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 as well as a reduction in 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 relevant for developing countries and the economic general equilibrium effects in assessing the impact of environmental taxation in those countries.

Keywords: informal sector, matching frictions, energy taxes, subsidies, rural-urban migration

JEL Classifications: H20, H23, H30

1I thank Alex Bowen, Emmanuel Combet, Richard Freeman, Rick van der Ploeg as well as participants at the seminar at LSE, GRI-GGGI Green Growth conference, the World Congress of Environmental and Resource Economics (Istanbul) for helpful comments and suggestions. 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. Contact: k.z.kuralbayeva@lse.ac.uk
1 Introduction

A large number of studies have analyzed the incidence of carbon taxes in developed countries of which a subset of these studies has 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 characterized by “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 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.

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, and rural agricultural. The search and matching frictions following Pissarides (2000) form the 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 self-employment 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 calibrate it to match some key aspects of labor markets in Mexico. I find that the absence of modeling key features of developing countries, namely rural-urban migration, clouds the incidence of higher energy taxation on poverty within the context of developing countries. As in the simplified version of the main model, even though agricultural workers do not pay energy nor labor taxes, they still bear the burden of environmental taxation through reduced wages. Potential explanation for this is as follows: (a) when the unemployment benefits and income from self-employment in the informal sector are real fixed, 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 proportion of 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 by migrating into an urban area, which pushes wages down in rural area.

I also find that fixing the energy tax in the agricultural sector, whilst increasing the energy tax imposed in the urban area results in a higher reduction in earnings of workers in the rural sector than when the energy taxes change universally in the economy. This is because the former policy is associated with relatively higher burden on urban sector than the latter, resulting in a higher outflow of labor into rural area, which leads to a higher decline in earnings of workers in agricultural sector. Further, simulations of the model with energy subsidies in agricultural sector also suggests that higher energy subsidies to protect the incomes of workers in that area 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 workers in that area from the adverse effects of environmental taxation in the urban area.
in earnings of rural workers when 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 can 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 poverty incidence.

Finally, the results indicate that energy intensity of the urban sector is important for the size of the potential double dividend effects, and consequently on 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 higher reduction in payroll taxes and consequently in higher employment leading to lower migration and a decline in rural sector wages.

The 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 urban 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 can be sizable and comparable with the effects of regulation on incomes of the unemployed. The simulations of the benchmark model under the assumption that income of the unemployed are proportion of the after-tax urban wage and when labor taxes are evaded in informal sector suggest that a doubling of the energy tax rate from baseline value results in a reduction in income for the unemployed by 4.48%, whilst for the rural workers by 2.77%. Therefore, the effects of environmental regulation in developing countries have to be analyzed in an intrinsically different theoretical framework than conventional models suggest. Even though the focus of the paper is on the effects of energy taxes, similar issues arise with an analysis of incidence of other taxes 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 though which environmental regulation can yield other dividends which are important in assessing the overall welfare effects of regulations in developing countries. For instance, in many cases in developing countries, large rural-urban migration accompanied with an inability of city authorities to offer access to housing and basic public services, 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 into account these general equilibrium effects. Another potential extension of the model could be to a case where workers 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 sections 5 and 6, I test the sensitivity of both the baseline results to varying levels of energy intensity (in both sectors), and the assumption on the production function in the urban area. Section 7 concludes.
2 Model

The model used in this paper extends a general equilibrium model of Satchi and Temple (2009), with a large informal sector and a scope for rural-urban migration, in a setting with a polluting production factor and environmental taxes. The economy comprises two regions/sectors: urban and rural/agricultural, denoted by $m$ and $a$. The urban sector is characterized by search matching frictions in tradition of Pissarides (2000), which lead to unemployment to be an equilibrium outcome. This in turn partitions the sector into informal (unregistered) and formal (registered production activities), as I use the term “unemployed” to describe self-employed in informal sector. The size of population is normalized to 1 and can be decomposed into:

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

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

There are two types of firms: agricultural sector firms and registered firms in urban sector. 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 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 further assume that revenues collected from taxing energy and labor are used to provide general government goods and transfers to the unemployed.

2.1 Agricultural sector

The 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 per worker production is:

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

The worker is paid a wage $w_a$, and derives positive utility from living in a rural area, $\chi_a > 0$. The firms import energy at given international energy prices (small open economy assumption) and pay taxes on use of energy. The agricultural sector (A-sector) is assumed to be perfectly competitive, which implies that:

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

return on fixed capital:

$$r_a = g'_a(k_a, e_a) \quad (5)$$

and demand for energy in A-sector:

$$g'_{e_a}(k_a, e_a) = p_E (1 + \tau_E) \quad (6)$$
2.2 The urban labor market

The urban sector goods can be produced either from formal or informal activities. Labor market search and matching frictions form distinction between formal goods and informal goods production activities.

2.2.1 The labor market

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

\[ m = m(uL_m, vL_m, M) = M(suL_m)^\gamma(vL_m)^{1-\gamma} \]  

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 one vacancy to be filled is:

\[ q = \frac{m}{vL_m} = M \left( \frac{su}{v} \right)^\gamma = M \theta^{-\gamma} \]  

where

\[ \theta = \frac{v}{su} \]  

measures labor market tightness and \( 1/q \) the expected duration of a 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 formal sector is destroyed with an exogenous Poisson rate \( \lambda \). Thus the law of motion for the number of unemployed satisfies to:

\[ uL_M = L_m(\lambda(1-u) - su\theta q(\theta)) \]  

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

\[ \lambda(1-u) = su\theta q(\theta) \]  

which determines the relationship between the unemployment rate and the rate of vacancies (labor market tightness) i.e. the Beveridge curve.

2.2.2 The worker’s expected gains

In the informal sector, each worker receives \( z + b - \sigma(s; z) \), where \( z \) denotes the labor productivity (output) of each worker\(^3\), \( b \) 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, discussing specifications of \( b \) and \( z \) below in section 2.2.5.

I denote by \( U \) and \( W \) the value to the worker of being unemployed (and searching for a formal job) and being employed on a formal job. There is an incentive to search for jobs in the formal segment of the urban

\(^3\)This simple specification implies that I do not model explicitly how factors of production (energy, capital, labor) are utilized in the production process in the informal sector and thus allows 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, the informal and formal services sectors.
sector as the ex-post value of working in formal jobs is highest. Informal sector workers decide how actively they search for a formal sector job. As discussed in Satchi and Temple (2009), 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 \( s_i/s \):

\[
\bar{q}_i = \frac{s_i}{suL_m}m(suL_m, vL_m) = s_iq\theta = s_iM\theta^{1-\gamma}
\]  

(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:

\[
\sigma'_{s}(s; z) = \theta q(W - U)
\]  

(13)

with \( sq\theta \) as the probability of finding a job for every job searcher.

Worker’s expected utility of being unemployed and employed at a formal job can be defined as follows:

\[
rU = z + b - \sigma + sq\theta(W - U)
\]  

(14)

\[
rW = w_m + \lambda(U - W + P),
\]  

(15)

where \( P \) is a severance payment paid by the firm to the departing employee.

### 2.2.3 Firms and labor demand

Firms pay a flow cost \( c \) to post a vacancy. Once it is filled, firms employ one worker who is paid the wage \( w_m \), rent capital \( k_m \) from international capital markets and, import 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 TFP 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:

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

(16)

\[
rV = -c + q(J - V),
\]  

(17)

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

\[
A_m f'_k(k_m, e_m) = r_m; A_m f'_e(k_m, e_m) = p_E(1 + \tau_{e,m})
\]  

(18)

which imply that:

\[
rJ = y(k_m, e_m) - (1 + \tau_L)w_m - \lambda(J + P - V)
\]  

(19)

where:

\[
y(k_m, e_m) = A_m f(k_m, e_m) - r_m k_m - p_E(1 + \tau_{e,m})e_m
\]
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:

\[
J = \frac{c}{q}
\]  

(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, \( c = \nu(1 + \tau_L)w_m \), I can obtain:

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

(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 its 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 bargain. Using the parameter \( \beta \) to index worker bargaining power, a wage bargain in the formal sector determines wages for formal urban jobs according to:

\[
w_m = \arg\max(W - U)^\beta(J - V)^{1-\beta}
\]  

(22)

that yields the following first-order condition:

\[
(1 - \beta)(1 + \tau_L)(W - U) = \beta J
\]  

(23)

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

\[
\frac{w_m - (z + b - \sigma)}{w_m} + \frac{\lambda P}{w_m} = \frac{\beta}{1 - \beta} \nu \left( \frac{\lambda}{q} + s\theta \right)
\]  

(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 (\( \theta \)) raise the rents from a job match and thus raise the wage.

I could also re-write the equation that determines the optimal level of search intensity, using (13), (20) and (23), as:

\[
\sigma'_s = \frac{\beta}{1 - \beta} \theta \nu w_m
\]  

(25)

### 2.2.5 Unemployment benefits and informal sector labor productivity

Under Nash bargaining, the outside option of the workers - income of unemployed - affects the bargaining position of workers and thus the equilibrium wages. This in turn impacts the hiring decisions and determines the equilibrium unemployment in the economy. In particular, how environmental taxation affects income of the unemployed influences the scope for a double dividend (see, e.g., Koskela and Schob (1999), Bovenberg and van der Ploeg (1998)).

Following Bovenberg and van der Ploeg (1998), I consider two different assumptions on income of the unemployed: fixed real benefits and fixed real income generated in informal sector, that is \( b = \bar{b} \) and \( z = \bar{z} \) and
when 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, such as carbon tax or tax on energy (see, e.g., [Liu (2013)])). In discussion of the simulation results, I refer to the first assumption on the income of the unemployed as real UI and to the second assumption as proportional UI.

There are potentially many other indexation schemes (see, e.g., [Koskela and Schob (1999) or Bovenberg and van der Ploeg (1994)], with environmental (or other) tax reform exerting different impacts on the income in unemployment. The chosen cases represent two opposing cases when the green tax reform cannot affect the income in unemployment and when it can shift the brunt of the tax burden on the unemployed, respectively. These cases are also broadly supported by stylized facts on benefit indexation schemes currently present in some Latin American countries as discussed in the next section.

### 2.2.6 Unemployment insurance systems in Latin American countries: short overview

By looking at a sample of Latin American countries\(^4\), I broadly group unemployment benefits into two categories, summarized in Table 4. In most countries, unemployment benefits are tied to earnings, with minimum and maximum thresholds. Argentina, Uruguay, Venezuela, 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 unemployment insurance scheme. However, there is a social security system\(^5\) in place that allows registered workers to withdraw a maximum of 30 days worth of their pension savings from their individual account in case of unemployment once every 5 years. Moreover, temporary employment programs are in place for workers from the rural areas (with benefits being set at 99% of the local minimum wage) and in order to deal with the weak coverage (less than 50%) 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 of 30 days of minimum wage. The existing Mexican programs have features that resemble flat-rate systems.

As such the stylized facts presented in Table 4 provide evidence and support the flat-rate system and earnings-related indexation scheme of benefits.

### 2.3 Urban-rural migration

As in [Satchi and Temple (2009)] paper, I allow for rural-urban migration and assume that migrants from agriculture initially enter the informal sector. Migration involves a cost $\phi_f |f|$, where $\phi_f$ represents the congestion effect caused by migration intensity\(^6\) and $f$ represents migration flows from the agricultural

---

4Some forms of unemployment insurance (UI) currently exists in a handful of developing countries (see Vodopivec (2013), Velasquez (2010) and Gerard and Gonzaga (2012), most of them Latin American countries.

5See: http://www.socialsecurityextension.org/gimi/gess/ShowTheme.do?tid=2667

6Migration from rural area to urban end up making more difficult for workers in informal sector to find jobs in formal sector, undermining the relative attractiveness of being in informal urban sector.
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 agricultural sector must be equal to the workers’ expected utility from entering informal sector:

\[ w_a + \chi_a + r\phi_f f = rU \] (26)

In steady-state migration flows cease, so that \( f = 0 \), and the above migration equation can be re-written, using (14) and (13), as:

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

where \( \varepsilon_\sigma = s\sigma'(s)/\sigma \) is the elasticity of search costs with respect to \( s \). Equation (27) implies that in the steady-state, workers are indifferent between staying in agriculture and the informal urban sector. The migration equation (27) 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 of 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 hence 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:

\[ G + uL_m b = \tau_L w_m (1 - u)L_m \left( 1 + \nu \frac{r + \lambda}{q} \right) + \tau_{e,m} Pe_m (1 - u)L_m + \tau_a Pe_a L_a \] (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 \( \tau_{e,m} Pe_m (1 - u)L_m \) and agricultural sector \( \tau_a Pe_a L_a \), total payroll taxes paid by employees in the formal sector, \( \tau_L w_m (1 - u)L_m \), and from taxing capitalized recruitment costs, \( \tau_L w_m (1 - u)L_m \nu(r + \lambda)/q \). When \( \tau_a < 0 \), the government provides energy subsides to the A-sector. Throughout the paper, I consider green tax policies under which government spending remains constant.

3 Parameterization

A primary target of the calibration is to produce reasonable figures for labor market characteristics such as the size of the informal sector, agricultural employment, and average employment duration in the case of Mexico. I calibrate the parameter values using the latest available official data and values similar to existing studies that analyze labor market policies in Mexico or Latin American countries, which share many similar labor characteristics with the former. The baseline parameter values are summarized in Table 2. Table 1 reports the characteristics of the labor market implied by the theoretical model as well as the corresponding values from Mexican data. The time period is assumed to be one month.
3.1 Matching and labor market parameters

I assume that the matching function is a Cobb-Douglas function \( m(s,v,u) = M(su)^{\gamma}v^{1-\gamma} \), and set the value of \( \gamma \) equal to 0.5 which is commonly accepted value in the literature\(^7\). \( M \) and \( s \) are chosen to yield a plausible value for the duration of employment (see Table 1), set at 0.1 and 0.5, respectively. I set the value of \( \beta \) at 0.5 as it is accepted in most of the literature\(^8\). \( M \) and \( s \) are chosen to yield a plausible value for the duration of employment (see Table 1), set at 0.1 and 0.5, respectively. I set the value of \( \beta \) at 0.5 as it is accepted in most of the literature\(^8\). The value of parameter \( \nu \) in a cost of posting a vacancy \( c = \nu(1 + \tau_L)w_m \) set at 0.4; for comparison Satchi and Temple (2009) set 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 \( z_P = 3.36 \).

The annual interest rate, \( r \) and \( r_m \), is set to 4%, 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. Gerard and Gonzaga (2012) who base their estimate on monthly data for Brazil report a monthly separation rate of 0.04. Satchi and Temple (2009) using quarterly estimates from Gong and van Soest (2002) calibrate \( \lambda \) at 0.06. I decide to set \( \lambda \) to 0.04, which allows me to match the labor data statistics better. The parameterization yields an unemployment rate of about 31%. This number is very close to official estimate of 34.1% for Mexico (2009 Q2), of the number of people employed in the informal sector as a share of non-agricultural employment\(^9\).

3.2 Search intensity, labor income and government

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

\[
\sigma(s) = \Pi z s^\phi
\]

(29)

I assume that \( \phi = 2 \) in line with Satchi and Temple (2009) and the value of 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\(^10\), which matches the data for Mexico in 2010. The value of \( \chi_a \) is then inferred from the model’s migration equation.

The payroll tax rate, \( \tau_L \) is set at 0.25. OECD data on the average labor income tax (tax wedge) faced by Mexican workers suggests 19.0% and an average compulsory payment wedge of 26.9% in 2013\(^11\). At the same time, payroll taxes may make up a maximum 35% of payroll in Mexico (see Handbook (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 allow me to match the share of public consumption in GDP quite well. Specifically, I assume that government spending accounts for 10% of GDP (i.e., \( \psi = 0.1 \)), which is consistent with the empirical evidence for Mexico. In particular, the average share of general government spending

\(^7\)e.g., see Pissarides (1998), Satchi and Temple (2009) and Zenou (2008)

\(^8\)see, e.g., Mortensen and Pissarides (1994), Zenou (2008), Albrecht et al. (2009), Pissarides (1998)

\(^9\)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. For illustration, 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%.

\(^10\)Please note that given this parameterization, the agricultural sector is a proxy for rural area and thus in the paper, agricultural sector and rural area will be used interchangeably.

\(^11\)http://www.oecd.org/ctp/tax-policy/taxingwages-mexico.htm; average compulsory payment wedge measures the taxes and non-tax compulsory payments
final consumption expenditure in GDP is 11.4% during period from 1991 to 2013, however the average share is 10% for the period from 2004 to 2008. The baseline value of energy subsidies in agricultural sector is set at -0.15.

3.3 Urban sector production function

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

\[ Y_m = A_m K_m^{\alpha_1} ((1-u) L_m)^{\alpha_2} E_m^{1-\alpha_1-\alpha_2}; \]  

(30)

and in intensive form is given by:

\[ A_m f(k_m, e_m) = A_m k_m^{\alpha_1} e_m^{1-\alpha_1-\alpha_2}; \]  

(31)

Cobb-Douglas technology has been used widely (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 for developing countries, this version of the model can be seen as capturing long-run adjustment and thus Cobb-Douglas specification is consistent with this assumption. For the baseline Cobb-Douglas technology specification (33), I set the values of the parameters as \( \alpha_1 = 0.269, \alpha_2 = 0.5, \) 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%, which is broadly consistent with some evidence for developing countries. For instance, a value of 40.7% is an estimate of energy intensity of Chinese industry (Yuan et al. (2009)). The estimates of 35% and 17% are values of energy input per unit of value added in non-metallic mineral products and paper and, paper products respectively across developing countries (Upadhyaya (2010)). But, much lower values for the expenditure share of energy have also been used in recent macroeconomic models of climate change (see, e.g, Golosov et al. (2014), Barrage (2012)) of \( 1-\alpha_1-\alpha_2 = 0.03. \) To accommodate these estimates, I perform sensitivity analysis of my results.

I also test how results are sensitive to a 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 Cobb-Douglas production function, assuming formal sector production is given by:

\[ Y_t = [(1-\gamma_2)[A_t K_t^{\epsilon} ((1-u) L_t)]^{1-\alpha} + \gamma_2 [A_t E_t]^{1-\epsilon}]^{1/\epsilon}, \]  

(32)

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

For the nested CES production function (32), I set the values of the parameters of the production function as \( \alpha = 0.3, \epsilon = 0.05 \) and \( \gamma_2 = 0.11 \). The values of the exogenous price of energy and augmenting

---

**General government final consumption expenditure (% of GDP) (NE.CON.GOV.TS)** 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.

**The value of the elasticity \( \epsilon = 0.05 \) (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 \( A = A^E \).**

**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.**
technology are chosen to match the labor data statistics so that the baseline values for both production function specifications are the same.

Finally, small open economy and an 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

The baseline specification of production function of the agricultural sector, as of the formal sector, is assumed to be Cobb-Douglas functions:

\[
Y_a = A_a K_a^{\gamma_1} L_a^{\gamma_2} E_a^{1 - \gamma_1 - \gamma_2};
\]  

and in intensive form is given respectively by:

\[
g(k_a) = A_a k_a^{\gamma_1} e_a^{1 - \gamma_1 - \gamma_2}
\]

Energy usage is a considerable part of agricultural production as it is used in terms of fossil fuel, chemical fertilizers, pesticides, machinery and electricity for the production processes such as land preparation, irrigation, intercultural operation, threshing, harvesting, transportation, and packaging. For US, 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 on energy inputs in 2011. Direct and indirect energy related expenses represented an average of more than 13 percent of total farm production expenses in 2005-08. (Direct energy use averaged about 6.7 percent of total production expenses in the sector, while fertilizer expenses represented another 6.6 percent.)\(^{15}\) According to the 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 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 labor share stands at 0.22.

As \(K_a\) represents a fixed factor in agricultural production I can normalize its value to one 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 households surveys to find the rural/urban or agricultural/manufacturing gap at least a factor of two. 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, the calibration is consistent with all of the model’s assumptions. In particular, I have verified that the following conditions of the model (1) \(w_m + \lambda P > z + b - \sigma\) and (2) \(P < w_m / \lambda\) do hold. The first condition implies that workers will only engage in job search if it is worthwhile, that is the expected return from formal job is greater than the return from being in 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.

\(^{15}\)Agricultures Supply and Demand for Energy and Energy Products, USDA Report, 2013
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 a core model, and to its simplified version in which the agricultural sector does not use energy as an input into a production process, as a 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 benefits indexation schemes. It confirms the findings of the previous studies that in the models with involuntary unemployment the double dividend (a decline in the unemployment rate) arises when the unemployed bear the burden of higher energy taxation. Intuition for this result is clear and discussed in the literature (see e.g., Koskela and Schob (1999), Bovenberg and van der Ploeg (1998)). When unemployment benefits are fixed, 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 employment in the formal sector. 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 towards carbon taxes has a heavier impact on the income of the unemployed from informal activities. Since the income from informal activities, \( z \), represents the bulk of the income of the unemployed, 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. This figure 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. The model illustrates that the traditional model for analysis of tax incidence as in a developed country case 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 potential costs of environmental regulations. More specifically, it has been shown that green tax reforms can reduce unemployment and thus produce a double dividend when the tax burden is shifted on to the informal sector in similar models but without rural-urban migration (e.g., Koskela and Schob (1999), Bovenberg and van der Ploeg (1998)). However, the key difference from these studies is that the incidence of the carbon tax in the developing country is partly shifted on to the rural sector through rural-urban migration channel. Although agricultural workers pay neither energy nor labor taxes, as in the benchmark model, they still bear part of the burden through reduced wages\(^{16}\).

Specifically, when unemployment benefits are real fixed benefits, a decrease in formal sector employment is partially absorbed by the agricultural sector as the urban sector shrinks. The inflow of labor into rural

\(^{16}\)The earlier studies that 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, include Shah and Whalley (1991).
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 do have different impacts on income during 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 thus the unemployed escape some of the additional tax burden on labor. The energy tax, in contrast, decreases both unemployment benefits and productivity in the informal sector with income generated in informal sector declining by more than unemployment benefits: a 100% increase in the energy tax rate from a baseline value of 0.15 leads to a decrease of unemployment benefits by 0.72% and a decrease in income for those in self-employment by 5.45%, with the decline in total income of the unemployed constituting 4.48%.

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 increases. Since not all workers are able to find a job in formal sector, some of them migrate into the rural area. As before, an inflow of labor into the agricultural sector pushes the wage down.

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

Thus far, I have considered the benchmark model of the economy that does not use energy in the agricultural sector. As we saw in the previous sections, this does not preclude workers in agricultural sector to bear the burden of higher energy taxes through the migration channel. However, different energy intensities of rural-living versus urban-living can further impact the migration channel and could, in addition, 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 value of energy tax levied across the sectors of the economy, that is $\tau_e = \tau_a$. The decline in the earnings of the workers in the agricultural sector is larger in the core model for the following reasons. Real earnings generally fall in response to higher carbon taxes in each sector, and particularly in the agricultural sector. This is because higher emission taxes reduce demand for energy, which in turn reduces labor productivity and consequently demand for labor. Furthermore, payroll taxes are imposed on urban sector incomes only, implying that the government cannot offset the adverse effects of pollution tax on agricultural workers, so that the overall tax burden on those workers tend to rise. In addition, the rural-urban migration effect discussed above exacerbates the adverse effect of a pollution tax, pushing further down the earnings in the rural area.

Above, I considered the situation in which the pollution taxes are imposed universally in the economy. However, there also exist circumstances when carbon taxes are levied at various rates across different sectors. So next, I consider two different assumptions on the pollution tax in the agricultural sector: a fixed energy tax versus a tax rate that varies alongside energy tax imposed in urban area, i.e., $\tau_e = \tau_a$. Figure 4 shows how earnings in agricultural sector vary by these assumptions with the (real) unemployment benefits being fixed. Similar results go through for the case when unemployment benefits are a proportion of the after-tax urban wages. Fixing the energy taxes in the agricultural sector results in a higher tax burden on workers
in the agricultural sector than when carbon taxes are levied at the same rate across sectors. This is driven by the fact that payroll taxes are reduced by less in the urban area when energy taxes in the agricultural sector are fixed, resulting in a higher unemployment rate and thus larger migration into the urban area. This pushes the wages in the agricultural sector further down, resulting in lower earnings by workers in that sector.

4.4 Energy subsidies and income of agricultural workers

It is well documented how pervasive energy subsidies are in developing countries, particularly in the agricultural sector. 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 carbon tax in the urban area (manufacturing sector) and a reduction in energy subsidies in the agricultural sector. Figure 5 presents the effects of a carbon tax on unemployment (scaled relative to the baseline values) in the model with different values of the subsidies: the blue line corresponds to the case with subsidy imposed at baseline value of −0.15. This figure shows the case with proportional UI. A lower value of subsidies 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 of 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 just discussed, 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 the sector.

5 Varying the energy intensity of the formal sector

In this section, I investigate how the results presented in the previous section would 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 manufacturing sub-sectors across developing countries, but is a much higher than the values of energy expenditure shares used in recent macroeconomic models of climate change which have used a value of 0.04. To accommodate these differences in estimates, I consider alternative values of the expenditure share of energy, $1 - \alpha_1 - \alpha_2 \equiv \omega_E$ between 0.04 and 0.1, whilst keeping the value of $\alpha_1$ (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 an energy share in an agricultural sector range from 0.05 to 0.1 and they 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 $\tau_a = -0.15$ under alternative

\footnote{Similar results follow in the case of energy taxes levied on the agricultural sector.}
values of $\omega_E$. The 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 less pronounced. Although, payroll taxes have a wider tax base, there are also less energy tax revenues to be recycled, 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 is 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 15.

In order to understand how calibration of energy intensity in agricultural sector affects the results, figures 9 and 10 display the change in aggregate unemployment and wage in the agricultural sector. The figures depict the results in the benchmark model and in the core model under alternative energy intensities of the agricultural sector and 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, relatively higher energy intensity of manufacturing/urban sector), the higher is the decline in unemployment with a lower reduction in wages of the agricultural sector workers. 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 the sector.

6 A nested CES production function

As discussed in the parametrization section, a Cobb-Douglas specification for the production process is a reasonable representation of energy input with a longer time horizon, whilst a CES specification is a better representation of energy demand in the short and medium terms. 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 two assumptions about the unemployment benefits and income of the unemployed and with the production function in the formal sector assumed to be a nested CES production function. I report the results for the case with proportional UI$^{18}$ in Table 3.

In all model simulations, the effects on 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 compensate for the higher tax burden associated with higher energy taxes just by little, consequently 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% lowers the payroll taxes by 1.7%, whilst under the same model but with the production modeled as the CES in urban area, the payroll

---

$^{18}$Other results are available upon request.
taxes are reduced by a mere 0.52%.

The results indicate that reducing emissions is a harder task under a lower elasticity, 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\(^{19}\).

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 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 country is that the incidence of the carbon tax in the developing country is partly shifted on to the workers in the rural area through urban-rural migration channel. Thus, even in situations when rural workers do not directly pay taxes, they bear part of the costs of environmental regulation through reduced wages. These results highlight 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 the paper therefore suggests that modeling developing countries whilst ignoring their distinctive features can result in contrasting conclusions of 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 be potentially very important in evaluating welfare implications of green tax reforms in developing countries. Particularly, 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 to 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, even though 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 relative energy intensity of rural vis-a-vis urban sector in studying both direct and spillover (through migration) effects of environmental regulation.

The framework developed in this paper can be extended and used in analysis of many other interesting research questions. Specifically, welfare analysis of environmental taxation and green tax reforms that take into account spillover effects on other sectors of the economy, could be evaluated. This could be done by incorporating the framework of this paper within a broader macroeconomic model of developing countries. Another direction where this framework can be useful is to study distributional implications of environmental regulation.

\(^{19}\text{For example, Jorgenson et al. (2000), using a computable general equilibrium model (IGEM) for the US economy, examine the role of flexibility in production (the ability of firms to substitute between labor, capital or other materials for energy) when imposing carbon emission reductions. They find that rigidity in production more than doubles the costs of mitigation policies.}\) The effectiveness of mitigation policies can also be sensitive to varying values of elasticity of substitution between energy and labor (capital).\(^{\text{Burniaux and Martins (2012) show that high inter-factor (between energy and value-added) and inter-fuel substitution elasticities can generate large carbon leakages.}}\)
taxation, by introducing heterogeneous agents in terms of their productivities. These extensions of the paper I leave for future research.
8 Appendix A

<table>
<thead>
<tr>
<th>Labor market characteristics</th>
<th>Model $\tau_{e,m} = 0.15$</th>
<th>Model $\tau_{e,m} = 0.15$</th>
<th>Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{a} = 0.15$</td>
<td>$\tau_{a} = -0.15$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural employment share, $L_a$</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>Mexico 2010, World Bank (SL.AGR.EMPL.ZS)</td>
</tr>
<tr>
<td>unemployment, $u$</td>
<td>30.94%</td>
<td>30.7%</td>
<td>34.1%</td>
<td>Mexico 2009, LABORSTA, ILO</td>
</tr>
<tr>
<td>payroll tax rate, $\tau_L$</td>
<td>0.25</td>
<td>0.25</td>
<td>0.19, 0.27</td>
<td>Mexico (2013) OECD</td>
</tr>
</tbody>
</table>

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

Table 2: Baseline parameter values
<table>
<thead>
<tr>
<th>$\tau_{c,m}$</th>
<th>$\tau_L$</th>
<th>$\theta$</th>
<th>$u$</th>
<th>$w_m/w_a$</th>
<th>$w_m$</th>
<th>$z$</th>
<th>$b$</th>
<th>$s$</th>
<th>$v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.2500</td>
<td>3.5449</td>
<td>0.2982</td>
<td>1.7838</td>
<td>2.3865</td>
<td>1.0771</td>
<td>0.0856</td>
<td>0.5000</td>
<td>0.5285</td>
</tr>
<tr>
<td>0.1575</td>
<td>0.2487</td>
<td>3.5446</td>
<td>0.2980</td>
<td>1.7847</td>
<td>2.3854</td>
<td>1.0755</td>
<td>0.0856</td>
<td>0.5005</td>
<td>0.5287</td>
</tr>
<tr>
<td>0.165</td>
<td>0.2473</td>
<td>3.5443</td>
<td>0.2978</td>
<td>1.7855</td>
<td>2.3847</td>
<td>1.0740</td>
<td>0.0856</td>
<td>0.5010</td>
<td>0.5288</td>
</tr>
<tr>
<td>0.2</td>
<td>0.2411</td>
<td>3.5428</td>
<td>0.2969</td>
<td>1.7898</td>
<td>2.3800</td>
<td>1.0665</td>
<td>0.0854</td>
<td>0.5033</td>
<td>0.5294</td>
</tr>
<tr>
<td>0.25</td>
<td>0.2321</td>
<td>3.5405</td>
<td>0.2956</td>
<td>1.7955</td>
<td>2.3741</td>
<td>1.0562</td>
<td>0.0852</td>
<td>0.5066</td>
<td>0.5302</td>
</tr>
<tr>
<td>0.3</td>
<td>0.2231</td>
<td>3.5381</td>
<td>0.2943</td>
<td>1.8012</td>
<td>2.3686</td>
<td>1.0461</td>
<td>0.0850</td>
<td>0.5100</td>
<td>0.5310</td>
</tr>
<tr>
<td>0.35</td>
<td>0.2141</td>
<td>3.5356</td>
<td>0.2930</td>
<td>1.8068</td>
<td>2.3634</td>
<td>1.0361</td>
<td>0.0848</td>
<td>0.5134</td>
<td>0.5318</td>
</tr>
<tr>
<td>0.4</td>
<td>0.2051</td>
<td>3.5329</td>
<td>0.2916</td>
<td>1.8123</td>
<td>2.3584</td>
<td>1.0262</td>
<td>0.0846</td>
<td>0.5169</td>
<td>0.5326</td>
</tr>
</tbody>
</table>

Table 3: Benchmark model with CES production function, proportional UI
Figure 1: Benchmark model: Aggregate unemployment by income of the unemployed

Figure 2: Benchmark model: Earnings in agricultural sector
Figure 3: Earnings in agricultural sector by model

Figure 4: Earnings in agricultural sector by energy tax in A-sector
Figure 5: Aggregate unemployment by energy subsidies

Figure 6: Earnings in agricultural sector by energy subsidies
Figure 7: Aggregate unemployment by energy intensity of urban sector

Figure 8: Earnings in agricultural sector by energy intensity of urban sector
Figure 9: Aggregate unemployment by energy intensity of A-sector

Figure 10: Earnings in agricultural sector by energy intensity of A-sector
References


_ and Raymundo M. Campos-Vazquez_, “The trade-offs of social assistance programs in the labor market: The case of the Seguro Popular program in Mexico,” Serie documentos de trabajo del Centro de Estudios Economicos 2010-12, El Colegio de Mexico, Centro de Estudios Economicos Oct 2010.


Dissou, Yazid, Lilia Karnizova, and Qian Sun, “Industry-level econometric estimates of energy-capital-labor substitution with a nested CES production function,” *working paper n1214E, department of economics, University of Ottawa*, 2012.


## 9 Online Appendix: not for publication

<table>
<thead>
<tr>
<th>Country</th>
<th>Unemployment benefits</th>
</tr>
</thead>
</table>
| Argentina | earnings-related and declining after 4 months  
            | non-declining for shorter terms  
            | there are min. and max. values of benefits |
| Brazil    | earnings-related, but within ranges:  
            | previous income up to 767.6 BRL: 80% of the average wage  
            | 767.6-1279.46 BRL: 614.08 BRL+ 50% of the excess over 767 BRL  
            | previous income above 1279.46 BRL: 870.01 BRL  
            | there are min. and max. values of benefits |
| Chile     | earnings-related and descending:  
            | 50% of the renumeration the first month  
            | 45%, 40%, 35% and 30% in the following |
| Ecuador   | earnings-related:  
            | sum set equal to 3 times the average salary of last 12 months |
| Uruguay   | earnings-related and descending:  
            | for workers with monthly compensation and jobbers:  
            | 50% of wage over the last 6 months, in case of the suspension  
            | in case of a layoff 66%, 57%, 50%, 45%, 42% and 40% of the salary  
            | there are min. and max. values of benefits |
| Venezuela | earnings-related:  
            | 60% the of average weekly wage of the last 50 weeks  
            | min. benefit is 60% of the minimum wage |
| Mexico    | no nationwide UI, flat-rate systems linked to the minimum wage |

Table 4: Unemployment insurance systems in Latin America