smaller decline in demand for energy. The results indicate and confirm findings of other studies that point out the importance of the elasticity of substitution between energy and labor (capital) for the effectiveness of emission reduction initiatives.<sup>25</sup>

## 6 | EXTENSIONS

In this section I consider three extensions of the core model. First, the model allows for payroll taxes paid by employees. Second, the model is extended to explicitly differentiate between unemployed and self-employed, and allows for three states of the labor market in urban sector: employed, self-employed in the informal sector, and unemployed. Finally, the model allows an endogenous job destruction rate.

### 6.1 | Payroll taxes paid by employees

This is an extension of the model in which I incorporate taxes paid by workers in the formal sector, denoted  $\tau$ . Payroll taxes are important in the Mexican economy<sup>26</sup> as they made up 37.2

percent of total government revenue (65.8 percent of government tax revenue) in 2012. In comparison, all IEPS taxes (including energy taxes) make up 3.2 percent of total revenue.<sup>27</sup>

The key changes to the baseline model are reflected in the Bellman equation for employed workers (36), the wage determination equation (39), and the government budget constraint (40):

$$rW = w_m(1 - \tau) + \lambda(U - W + P). \quad (36)$$

In each period the wage is determined by

$$w_m = \arg \max (W - U)^\beta (J - V)^{1-\beta}, \quad (37)$$

which yields the first-order condition

$$(1 - \beta)(1 + \tau_L)(W - U) = \beta(1 - \tau)J, \quad (38)$$

and the wage determination equation becomes

$$\frac{w_m - (z + b - \sigma)}{w_m} + \frac{\lambda P}{w_m} = \frac{\beta}{1 - \beta} v(1 - \tau) \left( \frac{r + \lambda}{q} + s\theta \right), \quad (39)$$

$$G + uL_m b = \tau_L w_m (1 - u) L_m \left( 1 + v \frac{r + \lambda}{q} \right) + \tau_{e,m} p_E e_m (1 - u) L_m + \tau_a p_E e_a L_a + L_m (1 - u) w_m \tau. \quad (40)$$

Table 11 in the online appendix summarizes the results of varying energy taxes in the baseline core model and its extension, with payroll taxes paid by employees under the fixed UI scheme (similar results hold for proportional UI). The left panel of the table represents the results of the extension, and the right panel shows those of the baseline model. The following quantitative differences in the results are worth highlighting. The unemployment rate is higher and formal-sector wages are lower in the model where workers pay payroll taxes. Cities tend to be smaller and consequently wages in the agricultural sector are lower in the extended model.

Intuitively, equation (38) suggests that both labor taxes paid by firms and payroll taxes paid by employees work in the same direction, as they both tend to reduce the value of being employed relative to being unemployed ( $W - U$ ). An extra distortion in the form of payroll taxes paid by employees triggers a larger decline in employment, smaller cities, and larger declines in the incomes of all workers.

## 6.2 | Unemployed versus informal workers

I consider the version of the model in which there are three states of the labor market in the city: employed in the formal sector, unemployed, and employed in the informal sector.<sup>28</sup> Once agricultural workers migrate from rural areas, they decide whether to search for jobs in the formal sector (and be unemployed) or take employment in the informal sector. The returns from being unemployed or employed in the informal sector must be equalized in the steady state. There are two other key features that distinguish the current version of the model from the baseline, which is worth emphasizing. First, the income of the unemployed in the baseline model is defined as  $b + z$ , while in the modified version  $b$  is the income of unemployed and  $z$  is the income that workers earn working in the informal sector. Second, as the size of the informal sector (and consequently income  $z$ ) must be determined endogenously within the model, I follow the literature and assume that informal-sector production exhibits decreasing marginal returns. The above considerations suggest that there is no one-to-one mapping from the proportional and fixed UI policies studied within the benchmark model to similar policies within the current setup. Instead, I examine the effects of the following four scenarios. I consider two indexation schemes ( $b = \bar{b}$  and  $b = \pi_b w_m$ ), which I

run against two assumptions about informal-sector taxation: in the first, energy taxes are evaded in the informal sector, with the government budget constraint given by

$$G + uL_m b = \tau_L w_m (1 - u) L_m \left( 1 + v \frac{r + \lambda}{q} \right) + \tau_{EP} e_m (1 - u) L_m + \tau_a p_{EE} e_a L_a; \quad (41)$$

and in the second, informal-sector workers pay taxes on energy, with the government budget constraint given by

$$G + uL_m b = \tau_L w_m (1 - u) L_m \left( 1 + v \frac{r + \lambda}{q} \right) + \tau_{EP} e_m (1 - u) L_m + \tau_a p_{EE} e_a L_a + \tau_{EP} E_{Sm}. \quad (42)$$

Table 12 in the online appendix reports the simulation results of two indexation schemes when energy taxes are not evaded in the informal sector. The results for the other two experiments convey similar messages and are available upon request. For a given parameterization, the results of this extension are opposite to what I obtain in the benchmark model and imply that the double dividend arises under the first indexation scheme  $b = \bar{b}$ , while the unemployment rate increases under the other indexation scheme  $b = \pi_b w_m$  (columns (4) across tables). These results hold regardless of whether or not energy taxes are evaded in the informal sector and can be explained as follows. First, comparing columns (4), (8) and (10) across tables, note that the total unemployment benefits paid by the government,  $uL_{mb}$ , decline in response to the tax policy under both indexation schemes, but by more when unemployment benefits are fixed. This creates extra room in the budget for a reduction in payroll taxes (which fall by more, as columns (2) across tables show) under the first indexation scheme,  $b = \bar{b}$ , than in the second one,  $b = \pi_b w_m$ , resulting in a reduction in the unemployment rate under the former and an increase under the latter.

Why are the results are different than under benchmark model? In the baseline model, the income of informal workers comprises unemployment benefits  $b$  and income from informal activities  $z$ , with  $z$  representing the bulk of the income of informal workers (93 percent). So, in the baseline model, a double dividend arises as the tax burden shifts onto the unemployed through the effect of tax policy, primarily on the income generated in the informal sector  $z$ , by introducing energy taxes that have a heavier burden on the income of informal workers than labor taxes (which are evaded in informal sector). In contrast, in this extension, unemployed and informal workers are separate groups, and since the returns on both activities are equalized in equilibrium, it does not matter whether energy taxes are evaded or not in the informal sector, but rather it matters how energy tax reform affects payments to unemployed.

### 6.3 | Endogenous job destruction

In this section I endogenize the job destruction rate  $\lambda$  by introducing productivity shocks in the model. I assume that each job is endowed with a random idiosyncratic productivity parameter  $\zeta$  drawn from a stationary and known distribution function  $G(\zeta)$ , which has finite support  $[\zeta_{\min}, \zeta_{\max}]$ . I assume a uniform distribution on the support  $[0, 1]$ , so that  $G(\zeta) = \zeta$ . The stochastic process governing productivity shocks is Poisson with arrival rate  $\delta$ . It is assumed that a new job is created with the highest productivity  $\zeta_{\max}$ . A job is destroyed only if the idiosyncratic productivity parameter falls below some critical value  $\zeta^*$ . As a result, jobs are destroyed at the rate  $\delta G(\zeta^*)$ .

### 6.3.1 | Labor market equilibrium

The steady-state Bellman equations for unemployed and employed workers are given by

$$rU = z + b - \sigma + sq\theta(W(\zeta_{\max}) - U), \quad (43)$$

$$\begin{aligned} rW(\zeta) &= w_m(\zeta) + \delta \int_{\zeta^*}^{\zeta_{\max}} (W(x) - W(\zeta))dG(x) + \delta G(\zeta^*)(U - W(\zeta)), \\ &= w_m(\zeta) + \delta \int_{\zeta^*}^{\zeta_{\max}} W(x)dG(x) - \delta W(\zeta) + \delta G(\zeta^*)U. \end{aligned} \quad (44)$$

These equations can be interpreted as follows. Equation (43) says that an unemployed worker, who gets an instantaneous utility  $z+b-\sigma$  today, can find a job at a rate  $sq\theta$ , in which he will start at the highest productivity level  $\zeta_{\max}$  and thus obtain an expected utility of  $W(\zeta_{\max})$ . Equation (44) says that an employed worker, who works at a certain productivity level  $\zeta$  and obtains an instantaneous utility  $w_m(\zeta)$ , can be hit by a productivity shock at a rate  $\delta$  and will then continue working in that job only if the productivity of the match is at least equal to  $\zeta^*$ . If, however, the productivity of the match is below the threshold level  $\zeta^*$ , which happens with probability  $\delta G(\zeta^*)$ , the worker becomes unemployed and loses  $W(\zeta)-U$ .

For firms, the values of a filled job and a vacancy are given by the following equations, respectively:

$$rV = -c + q(J(\zeta_{\max}) - V), \quad (45)$$

$$\begin{aligned} rJ(\zeta) &= y(k_m, e_m)(\zeta) - (1 + \tau_L)w_m(\zeta) + \delta \int_{\zeta^*}^{\zeta_{\max}} (J(x) - J(\zeta))dG(x) + \delta G(\zeta^*)(V - J(\zeta)) \\ &= y(k_m, e_m)(\zeta) - (1 + \tau_L)w_m(\zeta) + \delta \int_{\zeta^*}^{\zeta_{\max}} J(x)dG(x) - \delta J(\zeta). \end{aligned} \quad (46)$$

### 6.3.2 | Labor demand condition

The free entry condition implies that  $V = 0$  and the value of a new job is given by

$$J(\zeta_{\max}) = \frac{c}{q}. \quad (47)$$

### 6.3.3 | Wage determination

In each period, the wage is determined by

$$w_m = \arg \max (W(\zeta) - U)^\beta (J(\zeta) - V)^{1-\beta}, \quad (48)$$

which yields the first-order condition

$$(1 - \beta)(1 + \tau_L)(W(\zeta) - U) = \beta J(\zeta). \quad (49)$$

It can be shown that the wage determination equation is given by

$$w_m(\zeta) = \beta \frac{y(k_m, e_m)(\zeta)}{1 + \tau_L} + (1 - \beta)(z + b - \sigma) + \frac{s\theta\beta c}{1 + \tau_L}. \quad (50)$$

### 6.3.4 | Unemployment rate

The number of workers who enter unemployment is  $\delta G(\zeta^*)L_m(1 - u)$ , and the number of unemployed who become employed is  $L_m s u \theta q(\theta)$ . In the steady state, these two flows are equal:

$$u = \frac{\delta G(\zeta^*)}{\delta G(\zeta^*) + s\theta q}. \quad (51)$$

### 6.3.5 | Job creation and job destruction

It can be shown that the job creation condition can be written as

$$\frac{c}{q} = \frac{1 - \beta}{r + \delta} [y(k_m, e_m)(\zeta) - y(k_m, e_m)(\zeta^*)], \quad (52)$$

while the job destruction condition can be written as

$$(1 - \beta)(1 + \tau_L)(z + b - \sigma) + s\theta\beta c + \delta \frac{1 - \beta}{r + \delta} y'_\zeta(k_m, e_m) \int_{\zeta^*}^{\zeta_{\max}} G(x) dx = (1 - \beta)y(k_m, e_m)(\zeta^*) + \delta \frac{c}{q}. \quad (53)$$

### 6.3.6 | Results

In this model simulation, I take 100 draws from the distribution  $G(\zeta)$  and take averages of all variables. Table 13 in the online appendix reports the results for the case where  $b = \pi_b w_m$  and  $z = \pi_z(1 + \tau_L)w_m$ . The left panel of the table reports the results of the model with endogenous job destruction, while the right panel presents the results of the model with exogenous job destruction. The table suggests that for a given increase in carbon taxes, the model with an exogenous separation rate

The table suggests that in the model with an endogenous separation rate, the decline in the unemployment rate under a UI compensation scheme (also observed in the model with exogenous separation rate) happens only when both the level of carbon taxes and the level of unemployment reaches some higher level than the baseline values. This can be explained as follows. The model with exogenous job destruction assumes constant productivity of 1 for urban-sector firms. In contrast, in the model with endogenous job destruction, the productivity of firms varies depending on a random draw from the uniform distribution over support  $(0,1)$ , so that average productivity is less than unity. In response to this low productivity, for a given level of carbon taxes, the optimal strategy for firms is to hire fewer workers and impose a higher level of labor taxes. It is only optimal to increase the number of employees when the number of employed workers becomes low enough, and this is achieved through a reduction in labor taxes as in the model with an exogenous separation rate.

## 7 | CONCLUSION

This paper uses a simple dual economy, general equilibrium model with job search frictions to analyze the effects of environmental taxation on aggregate unemployment and wages. It confirms the findings of existing studies on developed countries that green tax reforms can reduce unemployment when the tax burden is shifted on to workers in other sectors (informal and rural). The key difference from existing studies that focus on developed countries is that the incidence of carbon taxes is partly shifted on to rural workers through the rural–urban migration channel. Thus, even in situations where rural workers do not directly pay taxes, they bear part of the costs of environmental regulation through reduced wages. These results highlight the fact that the labor market consequences of carbon tax reforms can spread beyond the sector that is subject to the taxation and thus can be counter-intuitive. The analysis of this paper therefore suggests that modeling developing countries while ignoring their distinctive features can result in qualitatively different conclusions on the effects of environmental regulation from conventional studies on developed countries.

The general equilibrium framework developed in this paper incorporates two key features of developing countries: a large informal sector, and rural–urban migration. By illustrating the importance of rural–urban migration through which adjustment to environmental taxation occurs, the model underlines issues that can potentially be very important in evaluating the welfare implications of green tax reforms in developing countries. In particular, probable issues associated with rural–urban migration in developing countries are many and range from limited access to credit, infrastructure, and services, and unfair property rights of rural migrants in urban areas. Under such circumstances, migration of urban workers back to the rural area in response to high energy taxes in the urban area, although associated with a decline in real rural wages, can be beneficial from an overall welfare point of view. The model also highlights the importance of modeling the relative energy intensity of the rural *vis-à-vis* the urban sector in studying both direct and spillover (through migration) effects of environmental regulation. Welfare implications of environmental taxation could be analyzed by incorporating the framework of this paper within a broader macroeconomic model of developing countries.

## ACKNOWLEDGMENT

I thank Alex Bowen, Emmanuel Combet, Richard Freeman, Rick van der Ploeg for helpful comments and suggestions, as well as Eileen Tipoe for research assistance. I also thank the referees for valuable comments which have significantly improved the paper. I acknowledge financial support by the Global Green Growth Institute (GGGI), the Grantham Foundation for the Protection of the Environment and the UK Economic and Social Research Council (ESRC) through the Centre for Climate Change Economics and Policy. All potential errors are my own.

## ENDNOTES

<sup>1</sup> Albrecht et al. (2009), Zenou (2008), Bosch and Esteban-Prete (2012), and Ulyssea (2010), for instance, have modeled the informal sector to study the implications of various labor market institutions and different tax policies, such as severance payments, or enforcement of regulations on labor market outcomes in developing countries. They have not looked at the interactions of labor markets and environmental regulations as I do in this paper.

<sup>2</sup> The description of the core setting of the model draws heavily on Kuralbayeva (2017) who uses a simplified version of this model to study interaction between environmental taxation, employment, and public spending in developing countries.

- <sup>3</sup> The model thus assumes random search in the urban sector. To examine sector-specific search, the model should consider more disaggregated sectors (e.g. manufacturing and services), which is beyond the current scope of the paper.
- <sup>4</sup> This simple specification implies that I do not explicitly model how factors of production (energy, capital, labor) are utilized in the production process in the informal sector, and thus allows me to disregard the effects of tax policy that operate through the relative energy intensities of the formal sector and the informal sector. Bento et al. (2012) examine how an untaxed informal sector can sharply reduce the cost of energy tax reforms through an expansion of the tax base. For their analysis, the sign of the effect is critically dependent on the relative energy intensities of the manufacturing, informal, and formal services sectors.
- <sup>5</sup> See Goulder (2013) for a recent survey of the existing literature on the conditions for a double dividend.
- <sup>6</sup> The model assumes that energy is imported at given world prices. Future research should account for the fact that retail prices of energy products are often controlled by the government.
- <sup>7</sup> The tax gap is the difference between the theoretical tax revenue (based on estimates of the tax base) and the actual amount of taxes received.
- <sup>8</sup> Some forms of unemployment insurance (UI) currently exist in a handful of developing countries (see Vodopivec, 2013; Velásquez, 2010; Gerard and Gonzaga, 2012), most of them Latin American countries.
- <sup>9</sup> See <http://www.socialsecurityextension.org/gimi/gess/ShowTheme.do?tid=2667>.
- <sup>10</sup> Migration from rural to urban areas makes it more difficult for workers in the informal sector to find jobs in the formal sector, undermining the relative attractiveness of being in the informal urban sector.
- <sup>11</sup> This section draws heavily on a corresponding one in Kuralbayeva (2017).
- <sup>12</sup> For example, see Pissarides (1998), Satchi and Temple (2009), and Zenou (2008).
- <sup>13</sup> See, for example, Mortensen and Pissarides (1994), Zenou (2008), Albrecht et al. (2009), and Pissarides (1998).
- <sup>14</sup> This share also comprises those who have a formal job. Formal employment in the informal sector, however, represents only a very small fraction of non-agricultural employment. To illustrate this point, I also compute the informal employment in informal sector as share of non-agricultural employment, by using the data (ILO, 2012) on the number of people in informal employment and the number of people in informal employment outside the informal sector. The estimate is 33.5 percent.
- <sup>15</sup> Note that, given this parameterization, the agricultural sector is a proxy for rural area production and thus, in this paper, the terms 'agricultural sector' and 'rural area' will be used interchangeably.
- <sup>16</sup> See <http://www.oecd.org/ctp/tax-policy/taxingwages-mexico.htm>; average compulsory payment wedge measures the taxes and non-tax compulsory payments.
- <sup>17</sup> General government final consumption expenditure (as a percentage of GDP, NE.CON.GOV.T.ZS) from World Development Indicators, World Bank, includes all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most expenditures on national defense and security, but excludes government military expenditures that are part of government capital formation.
- <sup>18</sup> The assumption of an open capital account also ensures that the Hosios condition for efficiency is satisfied in the model. Given similarity between the setup of this paper and the one in Satchi and Temple (2009), for similar reasons, when the Hosios condition is not satisfied and the capital account is closed, the level of search intensity can be inefficiently high and the city size is too large.
- <sup>19</sup> The value of the elasticity  $\varepsilon = 0.05$  (or below), as shown by Hassler et al. (2012), implies the sensible energy-saving and capital-labor saving technology series if interpreted as technologies. Their estimates also suggest that the technology trends are positive and of very similar magnitude, so that I set  $A = A^E$ .
- <sup>20</sup> Empirical estimates of the share of energy in production  $\gamma_2$  vary by industry. For example, Dissou et al. (2012) find that the value of  $\gamma_2$  varies between 0.024 (transportation equipment) and 0.186 (primary metals). Hence, I set the value of  $\gamma_2$  in the range of these estimates, close to estimates of the energy share in non-metal mineral products or in chemicals.
- <sup>21</sup> Table 7 in the online appendix, which accompanies Figures 1 and 2, shows the effect of a given change in energy taxes on a number of variables in the model.
- <sup>22</sup> Some earlier studies, such as Shah and Whalley (1991), have pointed to the fact that tax incidence results are different in developing countries compared with that in developed ones, given the particular features of the former.
- <sup>23</sup> Similar results follow in the case of energy taxes levied on the agricultural sector.



- <sup>24</sup> Other results are available upon request.
- <sup>25</sup> For example, Jorgenson et al. (2000), using a computable general equilibrium model for the US economy, examine the role of flexibility in production (the ability of firms to substitute between labor, capital, or other materials for energy) when imposing carbon emission reductions. They find that rigidity in production more than doubles the costs of mitigation policies. The effectiveness of mitigation policies can also be sensitive to varying values of elasticity of substitution between energy and labor (capital). Burniaux and Martins (2012) show that high inter-factor (between energy and value-added) and inter-fuel substitution elasticities can generate large carbon leakages.
- <sup>26</sup> Payroll taxes are paid by employees (individual income tax, also referred to as ISR in Mexico).
- <sup>27</sup> Data are taken from the report Confederación Patronal de la República Mexicana, Visión Coparmex, Reforma fiscal a revisión, Coparmex, México, 2013.
- <sup>28</sup> I follow Charlot et al. (2013) in defining the distinction between unemployed and informal sector workers. See the online technical appendix for an outline of this version of the model.

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**How to cite this article:** Kuralbayeva K. Unemployment, rural--urban migration and environmental regulation. *Rev Dev Econ*. 2018;22:507–539. <https://doi.org/10.1111/rode.12360>