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Effects of carbon taxes in an economy with large informal sector and rural-urban migration[1]

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Abstract

I build an equilibrium search and matching model of an economy with an informal sector and rural-urban migration to analyze the effects of budget-neutral green tax policy (raising pollution taxes, while cutting payroll taxes) on the labor market. The key results of the paper suggest that when general public spending varies endogenously in response to tax reform and higher energy taxes can reduce the income from self-employed work in the informal sector, green tax policy can produce a triple dividend: a cleaner environment, lower unemployment rate and higher after-tax income of the private sector. This is due to the ability of the government, by employing public spending as an additional policy instrument, to reduce the overall tax burden when an increase in energy tax rates does not exceed some threshold level. Thus governments should employ several instruments if they are concerned with labor market implications of green tax policies.

Keywords: informal sector, matching frictions, pollution taxes, double dividend
JEL Classifications: H20, H23, H30

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1 Introduction

This paper investigates the effects of green tax policy on labor market outcomes in developing countries. Green tax policy involves raising taxes on the polluting factor and using the revenues to reduce distortionary taxes on labor. The expenditure side responds endogenously to these changes in public revenues so as to render the policy budget-neutral. In doing so, the paper focuses on the employment consequences of the tax reform, abstracting from analyzing potential feedback effects of a cleaner environment on employment. Further, this paper does not examine the optimal level of carbon taxation and no attempt is made to analyze the welfare effects of the tax reform.

There is already extensive literature on the employment effects of environmental policies[2]. My reasons for writing yet another paper on this topic are three. First, the paper extends earlier work by developing a model of the labor market which incorporates features relevant for analysis of this issue within a context of developing countries. In particular, features such as large informal sector, rural-urban migration, and severance payments are important elements of the model. This extension is important because earlier double dividend literature has focused on the case of developed countries. Second, the paper examines how different types of unemployment insurance policies influence the effects of green tax policies on the labor market. This point is highly relevant as unemployment insurance (UI) programs exist only in a handful of developing countries[3], but they are on the agenda in many. When introducing unemployment insurance programs, alongside the primary effect of protection of the unemployed, their implications for the effects of carbon taxation on labor market outcomes have to be analyzed. Third, most earlier papers on double dividend that explicitly model unemployment benefits have not attempted to calibrate and simulate the model and have thus failed to provide an extensive quantitative analysis. This point is also important because, as I will demonstrate in the paper, the theoretical model can add some interesting and novel results to the double dividend literature, once the model is simulated. For instance, I show that when higher energy taxes can reduce the income from self-employed work in the informal sector, and the government reduces the level of public spending, the overall tax burden (measured by the reduction in after-tax income of the private sector) can be reduced for energy tax rates below some threshold level. In this scenario, it is possible to achieve a triple dividend: a cleaner environment, a lower unemployment rate and higher after-tax income of private sector. I discuss the intuition in more detail below as well as other main findings of the simulation exercises.

The theoretical framework is an extension of Satchi and Temple (2009) to a setting with a polluting production factor and environmental taxes. The model features three sectors: urban formal, urban informal[4] and rural agriculture. 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 and the unemployment rate is defined as the self-employment in the informal sector. The income of the unemployed thus comprises of unemployment benefits and income from self-employment in the informal sector. The formal sector pays payroll and taxes on energy which is assumed to be a dirty input into a production process. The informal sector does not pay any taxes

[2]See, e.g., Bovenberg and de Mooij (1994),Goulder (1995), Bovenberg (1995), Bovenberg and van der Ploeg (1998)

[3]See, e.g., Vodopivec (2013), Velasquez (2010) and Gerard and Gonzaga (2012).

[4]Albrecht et al. (2009), Zenou (2008), Bosch and Esteban-Pretel (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, 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.

directly, and green tax policies can affect the income of the unemployed indirectly through their effects on formal sector wages. This is possible if unemployment benefits are indexed to formal sector wages and goods produced in the informal and formal sectors are perfect substitutes.

I assume government revenues coming from taxation of energy and labor in formal sector are used to provide general government goods and transfers to the unemployed. Both energy and capital used in production of formal sector goods only are exported at the international prices. Finally, the model also features rural-urban migration, under the assumption that migrants from agriculture first enter the informal sector. The model also includes severance payments because they are important aspects of labor markets in developing countries as well as of endogenous search intensity of workers in the informal sector. For simulations, I use a Cobb-Douglas technology to model production in the formal sector, implying unit elasticity of substitution between energy and labor. A Cobb-Douglas production function has been used widely (e.g., Golosov et al. (2012), Barrage (2012) and references therein), but has been shown to be a poor representation of energy demand in the short and medium term (e.g. Hassler et al. (2012)). Nevertheless, as argued by Hassler et al. (2012), a Cobb-Douglas technology 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. I also perform a sensitivity analysis with a nested CES production function, with the elasticity of substitution between energy and labor being 0.05.

I examine the effects of green tax policy on labor markets by calibrating the model to data for Mexico, solving the model numerically and performing simulations under different specifications of green tax policies. In particular, I consider green tax policies that are different along two dimensions. First, I distinguish between two different assumptions imposed on general public spending: I assume that general public spending is either a constant fraction of formal sector output or constant. Second, I make different assumptions about taxation of the income of the unemployed assuming that it could be either fixed to formal sector wages or fixed in real terms and also consider the cases when labor taxes are evaded and not in the informal sector. In each policy experiment I start with the baseline case, vary the energy taxes and compare the resulting steady-states. I investigate the effects of such exogenous changes in energy taxes on aggregate labor-market outcomes: unemployment rate (the size of the informal sector), after-tax income of the private sector and the size of the urban sector.

I calibrate the model to the Mexican data, since Mexico is an interesting case given that the country is considering the introduction of a UI scheme and removing pervasive energy subsidies in the electricity sector. Mexico is also a country with a large informal sector. Hence, energy subsidy reforms, along with unemployment insurance programs, are likely to have important consequences on labor market outcomes in Mexico.

The key findings from my simulations can be summarized as follows. First, given the objective of the paper I do answer the question: do green reforms reduce unemployment? I show that green tax policies can boost employment if the burden of the tax incidence (measured by the reduction in after-tax private income) is shifted towards the self-employed in the informal sector. If, however, the workers in the informal sector cannot be forced to contribute to the costs of a cleaner environment (when their income is fixed in real terms) or bear an equal relative burden, green tax policy does not generate any positive employment effects. This result is not novel and has been shown in a number of papers on double dividend (see, e.g., Bovenberg and van der Ploeg (1998),Bovenberg (1995)). In this paper, I demonstrate that in addition to the unemployed, the costs of cleaner environment is shared by workers in rural area, resulting in a decline in their income and thus in a higher incidence of poverty.

Raising the tax burden on unemployed people can, however, be attractive from an efficiency point of view. I show that such policies improve labor market incentives, increasing search efforts by the unemployed. An increase in search efforts in turn introduces a wedge between labor market tightness and the vacancies rate so that they no longer move in the same direction. In the model labor market tightness depends on both the vacancy rate and inversely on the average job search intensity. Green tax policies, by shifting the tax burden to the unemployed, push search efforts up and labor market tightness follows the dynamics of search intensity and falls. A less tight labor market reduces the expected duration of vacancies so that green tax policy, by creating large incentives to enter the formal sector, induces labor reallocation from the informal towards the formal sector with a higher turn-over rate than before.

Thus green tax policies tend to be costly in terms of equity, leading to a less equitable income distribution and policy-makers in developing countries are rightly concerned with potential implications of higher energy taxes on the incidence of poverty in rural areas. There is one exception to this outcome among all policy scenarios of green tax policies considered in the paper. If public spending, modeled as a fraction of formal sector output, falls, then a green tax policy may produce a triple dividend, as incomes of both formally employed and agricultural sector workers can increase, while income of the unemployed may decrease by much less than under other policy experiments. By reducing public expenditure, the government creates extra budgetary room to reduce the marginal tax rates on labor. This enables the government to offset the adverse effects of higher energy taxes on labor productivity, and thus reduce the overall tax burden[5] when the rate of energy taxes does not exceed some threshold level. For particularly high energy tax rates, the overall tax burden starts rising resulting in the J-curve pattern of the tax burden. The J-curve pattern of the overall tax burden is reflected in the hump-shaped response of after-tax wages in the formal sector, the agricultural sector and unemployment benefits. These results suggest that when general public spending is reduced, it is possible to improve the labor market consequences of green reforms by increasing after-tax income of the private sector.

I show that the hump-shaped responses of variables and the J-curve pattern are robust to variations in the energy intensity of the formal sector if the elasticity of substitution between energy and labor is equal to one. In contrast, when the elasticity of substitution is lower, as for example estimated by Hassler et al. (2012), with a CES production function, then the effects of green tax policies on labor market are negligible, as imposing a carbon tax has a small impact on the relative cost of labor, and thus on labor demand. As such, a very small decline in payroll taxes does not allow for a fall of the overall tax burden so that the J-curve pattern of the tax burden and consequently a hump-shaped response of variables disappear. These results are in line with findings of earlier studies that indicate the importance of the elasticity of substitution between energy and value-added (labor-capital composite) for the effectiveness of emission reduction initiatives [6]. In the context of this paper, these results imply that when elasticity of substitution is small, it is difficult to achieve not only a double dividend but also a first one. But such green tax policies are accompanied by

[5]This paper shares many insights and arguments presented in Bovenberg (1995). But to the best of my knowledge this is the first paper that formalizes many of these arguments into a theoretical model and provides an extensive quantitative analysis.

[6]See, for example, Jacoby et al. (2006) find that the elasticity between energy and value-added (capital-labor composite) significantly affects the costs of a "Kyoto forever" scenario for the US economy. Burniaux and Martins (2012) show that high inter-factor (between energy and value-added) and inter-fuel substitution elasticities can generate large carbon leakages.

higher public revenues and thus allow a potentially higher level of general public spending.

Thus, my main contribution to the existing double dividend literature comes from relaxing the assumption of constant public expenditure, which has been used in earlier literature to study revenue-neutral green tax policies. As shown in this paper, endogenous public spending is, however, an important ingredient of policies that governments may explore if they want to improve labor market effects of environmental policies.

Simulation results of the model have important implications for policy-makers who are concerned with employment and equity considerations of environmental policies. The results support the arguments of Bovenberg (1995) and others who argue that environmental policies are rather inefficient instruments for reaching labor market objectives. And if policy-makers confront with multiple objectives such as equitable income distribution, lower unemployment and a cleaner environment, they should employ multiple instruments. It should be noted, however, that other factors beyond the scope of the model (such as a suboptimal structure of existing taxes) could still enhance the employment effects of green tax policy[7]. My arguments should thus be seen merely as shedding light on some of the channels through which green tax policies can affect labor markets rather than giving the overall picture of the effects of green tax reforms in developing countries.

The paper proceeds as follows. Section 2 presents the model. Section 3 calibrates the model. Section 4 discusses results of the policy experiments. In the same section, I examine the sensitivity of the baseline results. Section 5 concludes.

2 Model

2.1 Overview

The model is an extension of Satchi and Temple (2009) to a setting with a polluting production factor and environmental taxes. Within the model, the economy is grouped into three sectors: urban formal, urban informal and rural agriculture. Workers in the urban sector can be either employed in the formal sector or self-employed in the informal sector. Search and matching frictions in tradition of Pissarides (2000) form the distinction between the informal ("unregulated") and the formal ("regulated") sectors. The informal sector cannot be taxed directly, while formal sector pays two types of taxes on use of labor (payroll) and of energy (carbon). Workers in the informal sector are assumed to be looking for a formal sector job. I use the term "unemployed" to describe people working in the informal sector (i.e. workers not in formal employment), and thus treat the unemployment rate, u, as a size of the informal sector. The income of the unemployed comprises two components: from self-employment in the informal sector (denoted as z) and unemployment benefits (denoted as b).

I assume that the economy imports both energy and capital at given world prices and both are inputs into formal production only [8]. The rural (agricultural) sector, on the other hand, is assumed to be perfectly competitive and characterized by full employment. Land and labor are the only production factors in the

[7] If the initial tax system is suboptimal from a non-environmental point of view, then a fiscal reform can reduce both pollution and unemployment, see, e.g., Goulder (1995). This issue is especially relevant for the case of less developed countries, as fiscal inefficiencies and constraints are particular prevalent there (see Poterba (1993)).

[8] This is a simplification and future work should consider the case when the agricultural sector uses energy as an input of production to model the presence of pervasive electicity subsidies in the agricultural sector in Mexico. It is estimated that tariffs were below cost-recovery in the agricultural sector by about 30 percent in 2005-2006. See IMF (2013)

agricultural sector. The output of the urban formal sector could be traded on international markets at given world prices and goods from both sectors are assumed to be perfect substitutes.

The economy is made up of a continuum of identical workers of mass one. The urban formal and the agricultural sectors are indexed by i as $i = m$ and $i = a$ respectively. Informal sector workers represent the fraction u of the urban labor force so that:

$$L_a + (1 - u)L_m + uL_m = 1 \tag{1}$$

I further assume that all workers are risk neutral. Labor is assumed to be mobile across urban and rural areas, and once workers migrate from rural areas, they first enter informal urban sector from which they search for jobs in the formal sector. Finally, I assume that government revenues coming from taxing energy and labor in formal sector are used to provide general government goods and transfers to the unemployed.

In what follows I structure the model, by first presenting a block of equations that describe the "basic" textbook search equilibrium and then I present a set of additional equations that extend the framework to include some other features relevant for the question under investigation. More specifically, these additional features include modeling of the agricultural sector and associated with it labor mobility between rural and urban areas, endogenous search intensity and the government budget constraint.

2.2 The basic search model

The key idea behind the search model is that there are mismatches in labor markets so that it is costly for firms and workers to find partners with whom they produce output. The presence of mismatches is summarized in the matching function:

$$M_t = m(suL_m, vL_m, M) = M(suL_m)^{\gamma}(vL_m)^{1-\gamma} = L_m m(su, v) \tag{2}$$

which gives the number of matches between firms and workers as a function of the number of unemployed workers, uL_m, depending on the search efforts of the informal sector workers, s and the number of open vacancies, vL_m.

$$q \equiv \frac{M_t}{vL_m} = M\left(\frac{su}{v}\right)^{\gamma} = M\theta^{-\gamma} \tag{3}$$

where

$$\theta = \frac{v}{su} \tag{4}$$

measures labor market tightness and $1/q$ the expected duration of a vacancy. Note that $q(\theta)$ is a decreasing function of θ, and I define $\varepsilon_\theta \equiv -q'(\theta)\theta/q > 0$.

The one departure of the model in this paper from the textbook search model is that I introduce endogenous intensity of search efforts of informal workers, s, which means that I will need an equation that describes the optimal level of search efforts. I will get back to this in the next section where I describe the second block of equations that describe the extension of the basic search model.

Matches between workers and firms break at an exogenous Poisson rate λ, at which point the workers return to the informal sector. In the steady-state, in and outflows in the formal sector must balance:

$$\lambda(1 - u) = m(su, v) \tag{5}$$

which determines the relationship between the unemployment rate and the rate of vacancies (labor market tightness). This relation is called Beveridge curve. Within the context of the search model, this equation can be interpreted as a quasi-labor supply equation.

Now I turn to the production side and now describe equations that define quasi-demand labor equation.

I assume that firms pay a flow cost c to post a vacancy. Once the vacancy is filled, firms employ one worker who is paid the wage w_m, rent capital K_m and import the polluting production factor energy E_m at exogenously given prices p_E. Each operating firm with its one employee thus 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 production technology. I also assume that firms are liable to energy and payroll taxes. Once employment is terminated, 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 (I discuss this in more details in the calibration section below).

In Appendix 8.1, I derive the job creation equation (or hiring locus), which together with the wage determination equation (defined below), forms a quasi-labor demand equation.

$$y(k_m, e_m) - (1 + \tau_L)w_m - (\lambda + r)\frac{c}{q} - \lambda P = 0 \tag{6}$$

For the Cobb-Douglas production function and the assumption that hiring costs are a fixed proportion ν of the producer wage in the formal sector, $c = \nu(1 + \tau_L)w_m$, the equation (6) becomes:

$$y(k_m, e_m) = (1 + \tau_L)w_m \left[1 + (\lambda + r)\frac{\nu}{M}\theta^{\gamma}\right] + \lambda P \tag{7}$$

so that labor productivity equals total wage costs, including direct remuneration, the expected capitalized value of its hiring costs and expected severance payments.

The final equation that is needed to complete the basic search model is the wage determination equation. The presence of transaction costs in labor markets generates monopoly rents which are divided between firms and workers through a Nash bargaining process which determines the wages at which workers are employed. In Appendix 8.1, I derive the wage equation as the solution to a Nash bargaining problem:

$$\frac{w_m - (z + b - \sigma)}{w_m} + \frac{\lambda P}{w_m} = \frac{\beta}{1 - \beta}\nu\left(\frac{r + \lambda}{q} + s\theta\right) \tag{8}$$

The higher the bargaining power of workers (β), the larger is formal sector income (including expected severance pay). A higher interest rate (r), a larger separation rate (λ), or a tighter labor market (θ) raise the rents from a job match and thus raise the wage. The combination of supply and demand equations implies that this is an equilibrium model in the sense that both unemployment and wages are determined endogenously. I will now turn to a discussion of the extension of this simple set-up.

2.3 Additional equations

The basic framework outlined in the previous sub-section can be extended or embedded into large macro models to study the effects of various government policies. I extend it by incorporating features such as (1) rural-urban migration; (2) endogenous search efforts of the unemployed and (3) a government budget constraint to study the effects of tax reforms. To model rural-urban migration, I first need to define the agricultural sector.

Agricultural sector The agricultural sector is modeled as a subsistence agriculture, assuming that it does not use energy as an input into production; agricultural capital and labor are the only production factors. As in Satchi and Temple (2009), agricultural capital is interpreted as land. Hence, in agriculture each worker produces an output $g(k_a)$, where $g(k_a)$:

$$k_a = \frac{K_a}{L_a} \tag{9}$$

The worker is paid a wage w_a, and derives positive utility from living in a rural area, $\chi_a > 0$. The agricultural sector is assumed to be perfectly competitive, which implies that:

$$w_a = g(k_a) - g'_k(k_a)k_a \tag{10}$$

where $g'_k(k_a) = r_a$ denotes the rental costs of capital in the agricultural sector.

Informal sector and search intensity In the informal sector, each worker receives a utility $z + b - \sigma(s; z, \Pi)$, where z denotes the labor productivity (output) of each worker[9], b denotes unemployment benefits, and $\sigma(s; z, \Pi)$ represents formal job search costs.

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:

$$\bar{q}_i = \frac{s_i}{suL_m} m(suL_m, vL_m) = s_i q\theta = s_i M\theta^{1-\gamma} \tag{11}$$

I impose symmetry and assume that every unemployed worker searches for a job with the same level search intensity s, so that $sq\theta$ is the probability of finding a job for every job searcher.

Following Satchi and Temple (2009), in Appendix 8.1 I derive an equation that determines the optimal level of search intensity:

$$\sigma'_s(s) = \frac{\beta}{1-\beta}\theta\nu w_m \tag{12}$$

which is derived by imposing symmetry. The equation (36) equates the informal sector worker's marginal search costs, σ_{s_i} to the expected benefits of job search.

Urban-rural migration As in the original 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 $\theta_f|f|$, where θ_f represents the congestion effect caused by migration intensity and f represents migration flows from the agricultural sector to the city (a negative sign would imply a migration flow in the opposite direction). In steady-state migration flows have seized so that $f = 0$, and the migration equation (see Appendix 8.1 for details) is:

$$w_a + \chi_a = z + b + \sigma[\varepsilon_\sigma - 1] \tag{13}$$

[9] 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.

Equation (39) implies that in the steady-state, workers are indifferent between staying in agriculture and the informal urban sector. The migration equation (39) 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.

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

$$G + uL_m b = \tau_L w_m (1-u) L_m \left(1 + \nu \frac{r+\lambda}{q}\right) + \tau_{e,m} p_E e_m (1-u) L_m, \tag{14}$$

Government revenue includes revenues from taxing energy in the formal sector $\tau_{e,m} p_E e_m (1-u) L_m$, total payroll taxes paid by employees in the formal sector, $\tau_L w_m (1-u) L_m$, and from taxing capitalized recruitment costs, $\tau_L w_m (1-u) L_m \nu (r+\lambda)/q$. As a severance payment is only made to departing employees, it does not appear in the government's budget constraint.

I can re-write the budget constraint, by normalizing it with respect to the number of workers in the urban sector[10]:

$$g + ub = \tau_L w_m (1-u) \left(1 + \nu \frac{r+\lambda}{q}\right) + \tau_{e,m} p_E e_m (1-u) \tag{15}$$

where $g \equiv G/L_m$.

3 Parameterization

The model calibration involves selecting parameter values that are as consistent as possible with the main empirical features of labor markets in Latin American countries, especially Mexico. I calibrate the parameter values using the latest available official data and values similar to existing studies that analyze labor market policies in Latin American countries. The time period is assumed to be one month. The baseline parameter values are summarized in Table 9; Table 1 reports the characteristics of the labor market implied by the theoretical model as well as the corresponding values from Mexican data.

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 γ equal to 0.5 (as in Pissarides (1998), Satchi and Temple (2009) and Zenou (2008)). M and s are chosen to yield a plausible value for the duration of employment and the size of unemployment benefits (bearing in mind that unemployment benefits are lower than wage in any case). The average duration of employment in Mexico is considerably different for women and men, ranging from 12 to 27 months (data from 1993, see Gong and van Soest (2002)). Albrecht et al. (2009) obtain a value of 3.5 years for the duration of employment and Satchi and Temple (2009) 17 months. The parameterization ($M = 0.1$ and $s = 0.5$) yields a value of 16.33 months for the average duration of employment, a figure in between the estimates obtained in the literature as well as in the data.

[10] In the technical appendix 8.2, I demonstrate that the balance of payments equation is a redundant for the steady-state equilibrium of the model, as it can be obtained by substitution of the wage determination equation into the government's budget constraint

The cost of posting a vacancy, $c = \nu(1+\tau_L)w_m$, with the value of ν set at 0.4, constitutes 48% of the wages in the formal sector[11]. The parameter z_p governs the value of the severance payment. Following Satchi and Temple (2009), I assume that the average severance payment 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 severance payment systems in Latin American countries are usually more developed than unemployment benefit schemes and the evidence shows that severance payments, on average, exceed the protection provided by unemployment benefits, whose maximal duration is 12 months in most cases[12]. Given this parameterization, the model is consistent with existing empirical evidence and implies that severance payments are 24% higher than the protection provided by unemployment insurance, if the benefits are received for 12 months.

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, λ, 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 λ at 0.06. I decide to set λ to 0.04.

The parameterization yields an unemployment rate of 33%. Satchi and Temple (2009) use a value of 0.30 for the share of informal sector employment, Albrecht et al. (2009) report that estimates for some Latin American countries are even higher with 38.3% of the work force being in informal sector employment in their model. According to labor statistics of the ILO, the official unemployment rates in Latin American countries are low. The figure for Mexico was only 3.5% in 2008, Brazil 8.2% (2007), Peru 6.8% (2008), Venezuela 6.9% (2008). At the same time, the number of people employed in the informal sector as a share of non-agricultural employment in these countries is much higher[13]: Mexico 34.1% (2009, 2Q), Argentina 32.1% (2009, 4Q), Brazil 24.3% (2009), Colombia 52.2% (2010, 2Q). Given that in the model I treat the "unemployed" as workers engaged in informal employment in the informal sector, the value 34.1% is suited better for this purpose and it is also close to the value implied by the model.

Using labor force survey data for 1991, Satchi and Temple (2009) find that the formal sector wage is about 80% higher than the rural wage (thus, the rural wage accounts for approximately 55% of the formal urban wage, a value also obtained by Albrecht et al. (2009)). This suggests that the direct utility from living in a rural area χ_a has to be sufficiently high to deter migration. Using more recent data for Mexico, I target a ratio of 1.93 between formal and rural sector wage, which gives the inverse relationship of 0.52, an estimate close to both Satchi and Temple (2009) and Albrecht et al. (2009). The exogenous price of energy p_E is set to 4.47, which along with other parameters, yields a ratio of 1.93.

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

$$\sigma(s) = \Pi z s^{\phi} \tag{16}$$

I assume that $\phi = 2$ in line with Satchi and Temple (2009) and the value of parameter Π is chosen to generate plausible values for both productivity in the informal sector and the total income of the unemployed. The

[11]Satchi and Temple (2009) set the ratio c/w_m equal to 0.4.

[12]Hijzen (2011) reports that in Brazil the average value of support provided by the severance pay system is about 50% larger that that provided by UI.

[13]This share also comprises of 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 on the number of people in informal employment and the number of people in informal employment outside the informal sector. My estimate is 33.5%. Source: ILO (2012)

model implies that the total income of the unemployed $(b + z)$ constitutes 61% of the formal sector wage, whilst unemployment benefits make up 27.03% of formal sector wages, which is slightly lower than the data on unemployment benefits in Latin American countries suggest (see also the discussion in Section 7.4 and Table 10). This suggests that the search intensity costs account for about 43.74% of the total income of the unemployed. This also implies the values $\pi_b = 0.27$ and $\pi_z = 0.29$ for the coefficients in the indexation rules $b = \pi_b w_m$ and $z = \pi_z(1 + \tau_L)w_m$ (see the discussion in next section 4.1 about I model different taxation scenarios of the income of the unemployed).

The agricultural employment share, L_a, is set to 0.13, which matches the recent data for Mexico. Satchi and Temple (2009) use the value 0.28 to match the ILO data for Mexico in 1990. However, over the years the share of agricultural employment in Latin and South American countries has decreased substantially and while in some, such as Nicaragua (32%), Honduras (36%), Paraguay (27%) - it remained fairly high even in 2010. Conversely, for Mexico the 2010 value was 13%, Chile 11%, Uruguay 12% (2011), Venezuela 8% (2011)[14]. The value of χ_a is then inferred from the model.

The production functions of both the formal and the agricultural sector are assumed to be Cobb-Douglas functions:

$$Y_m = A_m K_m^{\alpha_1} E_m^{1-\alpha_1-\alpha_2}((1-u)L_m)^{\alpha_2}; \quad Y_a = A_a K_a^{\gamma_1} L_a^{1-\gamma_1}; \tag{17}$$

which implies that the production functions in intensive form in the formal and the agricultural sector are given by:

$$A_m f(k_m, e_m) = A_m k_m^{\alpha_1} e_m^{1-\alpha_1-\alpha_2}; \quad g(k_a, e_a) = A_a k_a^{\gamma_1} \tag{18}$$

I set the shares of labor and capital in domestic outputs as follows: $\alpha_1 = 0.269$, $\alpha_2 = 0.324$ (consistent with evidence for China based on a Cobb-Douglas production function with energy input, see Yuan et al. (2009)), and $\gamma_1 = 0.63$ (Satchi and Temple (2009)). These shares, along with other parameter values, yield a value of the share of energy costs in total production $(\omega_E \equiv p_E(1 + \tau_{e,m})e_m/(A_m f(k_m, e_m)))$ of 40.7%. This is slightly above the estimates of the value of energy input per unit of value added in manufacturing sub-sectors across developing countries (Upadhyaya (2010)), which provides an estimate of 35% for non-metallic mineral products. 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. (2012), Barrage (2012)) of $1 - \alpha_1 - \alpha_2 = 0.03$. This value is however based on estimates of the energy share of production in developed countries. Due to this fact, I proceed with the above-mentioned value of 40.7% and perform sensitivity analyses using other values of $1 - \alpha_1 - \alpha_2$.

A Cobb-Douglas technology has been used widely (see Golosov et al. (2012) as well as Barrage (2012) and references therein), but has been shown to be a poor representation of energy demand in the short-and-medium term (e.g. Hassler et al. (2012)). Nevertheless, as argued by Hassler et al. (2012), a Cobb-Douglas technology 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. Nevertheless, I also perform a sensitivity analysis with a nested CES production function:

$$Y_t = [(1-\gamma_2)[A_t K_t^{\alpha} L_t^{1-\alpha}]^{\frac{\varepsilon-1}{\varepsilon}} + \gamma_2 [A_t^E E_t]^{\frac{\varepsilon-1}{\varepsilon}}]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{19}$$

where L is labor, A_t the capital/labor-augmenting technology (later called A_m), A^E fossil energy-augmenting

[14]Based on the SL.AGR.EMPL.ZS indicator published by the World Bank (http://data.worldbank.org/indicator/SL.AGR.EMPL.ZS).

technology, ϵ the elasticity of substitution between capital/labor and fossil energy, and γ_2 is a share parameter. In intensive form it can be written as:

$$y(k_m, e_m) = [(1-\gamma_2)[A_t k_t^{\alpha}]^{\frac{\varepsilon-1}{\varepsilon}} + \gamma_2 [A_t^E e_t]^{\frac{\varepsilon-1}{\varepsilon}}]^{\frac{\varepsilon}{\varepsilon-1}} \tag{20}$$

I set the values of the parameters of the production function as follows: $\alpha = 0.3$, $\epsilon = 0.05$[15] and $\gamma_2 = 0.1$[16]. 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.

As K_a stands for a fixed factor in agricultural production I can normalize its value to one without loss of generality. Thus, given the knowledge of L_a, this pins down the value of land per worker in the rural sector, $k_a = 1/L_m$. In choosing productivity parameters in the urban and agricultural sector, it is useful to rely on empirical evidence that shows a large productivity gap in both sectors in developing countries, citing values added per worker in the non-agriculture sector as much as four times higher than in agriculture. When adjusted for different factors (sector differences, human capital per worker), the gap can be halved (see Gollin et al. (2013)). Accordingly, I set the productivity in the agricultural sector, A_a, to 1 and the productivity in the urban sector, A_m, to 2.

The value of the parameter that governs the bargaining power of workers, β, is usually set at 0.5 (see, e.g., Mortensen and Pissarides (1994), Zenou (2008), Albrecht et al. (2009), Pissarides (1998)). In contrast, Satchi and Temple (2009) treat the parameter β as unknown and infer its value from a calibration based on the informal sectors size in Mexico, obtaining an estimate of β at 0.7. I follow the literature and assume the symmetric Nash bargaining solution. Setting β at 0.7 would lead to a shorter duration of employment, as well as a higher informal share of total employment, which would be inconsistent with the data.

The payroll tax rate, τ_L is set at 0.19, which is based on OECD data on the average labor income tax (tax wedge) faced by Mexican workers (19.0% in 2012)[17]. Payroll taxes may make up a maximum 35% of payroll in Mexico (see Handbook (2012)). The values used in the literature differ considerably - while Satchi and Temple (2009) use a value of 0.1, Albrecht et al. (2009) use a much higher value for baseline payroll taxes. They set τ_L=0.5, reporting that values in the range between 0.40 and 0.60 are also acceptable. The choice of the appropriate energy tax value is a more complicated issue, as environmental taxes are rarely imposed as a percentage and usually as some fixed amount per tonne, liter or kWh. For the baseline calibration, I choose a value of 0.15.

I assume that government spending accounts for 0.05 of formal sector output, which is lower than the empirical evidence for Latin American countries suggests (for 1998 the share of government spending in output in Latin American countries ranges from 9.18% in El Salvador to 33.31% in Uruguay (Fan and Rao (2003)), but it allows me to match the labor data statistics rather well.

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.

[15]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 $A = A^E$.

[16]Empirical estimates of the share of energy in production γ_2 vary by industry. For example, Dissou et al. (2012) find that the value of γ_2 varies between 0.024 (transportation equipment) and 0.186 (primary metals). Hence, I set the value of γ_2 in the range of these estimates, close to estimates of the energy share in non-metal mineral products or in chemicals.

[17]http://www.oecd.org/ctp/tax-policy/taxingwages-mexico.htm

Labor market characteristics	Model	Data	Source
Agricultural employment share, L_a	0.13	0.13	Mexico 2010, World Bank (SL.AGR.EMPL.ZS)
Unemployment (informal sector share), u	33%	34.1%	Mexico 2009, LABORSTA, ILO
Formal sector wage/rural wage, w_m/w_a	1.93	1.93	Mexico (LABORSTA, ILO) average 1995-2008[18]
payroll tax rate, τ_L	0.19	0.19	Mexico (2012) OECD
Average employment duration	16.33 mths	12-27 mths[19]	Mexico (1992,1993) Gong and van Soest (2002)
Unemployment benefits/wage (formal)	27.0%	30-60%	Chile, Venezuela, see Velasquez (2010)

Table 1: Labor market characteristics: data vs. model

4 Budgetary neutral green tax policies

In this section I present the simulation results of the model by starting with an outline of policy experiments and a discussion of the channels through which exogenous changes in tax policy are spread to labor markets.

4.1 Policy experiments

I examine the effects of green tax policy on labor markets by solving the calibrated model numerically and performing policy experiments. I carry out four policy experiments, which I distinguish along two dimensions. First, I make different assumption about public expenditure g, considering two cases when government spending is a fraction of output $g = 0.05A_m f(k_m, e_m)$ and thus varies in response to changes in tax policy, and second when government spending is exogenous, by fixing its value to its baseline value $g = \bar{g}$. The second dimension along which I distinguish across different policy experiments is different taxation scenarios of the income of the unemployed. These taxation scenarios have been motivated by stylized facts on the existing unemployment schemes prevailing in a sample of Latin American countries (see Appendix 7.4 for more details). In most countries in the sample, unemployment benefits are tied to earnings, but minimum or maximum thresholds do exist, suggesting that the taxation system is thus also similar to a flat-rate system when the level of unemployment benefits does not not depend on the previous income of a given person. Thus, in my analysis, I distinguish between two cases with respect to to the unemployment benefits and productivity in the informal sector. First, I assume that the size of unemployment benefits is fixed in real terms resembling the flat-rate tax system: $b = \bar{b}$. I make a similar assumption for the income from self-employment: $z = \bar{z}$. Second, I make unemployment benefits earnings-related by assuming that $b = \pi_b w_m$. In that case, I also assume that income in the informal sector is indexed to the income of workers in the formal sector as $z = \pi_z w_m$[20]. I also consider a variation of this taxation scenario assuming that labor

[20] Similar indexation schemes has been considered by Bovenberg and van der Ploeg (1998) in their analysis of implications of budget-neutral switching from employment to anti-pollution taxes. Pissarides (1998) has also analyzed the effects of employment tax cuts on unemployment and wages depending on whether unemployment compensation is fixed in real terms or is indexed to wages. Bovenberg and van der Ploeg (1994) have also analyzed the impact of taxation in labor markets under different assumptions regarding the indexation of unemployment benefits.

taxes are evaded in the informal sector so that $z = \pi_z(1+\tau_L)w_m$. In sum, I consider the following green tax policies depending on different taxation scenarios of the income of unemployed: (1) $b = \bar{b}$, $z = \bar{z}$, g varies; (2) $b = \pi_b w_m$, $z = \pi_z w_m$, g varies; (3) $b = \pi_b w_m$, $z = \pi_z(1+\tau_L)w_m$, $g = \bar{g}$; (4) $b = \pi_b w_m$, $z = \pi_z(1+\tau_L)w_m$, g varies.

4.2 The impact of tax policy on labor market outcome: discussion of channels

In the model there are three distinct channels through which green tax policy can affect labor markets. First, the tax policy, by influencing the income of the unemployed, affects the bargaining position of workers. Policy action that increases unemployment benefits or (indirectly) income from self-employment, by improving the bargaining strength of workers, leads to higher wages and lower employment (Pissarides (1998)).

Second, the green tax policy affects labor market through the overall tax burden on labor[21]:

$$\hat{\tau} \equiv \hat{\tau}_L + \frac{\omega_E}{\omega_L}\hat{\tau}_{e,m} \tag{21}$$

where changes in taxes are expressed as absolute deviations from their baseline values, and

$$\omega_L \equiv y(k_m, e_m)/(A_m f(k_m, e_m)); \quad \omega_E \equiv p_E(1+\tau_{e,m})e_m/(A_m f(k_m, e_m)) \tag{22}$$

stand for the shares of total labor costs and energy costs in total production respectively. Labor taxes raise wage costs directly, whereas energy taxes raise wage costs indirectly by discouraging energy use and reducing labor productivity. Thus, if the drop in payroll taxes is not sufficient to compensate for these adverse effects of energy taxes, green tax policy raises the overall tax burden resulting in higher wage costs per unit of output or lower after-tax wages. If a higher tax burden is reflected in higher labor costs, then such tax policy is likely to discourage the demand for labor and thus to harm employment.

Finally, green tax policy affects the labor market via affecting severance payments, which enters the calibration as $P = z_P(1+\tau_L)w_m$. Lower payroll taxes reduce severance payments and thus lower the costs of filling a vacant job, thus reducing the labor market tightness, θ.

4.3 Summary: results from all policy experiments

Table 2 summarizes the effects of an increase in energy taxes from $\tau_{e,m} = 0.15$ to $\tau_{e,m} = 0.3$ on key labor market characteristics under different policy scenarios. The labor market characteristics include the unemployment rate, u, after-tax real income of the private sector (formal sector wage, w_m , income of the unemployed, $b+z$, rural sector wages, w_a), search efforts, s and labor market tightness θ. From the table we see that, for instance, the first green tax policy is associated with a decline in after-tax wages by 3.1%, wages of of agricultural workers by 7.4%, decline in both search efforts and labor market tightness.

First, it is important to note that the overall tax burden (not reported in the table) rises in all but the last policy experiment when it follows the J-curve pattern explained in more details in the next section. The overall tax burden measured by a loss in after-tax income of the private sector rises because a reduction in payroll taxes does not fully offset the adverse effects of the pollution tax. The erosion of the energy tax base is a reason of the incomplete offset. The erosion of the base of the energy tax results in lower public revenue so that the government is unable to reduce labor taxes sufficiently to compensate the workers for the adverse

[21]This definition of the aggregate tax burden was first introduced by Bovenberg and van der Ploeg (1998)

	g	UI	u	$\triangle w_m \downarrow\%$	$\triangle(b+z) \downarrow\%$	$\triangle w_a \downarrow\%$	s	θ
1.	g varies	$b = \bar{b}$ $z = \bar{z}$	$\uparrow$	3.1	0	7.4	$\downarrow$	$\downarrow$
2.	g varies	$b = \pi_b w_m$ $z = \pi_z w_m$	$\uparrow$	1.9	1.9	6.2	$\downarrow$	$\downarrow$
3.	$g = \bar{g}$	$b = \pi_b w_m$ $z = \pi_z(1+\tau_L)w_m$	$\downarrow$	3.6	9.5	8.9	$\uparrow$	$\downarrow$
4.	g varies	$b = \pi_b w_m$ $z = \pi_z(1+\tau_L)w_m$	$\downarrow$	-0.01	7.5	2.5	$\uparrow$	$\downarrow$

Table 2: Effects of an increase in $\tau_{e,m} = 0.15$ to $\tau_{e,m} = 0.3$ on labor market: four policy experiments

effects of energy taxes to maintain overall tax revenue for the provision of public goods and unemployment benefits.

The table first demonstrates that a double dividend (a decline in the unemployment rate) occurs when the additional tax burden associated with higher carbon taxation is shifted more on the unemployed. The intuition is that a cleaner environment is not a free good and someone has to bear its costs. In the first policy experiment, the income of the unemployed remains unaffected by green tax policy, and so that the tax burden of environment protection is borne by workers in the remaining sectors of the economy, urban formal and agricultural. On the other hand, under the second policy experiment, 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 (1.9%) when carbon taxes are increased from 15% to 30%. But this proves to be insufficient for a double dividend to occur. Instead, only when the additional tax burden due to a higher energy taxes is shifted more on the unemployed (the third and fourth policy experiments), green tax policy results in a lower unemployment rate.

It is also important to note that a large share of the tax burden falls on agricultural workers in all but the last policy experiment. Thus, policy-makers in developing countries are rightly concerned with a potentially higher incidence of poverty in rural area resulting from higher energy taxes. The explanation is that in the first two policy experiments, 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 increased. In the third green tax policy, a higher burden of taxation imposed on workers in the informal sector prompts the unemployed to escape the brunt of taxation by searching for a job in the formal sector or by migrating into rural areas. As before, an inflow of labor into agricultural sector pushes wages down in the sector. In the last environmental policy, agricultural wages w_a follow a hump-shaped pattern and this will be discussed in more detail in the next section. In addition to w_a, w_m and b also follow a hump-shaped pattern in response to higher energy taxes under the last environmental policy. This suggests that labor market implications of green tax policies can be improved. In particular, with an appropriate choice of energy taxes, green tax policy can produce a triple dividend: a cleaner environment, a lower unemployment rate and a higher after-tax income of private sector. This is possible because, by using the additional policy instrument of public expenditure, governments can cut overall tax burden and thus raise the after-tax income of the private sector. The discussion of the mechanism is provided in the next section.

Green tax policies that raise the tax burden on the unemployed could be still attractive from an efficiency point of view, as they improve labor market incentives: search efforts s by the unemployed increase in the last two policy cases. Such behavior of search efforts introduces a wedge between labor market tightness θ and the vacancy rate v so that these variables move in opposite directions. More specifically, with the endogenous value of search intensity, labor market tightness depends on two factors: the number of vacancies relative to the number of unemployed workers v/u, and also on the average search intensity of unemployed people (s):

$$\theta = \frac{v}{u}\frac{1}{s} \tag{23}$$

In the first two policy experiments, the labor market is less tighter because there are more unemployed workers relative to a number of vacancies in an economy, and θ follows the dynamics of the first channel v/u and falls. In contrast, in the last two policy scenarios, green tax policy, which reduces payroll taxes and raises energy taxes, imposes a heavier burden on the unemployed, through the effect on their income from self-employment z. In these cases, the unemployed attempt to evade taxation by a seeking job in the formal sector more actively, so that s rises. The higher search intensity makes it easier for employers to fill vacancies, and the labor market tightness, θ, by following the dynamics of search intensity s, falls. A less tight labor market reduces the expected duration of vacancies ($1/q(\theta)$) so that green tax policy of the third and fourth scenarios, by creating large incentives to enter the formal sector, induces labor reallocation from the informal towards the formal sector with a higher turn-over rate than before.

4.4 Green tax policy: $b = \pi_b w_m$ and $z = \pi_z(1+\tau_L)w_m$

In this section, I examine the effects of varying the energy taxes under the following indexation scheme: $b = \pi_b w_m$ and $z = \pi_z(1+\tau_L)w_m$, where values of π_b and π_z are fixed at 0.2703 and 0.2855 baseline values respectively.

Taxes										
$\tau_{e,m}$	τ_L	θ	u	w_m/w_a	w_m	z	b	s	L_m	v
0.1500	0.1900	2.6683	0.3287	1.9309	2.5833	0.8776	0.6982	0.5000	0.8700	0.4386
0.1575	0.1784	2.6649	0.3270	1.9337	2.5879	0.8706	0.6995	0.5043	0.8701	0.4395
0.1650	0.1671	2.6614	0.3253	1.9365	2.5920	0.8637	0.7006	0.5085	0.8701	0.4403
0.2000	0.1194	2.6451	0.3182	1.9505	2.6054	0.8327	0.7042	0.5269	0.8697	0.4435
0.2500	0.0623	2.6219	0.3098	1.9725	2.6106	0.7917	0.7056	0.5504	0.8677	0.4470
0.3000	0.0149	2.5996	0.3028	1.9968	2.6034	0.7543	0.7036	0.5712	0.8646	0.4496
0.3500	-0.0251	2.5784	0.2970	2.0232	2.5867	0.7200	0.6991	0.5898	0.8603	0.4516

Table 3: The effects of varying the energy tax rate: $b = \pi_b w_m$ and $z = \pi_z(1+\tau_L)w_m$

Table 3 reports the simulation results. The green tax policy with a constant replacement ratio results in a decrease in both the unemployment rate (u) and labor market tightness (θ), an increase in search intensity

(s), a decrease in informal sector income (z) and hump-shaped response patterns of formal sector wages (w_m), unemployment benefits b, city size (L_m) and w_a. This green tax policy is also associated with the "elasticity" of payroll taxes with respect to the energy taxes ($\varepsilon_\tau \equiv \frac{\triangle\tau_L}{\tau_L b} : \frac{\triangle\tau_{e,m}}{\tau_{e,m} b}$[22]) being greater than unity for low values of energy tax rates and less than unity for higher values of energy tax rate. In particular, a 5% increase of the energy tax lowers the payroll tax by 6.1%, resulting in an elasticity of $\varepsilon_\tau = 1.22$; similarly an increase in the tax on energy makes enables a decrease in payroll taxes by 12.05%, with a resulting elasticity value $\varepsilon_\tau = 1.2$. In contrast, an increase in energy taxes from 15% to 30% reduces payroll taxes from 19% to 1.5%, with the elasticity $\varepsilon_\tau = 0.92$.

When both unemployment benefits and income from the informal sector are related to labor productivity in the formal sector, a green tax reform directly influences total income during unemployment. But labor taxes and energy taxes do impact income during unemployment differently. Payroll taxes do not affect the 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 the productivity in the informal sector. Thus, green tax policy that involves replacing payroll taxes with energy taxes imposes a heavier burden of taxation on unemployed, through its effect on income from self-employment.

As such, decrease in the share of z is conceivable with higher level of energy taxes. This is indeed the case in the simulations. The unemployment benefits represent 44.3% of the total income of the unemployed in the baseline case at $\tau_{e,m} = 0.15$, but is then steadily increasing until 48.3% at $\tau_{e,m} = 0.3$ and 49.3% at $\tau_{e,m} = 0.35$. This implies increased dependence of the unemployed on benefits provided by the government rather than on income from self-employment in terms of income and consumption smoothing.

An increase in energy taxes affects the economy through two channels. First, it decreases energy demand, which results in an erosion of the energy tax base. Second, lower demand for energy reduces labor productivity and thus demand for labor. As discussed earlier, by shifting the tax burden on the unemployed, environmental policy can produce a double dividend. But this is also true for the third policy experiment. What makes the current green tax policy different from the third one is that the government now can vary the level of public spending which leads to (1) elasticity $\varepsilon_\tau > 1$ for low values of the energy tax rate and decreasing with respect to an increase in $\tau_{e,m}$; (2) a hump-shaped responses of w_m, b, w_a and L_m.

Intuitively, reduction in payroll taxes creates an extra budgetary room that the government can use to reduce marginal taxes on labor by more resulting in an elasticity ε_τ greater than one. As the government needs to raise sufficient revenue to cover its expenditures, with higher energy taxes the government is unable to reduce labor taxes sufficiently large and thus unable to maintain the high elasticity level, as higher energy taxes lead to an erosion of the energy tax base. This explains why the elasticity is a decreasing function of $\tau_{e,m}$. This also reflects the fact that green taxes have a narrower base than labor taxes and thus raising revenue through carbon taxation is more costly than through labor taxes.

Lower payroll taxes enable the government to offset the adverse effect of a higher energy tax on labor productivity and to lower the overall tax burden. For particularly high energy tax rates, a reduction in payroll taxes is not sufficient to compensate for such adverse effects and thus the tax burden starts increasing after some threshold level. The erosion in the energy tax base is a reason why the government is unable to offset the negative effects of the pollution tax. This results in the J-curve pattern of the overall tax burden, it is initially falling before it raising.

[22] $\tau_L^b = 0.19$ and $\tau_{e,m}^b = 0.15$ are baseline values and $\triangle\tau_i = \tau_i - \tau_i^b, i = L; e, m$

The J-curve pattern of the tax burden is reflected in a hump-shaped responses of w_m, b ($b = \pi_b w_m$) as well as w_a and L_m that peak at the same level of $\tau_{e,m}$, but earlier than w_m. First, this is because w_a is an increasing function of L_m only and thus L_m follows the pattern of w_a. Second, the early turning points for both w_a and L_m can be explained by referring to the migration equation and using the indexation rule $z = \pi_z(1 + \tau_L)w_m$ which shows that there are three factors that move w_a in different directions: w_m and b follow hump-shaped pattern, s increases and τ_L falls, so given these factors the resulting behavior of w_a depends on which dominate. Under the baseline calibration, w_a results in a hump-shaped response before the turning point of w_m is reached.

The main contribution of the paper comes from results of this policy experiment, which include a J-curve pattern of the overall tax burden and associated with it a hump-shaped response of after-tax private sector income (unemployment benefits, after-tax income of formal sector workers and wages of rural sector workers). Thus, it is important to investigate how these results are robust to changes in value of the key parameters and functional forms, which I examine in the next section.

5 Robustness checks

In this section, I examine the robustness of the baseline numerical results obtained under the second policy experiment: the hump-shaped pattern of w_m and the J-curve pattern of the tax burden. I start by varying the parameter that governs the costs of the search intensity function (Π); as it turns out, the value of Π does not affect the hump-shaped pattern, but the magnitude of the energy tax rate at which w_m peaks. Next, I vary the key parameter in the production function, the energy expenditure share, to examine its effect on the J-curve pattern of the tax burden. I find that the value of the energy share matters, substantially affecting the magnitude of the energy tax rate at which green tax policy raises the overall tax burden in an economy, but remaining the J-curve pattern unaffected. Finally, I repeat the three baseline policy experiments with a nested CES production function instead of the Cobb-Douglas production function used in the baseline specification.

Varying the costs of search intensity In the baseline case, the value of the parameter Π governs the costs of search intensity, $\sigma(s) = \Pi z s^{\phi}$ and was chosen to yield plausible productivity values in the informal sector (z) and consequently for the total income of the unemployed ($z + b$). By affecting the value of z, the parameter Π may alter both the hump-shaped pattern and its peak. The baseline value of Π is 3.14 and, by varying its value between 2.5 and 4, I repeat the simulations of the second policy experiment. I find that with a lower value of Π, the hump-shaped pattern in w_m peaks at higher energy tax rates (see Table 4). For a low value of Π, the steady-state value of productivity (z) is higher to deter migration from the urban informal sector to the agricultural sector[23]. A higher value of z indicates that a larger rise in carbon taxes is required to induce a significant reduction in the total income of the unemployed through the impact on z. Thus, energy taxes do impose a heavier burden on the unemployed for larger values of $\tau_{e,m}$ when z is higher, which explains why the hump-shaped pattern peaks at a higher level of energy taxes.

[23]The inverse relation between z and Π can be inferred from the steady-state optimal search intensity equation $\Pi z \phi s^{\phi-1} = \beta/(1-\beta)\theta\nu w_m$

			baseline		
Π	2.5	3.0	3.14	3.5	4.0
$\tau_{e,m}$	0.3	0.25	0.25	0.25	0.2

Table 4: Robustness of hump-shaped pattern in w_m to changes in Π

Varying the energy intensity of the formal sector The results of the J-curve pattern of the tax burden ($\hat{\tau} \equiv \hat{\tau}_L + \omega_E/\omega_L \hat{\tau}_{e,m}$) and thus the hump-shaped response of formal sector wages depend crucially on the energy and labor intensity of formal sector production. The baseline estimate of ω_E/ω_L is 40.7%, which as discussed in Section 3, implies a highly-intensive production process.

Except for industries producing non-metallic mineral products, industries overall tend to have a rather low energy intensity. For instance, the energy costs for a net output of US$1,000 in the electrics sector in developing countries is calculated at less than US$50 (see, e.g., Upadhyaya (2010)). I keep the value of α_1, the expenditure share of capital, at its baseline value of 0.269[24] and vary the expenditure share of energy $1 - \alpha_1 - \alpha_2$ between 0.407 (baseline) and 0.04[25]. The change in the values of energy expenditure share strongly affects the results Figures 1 show the responses of both formal wages and the tax burden to a green tax policy under different values of energy shares. The J-curve pattern can be observed for a range of different values of energy shares: the change in the tax burden has negative value initially, it decreases at higher values of $\tau_{e,m}$, then it turns, and starts increasing and becomes positive for higher value of energy taxes.

A comparison with the baseline case reveals that the reduction in payroll taxes becomes smaller for lower values of energy shares: for instance, a rise in carbon taxes by 5% lowers the payroll tax by 0.3% when the energy share is 0.04 (to be compared with baseline reduction in payroll taxes of 6.1%), similarly an increase in energy taxes by 10% enables a reduction in payroll taxes by 0.6% (compared 12.05% previously). At the same time, the value of energy taxes, at which the green tax policy imposes a heavier tax burden on labor markets, increases: it is higher for lower values of the energy share. Intuitively, when the energy share is low, the decrease in payroll taxes concerns a larger tax base, which implies the labor taxes can be cut by less and still dominate the decline in labor productivity stemming from a rise in carbon taxes. Consequently, with a smaller tax base, carbon taxes need to be higher to dominate cuts in total labor costs and thus to increase tax burden in an economy.

These results suggest that, given the same change in carbon taxes, green tax policy is associated with a smaller cut in payroll taxes and consequently lower effects on employment rates if implemented in regions with more-labor intensive industries. Intuitively, labor-intensive industries tend to employ a larger share of the labor force, and so that any increase in the employment rate (and a decrease in unemployment rate) is smaller. These tax policies, however, have negligible effects on the income of the unemployed, suggesting that the effects of the tax reforms on both the employment rate and the income of the private sector are less pronounced.

[24]which is the value used in the literature, for details see Section 3

[25]the value used in recent macroeconomic models of climate change, e.g., see Golosov et al. (2012), Barrage (2012)

A nested CES production function I repeat the simulations of all three policy experiments when the production function in formal sector is assumed to be a nested CES production function as in (19).

In all policy experiments, the effects on variables are less pronounced, since with a lower elasticity of substitution between labor and energy, imposing of a carbon tax has a small impact on the relative cost of labor, and thus on labor demand and overall labor market outcomes. Another key result for the case with a nested CES function is that the hump-shaped pattern of some variables under the second policy experiment (Table 5)[26] disappears. The low elasticity of substitution between labor and energy, along with imposition of energy taxes, do not allow fall of the overall tax burden (as, e.g., an increase in energy taxes by 5% lowers the payroll taxes by a meager 0.79%, compared with 6.1% in the baseline second policy experiment case), so that hump-shaped pattern disappears.

There 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 [27]. The results indicate that reducing emissions is a harder task under a lower elasticity, since there then is a smaller decline in demand for energy. On other hand, this also implies that green tax policies under a lower elasticity are associated with higher public revenues and consequently with higher general public spending.

Taxes										
$\tau_{e,m}$	τ_L	θ	u	w_m/w_a	w_m	z	b	s	L_m	v
0.1500	0.1900	2.6683	0.3287	1.9309	2.5832	0.8776	0.6982	0.5000	0.8700	0.4386
0.1575	0.1885	2.6679	0.3285	1.9319	2.5825	0.8763	0.6980	0.5006	0.8698	0.4387
0.1650	0.1871	2.6675	0.3283	1.9328	2.5821	0.8751	0.6979	0.5011	0.8697	0.4388
0.2000	0.1803	2.6655	0.3273	1.9374	2.5790	0.8690	0.6971	0.5036	0.8690	0.4393
0.2500	0.1706	2.6625	0.3258	1.9437	2.5753	0.8606	0.6961	0.5072	0.8680	0.4400
0.3000	0.1609	2.6594	0.3244	1.9498	2.5719	0.8524	0.6951	0.5108	0.8670	0.4407
0.3500	0.1513	2.6563	0.3230	1.9558	2.5687	0.8443	0.6943	0.5145	0.8661	0.4414

Table 5: Effects of varying the energy tax rate: constant replacement ratio, τ_L do not impact z

6 Conclusion

In this paper, I build a search and matching model to analyze the effects of budget neutral green tax policy that raise taxes on polluting factor of production whilst cutting labor taxes, on labor market outcomes in developing countries that are characterized by sizable informal sector. On the expenditure side, there are two components through which these revenue changes are transfered to the rest of thee economy: transfers to the unemployed and transfers through provision of public goods. I have also analyzed the influence of unemployment compensation schemes and the (indirect) taxation structure of earnings in the informal sector

[26]Simulation results of the first and third policy experiments with a nested CES production function are available upon request.

[27]See, for example, Jacoby et al. (2006) find that the elasticity between energy and value-added (capital-labor composite) significantly affects the costs of a "Kyoto forever" scenario for the US economy. Burniaux and Martins (2012) show that high inter-factor (between energy and value-added) and inter-fuel substitution elasticities can generate large carbon leakages.

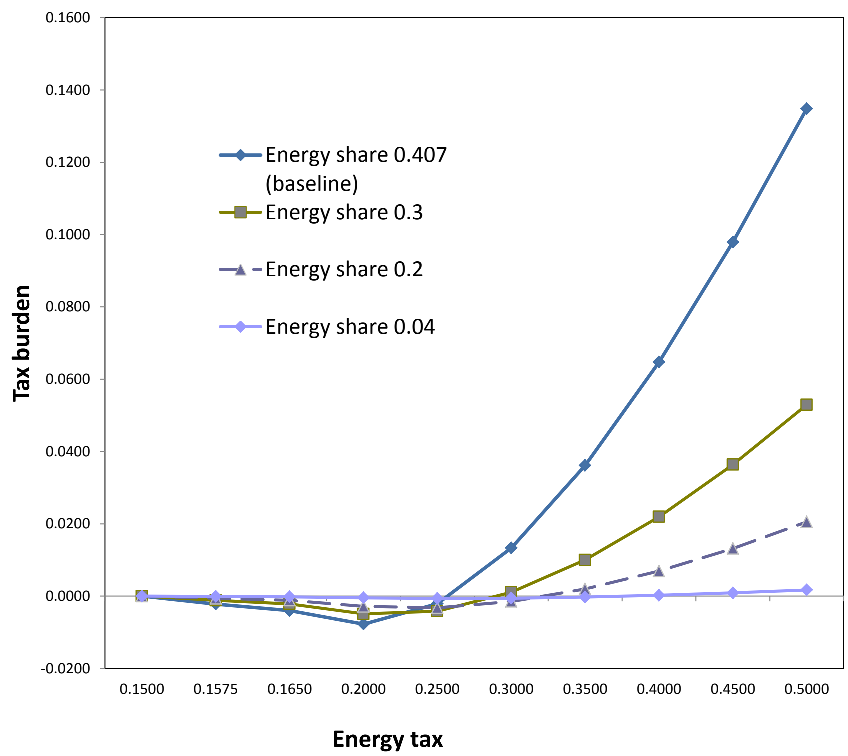
on the employment effects of tax reforms. The key finding of this paper is that when energy taxes can reduce the income from self-employment and unemployment benefits are indexed to wages, green tax policy yields a double dividend. The costs of the double dividend, however, include a lower after-tax private sector income and a smaller size of the urban sector. Further, such green tax policy moves informal workers to a formal sector with a higher turn-over rate than before tax reform.

However, if the government can also alter public spending as a policy instrument in addition to taxes, then as the simulations of the model demonstrate, the labor market outcomes of green tax reforms can be improved. More specifically, increasing taxes beyond a certain threshold level can be associated with an increase in income of both formal sector and rural workers, a smaller decline in income of the unemployed and larger size of the urban sector. As such, the results lend support to arguments by Bovenberg (1995) and others who suggest that policy-makers must make use of several instruments if they are confronted with multiple policy objectives, including the employment and poverty alleviation effects of green tax policies in developing countries.

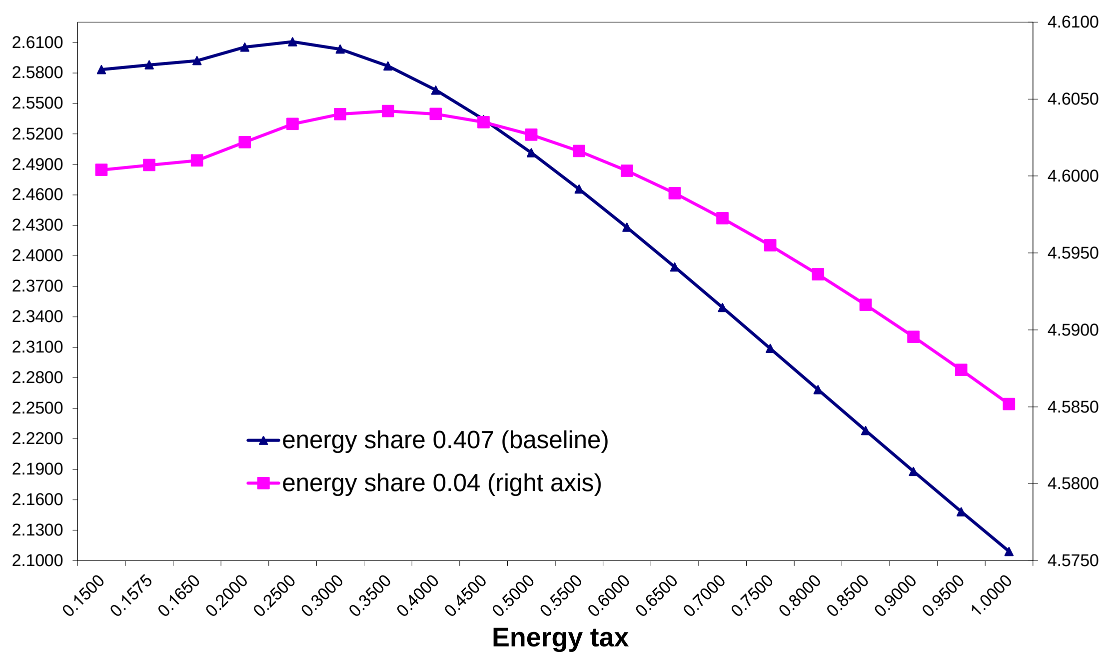
The analysis of the paper can be extended in a number of ways. First, the agricultural sector can be modeled to use energy as a factor of production. Second, the model utilizes a static framework and thus abstracts from taking into account potential feed-back effects of a cleaner environment on employment, which would require a dynamic setting. Third, the model abstracts from the analysis of distributional effects of green tax policy, for the purposes of which the OLG or a model with heterogeneous agents would be needed. I leave these extensions for future research.

7 Appendix

7.1 Figures



(a) Tax burden



(b) Wages in formal sector

Figure 1: Wages and tax burden as a function of energy tax for different values of energy share

7.2 Policy experiments: results

Taxes									
$\tau_{e,m}$	τ_L	θ	u	w_m/w_a	w_m	s	L_m	v	$g+ub$
0.1500	0.1900	2.6684	0.3287	1.9309	2.5833	0.5000	0.8700	0.4386	0.9020
0.1575	0.1807	2.6632	0.3294	1.9348	2.5828	0.4990	0.8695	0.4377	0.8970
0.1650	0.1718	2.6580	0.3301	1.9387	2.5819	0.4978	0.8691	0.4368	0.8921
0.2000	0.1344	2.6327	0.3342	1.9578	2.5722	0.4912	0.8662	0.4322	0.8708
0.2500	0.0910	2.5934	0.3416	1.9875	2.5447	0.4787	0.8606	0.4241	0.8441
0.3000	0.0574	2.5490	0.3512	2.0201	2.5036	0.4629	0.8532	0.4144	0.8217
0.3500	0.0323	2.4977	0.3631	2.0558	2.4504	0.4440	0.8439	0.4026	0.8033

Table 6: The effects of varying the energy tax rate: $b = \bar{b}$, $z = \bar{z}$

Taxes										
τ_E	τ_L	θ	u	w_m/w_a	w_m	z	b	s	L_m	v
0.1500	0.1900	2.6683	0.3287	1.9309	2.5833	0.8776	0.6982	0.5000	0.8700	0.4386
0.1575	0.1807	2.6634	0.3294	1.9348	2.5830	0.8775	0.6981	0.4991	0.8696	0.4378
0.1650	0.1716	2.6585	0.3300	1.9387	2.5824	0.8773	0.6980	0.4982	0.8691	0.4370
0.2000	0.1324	2.6376	0.3326	1.9577	2.5762	0.8752	0.6963	0.4943	0.8665	0.4336
0.2500	0.0842	2.6117	0.3359	1.9870	2.5589	0.8693	0.6916	0.4894	0.8619	0.4293
0.3000	0.0431	2.5895	0.3387	2.0187	2.5339	0.8608	0.6849	0.4852	0.8561	0.4256
0.3500	0.0078	2.5703	0.3412	2.0527	2.5032	0.8504	0.6766	0.4816	0.8494	0.4224

Table 7: The effects of varying the energy tax rate: $b = \pi_b w_m$, $z = \tilde{\pi}_z w_m$

Taxes											
τ_E	τ_L	θ	u	w_m/w_a	w_m	z	b	s	L_m	v	$g+ub$
0.1500	0.1900	2.6683	0.3287	1.9309	2.5833	0.8776	0.6982	0.5000	0.8700	0.4386	0.9020
0.1575	0.1814	2.6658	0.3275	1.9359	2.5811	0.8706	0.6976	0.5032	0.8693	0.4392	0.9009
0.1650	0.1731	2.6633	0.3262	1.9409	2.5785	0.8636	0.6969	0.5062	0.8685	0.4398	0.8999
0.2000	0.1378	2.6517	0.3210	1.9651	2.5626	0.8324	0.6926	0.5197	0.8646	0.4423	0.8948
0.2500	0.0954	2.6358	0.3147	2.0024	2.5303	0.7913	0.6839	0.5366	0.8577	0.4450	0.8877
0.3000	0.0604	2.6211	0.3095	2.0430	2.4895	0.7537	0.6729	0.5512	0.8492	0.4471	0.8808
0.3500	0.0312	2.6076	0.3052	2.0871	2.4427	0.7192	0.6602	0.5639	0.8392	0.4488	0.8740

Table 8: The effects of varying the energy tax rate: $g = \bar{g}$, $b = \pi_b w_m$, $z = \pi_z(1+\tau_L)w_m$

7.3 Baseline parameter values

Parameter	Cobb-Douglas pr.f.	CES pr.f.
ν parameter of vacancy posting cost	0.40	0.4
s search intensity	0.5	0.5
r monthly interest rate	0.04/12	0.04/12
r_m return on capital	0.04/12	0.04/12
γ matching function elasticity	0.50	0.50
λ monthly job separation rate	0.04	0.04
τ_e energy tax rate	0.15	0.15
p_E price of energy	4.47	0.6730
α_1 share of capital in formal sector production	0.269	-
γ_1 share of capital in agricultural sector	0.63	0.63
α_2 share of labor in formal sector production	0.324	-
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
ϕ search cost elasticity	2.00	2
β bargaining strength of workers	0.5	0.5
$g/A_m f(k_m, e_m)$ government spending/output	0.05	0.05
M matching function efficiency	0.1	0.1
z_p indexation of severance pay to wage	3.36	3.36
Π search intensity parameter	3.14	3.14
γ_2 share parameter in the nested CES function	-	0.1
ε elasticity of substitution btw capital/labor & energy	-	0.05

Table 9: Baseline parameter values

7.4 Unemployment insurance systems in Latin America

By looking at a sample of Latin American countries[28], I broadly group unemployment benefits into two categories, summarized in Table 10[29]

In most countries, unemployment benefits are tied to earnings, but minimum or maximum thresholds do exist. The system is thus more similar to a flat-rate system[30]. Argentina, Uruguay, Venezuela, Brazil are

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

[29]The information provided in the Table 10 is based on the most recent available data on the latest reforms of unemployment insurance schemes: 1991 in Argentina (http://www.trabajo.gov.ar/segurodesempleo/), 2009 in Chile, 2001 in Ecuador, 2008 in Uruguay, 2005 in Venezuela (http://www.seguridadsocialparatodos.org/aysss/content/sud-america/venezuela.html), 2007 in Mexico City. Values for Brasil are updated regularly (see, the website of Ministerio do Trabalho e Emprego, MTE, Governo do Brasil).

[30]In the flat-rate system the level of unemployment benefits does not depend on the previous income of a given person; it is set at a given level for all unemployed. The most notable example is Poland where the rate is based on the average wage in the

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 is a special case among Latin American countries. Despite being the only OECD country in the region, it does not have a nationwide unemployment insurance scheme. However, there is a social security system (see Bosch and Campos-Vazquez (2010)) in place that allows registered workers to claim their average earnings for 30 to 90 days in case of unemployment once every 5 years. Moreover, temporary employment programs are in place for workers from the rural areas (the benefits are 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 in 2007 (Programa seguro de desempleo del distrito federal). Benefits are restricted to 6 months, and the monthly benefit is based on 30 work days on minimum wage[31]. The existing Mexican programs, too, have features that resemble flat-rate systems.

Given the stylized facts presented in Table 10, I distinguish between two relevant cases for the developing countries with respect to the unemployment benefits: the flat-rate system and earnings-related. It is important to note that even in some countries unemployment benefits are earning related and descending depending on the duration of unemployment, I do not model such unemployment insurance scheme, but in the labor economics literature there are hazard rate models which deal with these types of unemployment programs.

economy (see Mazza (2000))

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

Country	Unemployment benefits
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 10: Unemployment insurance systems in Latin America (Sources: Velasquez (2010), Bosch and Campos-Vazquez (2010), Hijzen (2011))

8 Technical Appendix: not for publication

8.1 Derivation of the search equilibrium equations

In this Appendix I derive equations of search equilibrium by using dynamic programming and thus by writing the asset value equations. I write down four equations, on each for the expected returns from a vacant job, a filled job, an unemployed and an employed. As I describe the dynamic behavior out of steady state, in Bellman equations I also include the terms denoting the expected capital gains from changes in the valuation of a given variable.

The asset value of a vacancy is given by:

$$rV = -c + q(J - V) + \dot{V}, \tag{24}$$

where c is the cost of keeping an active job vacancy, J is the expected return from a filled vacancy, and $\dot{V}$ denotes expected capital gains from the valuation of the asset. Free entry into the creation of vacancies implies $V = 0$, and thus:

$$J = \frac{c}{q} \tag{25}$$

which states the intuitive result that in equilibrium, the expected profit from a job has to cover the expected cost of a vacancy.

The asset value of a filled vacancy, J is given by[32]:

$$rJ = y(k_m, e_m) - (1 + \tau_L)w_m - \lambda P - \lambda J + \dot{J}, \tag{26}$$

The labor market return from a filled vacancy is the worker's labor productivity, denoted as $y(k_m, e_m)$, less the total expected labor costs, $(1 + \tau_L)w_m + \lambda P$, and less the loss from the shock that results into the destruction of the job.

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

$$A_m f_k'(k_m, e_m) = r_m; A_m f_e'(k_m, e_m) = p_E(1 + \tau_{e,m}) \tag{27}$$

and the productivity of labor is defined as:

$$\begin{aligned} y(k_m, e_m) &\equiv A_m f(k_m, e_m) - A_m f_k' k_m - A_m f_e' e_m = \\ &= A_m f(k_m, e_m) - r_m k_m - p_E(1 + \tau_{e,m})e_m \end{aligned}$$

The Bellman equation for the unemployed is:

$$rU = z + b - \sigma + sq\theta(W - U) + \dot{U} \tag{28}$$

where $z + b - \sigma$ is the utility of unemployed, U is the present value of working in the informal sector, W is the asset value of formal employment, and $sq\theta$ is the probability of finding a job, given that every person searches for a job with the same search intensity s.

Finally, the asset value of formal sector employment, W is given by:

$$rW = w_m + \lambda P + \lambda(U - W) + \dot{W}, \tag{29}$$

[32]For simplicity I assume that capital does not depreciate.

where $w_m + \lambda P$ is the expected labor income from formal employment and $\dot{W}$ denotes the expected capital gain from changes in the value of employment in the formal sector, Subtracting (28) from (29), we obtain:

$$(r + \lambda + sq\theta)[W - U] = w_m - (z + b - \sigma) + \lambda P + (\dot{W} - \dot{U}) \tag{30}$$

Thus, workers will only engage in job search if it is worthwhile. Formally: $w_m + \lambda P > z + b - \sigma$.

Wages are determined as a solution to a Nash bargaining problem:

$$w_m = arg\max(W - U)^{\beta}(J - V)^{1-\beta} \tag{31}$$

and since

$$\frac{\partial(W - U)}{\partial w_m} = -\frac{1}{1 + \tau_L}\frac{\partial(J - V)}{\partial w_m} \tag{32}$$

yields the following first-order condition:

$$(1 - \beta)(1 + \tau_L)(W - U) = \beta J \tag{33}$$

If workers dominate the bargaining process, i.e $\beta \to 1$, it is clear from equation (33) that the value of the firm J will be equal to zero and the marginal product of labor equals to the costs of labor (including expected severance pay), $(1 + \tau_L)w_m + \lambda P = y(k_m, e_m)$. If, however, the firm holds the entirety of the bargaining power $\beta = 0$, then $W = U$. This simply means that formal sector wages equal workers' reservation wage, $w_m + \lambda P = z + b - \sigma$.

Hiring locus and wage determination equations Now, I make use some of the value equations to derive search equilibrium equations presented in the main body of the paper.

First, by combining equations (26) and (25) to eliminate J, and by assuming that hiring costs are a fixed proportion ν of the producer wage in the formal sector, $c = \nu(1+\tau_L)w_m$, I can obtain hiring locus equation:

$$(1 + \tau_L)w_m\left[1 + (\lambda + r)\frac{\nu}{q}\right] = y(k_m, e_m) - \lambda P \tag{34}$$

so that labor productivity equals total wage costs, including wage costs, the expected capitalized value of its hiring costs and expected severance payments.

Second, using (30) and (25) to eliminate $W - U$ and J respectively from (33) I can obtain the following expression for the wage rate:

$$\frac{w_m - (z + b - \sigma)}{w_m} + \frac{\lambda P}{w_m} = \frac{\beta}{1 - \beta}\nu\left(\frac{r + \lambda}{q} + s\theta\right) \tag{35}$$

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

$$\sigma_s'(s) = \theta q(W - U) \tag{36}$$

Equations (36), (25) and (33) imply that:

$$\sigma_s' = \frac{\beta}{1 - \beta}\theta\nu w_m \tag{37}$$

which now determines the optimal level of search intensity.

Rural-urban migration First, from (36) and (28), I obtain:

$$rU = z + b + \sigma[\varepsilon_\sigma - 1] \tag{38}$$

where $\varepsilon_\sigma = s\sigma'(s)/\sigma > 0$ is the elasticity of search costs with respect to s. In the calibration of the model, the costs of search intensity function, σ, yield a constant elasticity ε_σ.

The migration equilibrium condition is that agricultural workers are indifferent between staying in agriculture and entering the urban informal sector:

$$w_a + \chi_a + r\theta_f f = rU \tag{39}$$

I can re-write the migration equation by substituting (38) for rU to obtain migration equation of the main text:

$$w_a + \chi_a + r\theta_f f = z + b + \sigma[\varepsilon_\sigma - 1] \tag{40}$$

8.2 Balance of payments and government budget constraint equations

In this section I prove that the balance of payments equation is redundant in defining the steady-state equilibrium of the model.

Government I assume that government needs to finance an exogenously given stream of public goods G as well as transfers to the unemployed:

$$G + uL_m b = \tau_L w_m (1-u) L_m \left(1 + \nu \frac{r+\lambda}{q}\right) + \tau_{e,m} p_E e_m (1-u) L_m, \tag{41}$$

We can re-write the budget constraint, by normalizing it with respect to the number of workers in the urban sector:

$$g + ub = \tau_L w_m (1-u) \left(1 + \nu \frac{r+\lambda}{q}\right) + \tau_{e,m} p_E e_m (1-u) \tag{42}$$

where $g \equiv G/L_m$.

Balance of payments Aggregate consumption in the rural area amounts to $C_a = w_a L_a$; aggregate production of agricultural goods amounts to $g(k_a)L_a$, so that the excess income in the rural area that exceeds demand is used to rent fixed capital in the agricultural sector:

$$g(k_a)L_a - C_a = r_a K_a \tag{43}$$

where K_a is the total stock of capital used in the agricultural sector. Given perfect competition in the agricultural sector, equation (43) holds.

Aggregate private consumption in the city amounts to consumption of the formally employed and the unemployed:

$$C = w_m(1-u)L_m + \lambda P(1-u)L_m + uL_m b + uL_m z, \tag{44}$$

The firm-level capitalized hiring costs amount to:

$$\frac{\lambda + r}{q} c = \frac{\lambda + r}{q} \nu w_m + \frac{\lambda + r}{q} \nu w_m \tau_L \tag{45}$$

where the second term is a payment to the government by a firm. The aggregate hiring costs are then:

$$\frac{\lambda + r}{q}\nu w_m(1-u)L_m \tag{46}$$

and the balance of payments in an economy implies that as the excess of the aggregate income in the city over the aggregate demand is used to import both capital and energy at the international markets:

$$\begin{aligned}\left[(1-u)L_m A_m f(k_m, e_m) + uL_m z - \frac{\lambda + r}{q}\nu w_m(1-u)L_m\right] - C - G = \\ p_E e_m(1-u)L_m + r_m k_m(1-u)L_m\end{aligned} \tag{47}$$

By substituting into (47) the expression for C from (44) and dividing by L_m we obtain:

$$\begin{aligned}(1-u)A_m f(k_m, e_m) - w_m(\lambda + r)\frac{\nu}{q}(1-u) - \frac{G}{L_m} - w_m(1-u) - \lambda P(1-u) - ub = \\ p_E e_m(1-u) + r_m k_m(1-u)\end{aligned} \tag{48}$$

Substituting instead G/L_m by the expression from the budget constraint (42), and dividing by $1-u$, I obtain:

$$\begin{aligned}A_m f(k_m, e_m) - w_m(\lambda + r)\frac{\nu}{q} - w_m - \lambda P - \tau_L w_m(1 + \nu\frac{r + \lambda}{q}) - \\ -\tau_{e,m} p_E e_m = p_E e_m + r_m k_m\end{aligned} \tag{49}$$

which is exactly the wage determination equation derived as part of the steady-state equilibrium in the main text:

$$A_m f(k_m, e_m) - (1 + \tau_{e,m)} p_E e_m - r_m k_m = (1 + \tau_L)w_m\left[1 + (\lambda + r)\frac{\nu}{q}\right] + \lambda P$$

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