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Abstract

This paper investigates the impact of climate policies on the labor markets in developing countries characterized by a large informal economy. I conduct the analysis employing a dynamic general equilibrium model, which incorporates the three prevalent working groups in developing countries: informal self-employment, informal employment, and formal employment. To capture the mobility of workers between these groups, I use a search and match mechanism with search frictions for formal and informal firms and with on-the-job search. The model is calibrated to India to elaborate on the impact of climate policies envisioning a tax on energy with different redistribution schemes of the tax revenue. The results show that climate policies strengthening the position of the productive formal sector can lead to a triple dividend effect: emissions drop due to the energy tax, whereas the redistribution scheme increases the formal labor share and welfare. Developing countries with widespread informality can utilize climate policies to improve labor conditions while reaching their climate targets.

Keywords: development, climate policies, employment, search frictions, informality.

JEL codes: C68, E26, J46, J64, Q56.

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1 Introduction

> "What the developing countries have is an employment problem - that is, poverty amongst those who work - rather than an unemployment problem."(Fields, 2011, p.18)

Living in a developing country without an effective social security system often leaves no other option than working. That typically results in a low unemployment rate but in widespread working poverty due to a lack of good quality jobs: people work, despite poor conditions and low wages to make a living. Those jobs are essential, and a job loss, for example, due to a policy with a negative impact on the labor market, could lead to drastic consequences. Thus, the political viability of policies in developing countries is closely connected to its effect on the labor market. With the submission of national climate commitments in relation to the Paris agreement on climate change (2015), climate policies came into focus for developing countries. This paper studies how climate policies affect labor markets in developing countries. My objective is to explore the optimal design of climate policies in developing countries considering labor market effects.

The topic of climate policies and their effect on labor markets gained relevance in recent years due to global efforts addressing the challenges of climate change: on the one hand, such policies work as "job killers" for polluting industries because they decrease their relative profitability, and on the other hand, they create new "green jobs" for less-polluting industries. Besides the direct impact on the industry targeted by a climate policy, these two effects impact the economic-wide employment and wage structure. Hafstead and Williams (2018) develop a general equilibrium model capturing the entire labor market to elaborate on the net-job effect of a climate policy in developed countries. This analysis focuses on the quantitative job effect of a climate policy. In developing countries, which face a job-quality problem, the quantitative aspect is, however, not sufficient: it is not only the question of how many jobs but what kind of jobs are created, respectively lost, by a climate policy. Thus, analyzing the labor market in developing countries requires an analysis of the green job versus the job killer effect in quantitative and qualitative terms. So far, the economic literature does not deliver answers to this fundamental issue.

According to Loayza (2016), the employment of around 70% of the workforce in a typical developing country is not in accordance with government-imposed regulations and laws, making them the informal labor force in the economy (De Soto et al., 1989). Such informal jobs have no social protection, leaving their workers exposed to exploitation. Thus, the employment problem arises from the existence of an extensive informal sector in developing countries. It is widely recognized that the widespread informal sector in developing countries is a cause and, at the same time, a consequence of underdevelopment. The informal sector operates outside the legal framework, preventing governmental-imposed policies, which would be beneficial for development, from being effective. The informal sector is, however, for many, the only option to work and to earn money in underdeveloped countries. That leads to another issue regarding labor markets in developing countries closely related to informality - the segmented labor force.[1] Some individuals cannot switch to the formal sector even when they would be capable and willing to work there, leaving them trapped in the informal sector. In this regard, researchers developed various search and match models based on Mortensen and Pissarides (1994), where search frictions prevent informal workers from finding a job in the formal sector. These models deliver useful insights into a wide range of different aspects of the developing country's labor markets. The effect of climate policies, however, remains to be addressed. Therefore, a general equilibrium model containing search frictions for developing countries is needed to capture the effect of climate policies on the labor markets as already highlighted by Hafstead et al. (2018a).

India is a major emitter of greenhouse gas emissions and thus, of particular interest to study climate policies and labor market effects. Moreover, according to Mehrotra et al. (2019), around 90% of the workers in India are in the informal sector, making it the largest informal workforce worldwide. The informal sector is not homogenous and consists of two main groups: (informal) self-employment and informal employment in a firm. More than half of the workforce in India is self-, respectively, family-employed. Those individuals are engaged in own-production, which typically displays a high labor intensity and low productivity (e.g. family farms). The remaining informal workers mainly work in informal firms. Due to their informality, their employment is not in accordance with governmental regulations and differs substantially from formal employment. Furthermore, there is evidence showing that informal and formal firms generally differ in their structure. Informal firms tend to be smaller and have lower productivity than their formal counterpart (e.g. Bigsten et al. (2004); Prado (2011); La Porta and Shleifer (2014)). Thus, climate policies affect those employment groups differently, making it important to distinguish between informality and formality as well as within informality. In what follows, I briefly explain how I include those elements in my model and how this paper contributes to the literature.

1.1 Contribution

In this paper, I develop a dynamic general equilibrium model with heterogenous households. Considering the employment problem of developing countries, the model does not include unemployment. Instead, I disaggregate the workforce of each sector into the three prevalent working-groups in developing countries: (informal) self-employment, informal (firm) employment, and formal (firm) employment. The model relies on three main elements: on-the-job-search, search frictions, and a "three-stage matching structure". I assume that working individuals use their spare time to search for a better job. Thus, they can search and match with job-openings each

[1]See Fields (2009) for a review of segmented labor market models in developing countries.

period despite working. To create matches with searching individuals, informal and formal firms need to employ (costly) recruiters, meaning that firms have search frictions. That is in contrast to self-employment, which does not face search frictions, making it the outside option for firm-employment. As I include three working groups in my model, I extend the standard search and matching literature based on Mortensen and Pissarides (1994), which traditionally uses a "two-stage matching process" including unemployed and employed individuals. Instead, my model relies on a "three-stage matching process" with self-, informal- and formal employment, where individuals can, irrespective of where they are currently working, search for any better job. I assume that self-employed individuals match with informal and formal firms and informally employed individuals with formal firms only. Thus, informal employment is an intermediate step between self-and formal employment, where switching to informal employment leaves the possibility of matching with formal firms open. That structure allows me to capture the matches within informality and between informality and formality. Consequently, my model incorporates the flow of workers between the prevalent working-groups in developing countries. Thus, as I include energy for production and consumption, I can evaluate the disaggregated labor effects caused by different climate policies.

I establish a tractable model that could be applied to a wide range of developing countries. For this paper, I calibrate the model to India using the Input-Output table from the Asian Development Bank (2012), and labor data from Mehrotra et al. (2019) for the year 2011/2012. To capture the sector-specific labor response, I incorporate three sectors: agriculture, industry, and services. I simulate the impact of a climate policy decreasing the energy use up to 20%.[2] In my framework, I implement a tax on energy use, where its revenue is redistributed according to four measures: (1) equal lump-sum redistribution, (2) lump-sum redistribution to self-employed individuals, (3) decreasing the formal labor tax, and (4) lowering the bureaucratic costs per formal worker. Considering utilitarian welfare, the design of the optimal policy mix composed of these measures depends on its stringency. A combination of decreasing the formal labor tax and lowering its bureaucratic costs is optimal for an energy decrease up to 15%. From 15% onwards, the optimal policy mix additionally includes lump-sum transfers to self-employed individuals. I find that, until 18.5%, this policy mix leads to an increase of formal employment at the expense of self-and informal employment. Thus, the green job effect outweighs the job killer effect quantitatively (more jobs) and qualitatively (better jobs).[3] Moreover, next to reducing emissions, the optimal climate policy mix positively affects welfare for an energy reduction up to 13.4%. Thus, there is a range of energy taxes leading to a triple dividend effect. This policy mix, however, magnifies inequality. Such effects on inequality could hamper the political

[2]In 2012, the energy mix in India was mostly composed of non-renewable resources like coal and crude oil. Without a significant share of renewable energy sources, energy use goes hand in hand with emissions as switching to clean energy is, at least in the short term, not possible. Thus, I treat the energy use as a proxy for the emissions in my model.

[3]I consider firm-employment as jobs and self-employment as no jobs to analyze the green job versus job killer effect of a climate policy.

viability of the climate policy. Thus, I additionally evaluate the optimal policy mix keeping inequality constant. In that case, the revenue should be used to decrease the formal bureaucratic costs and for lump-sum transfers to the self-employed individuals. This policy mix leads to an increase in self-and formal employment while informal employment shrinks. Thus, fewer but better jobs are available, meaning that the green job effect outweighs the job killer effect in qualitative but not quantitative terms. Moreover, the policy mix enhances utilitarian welfare for an energy decrease up to 8.5%. These results are based on the following mechanisms:
Firstly, energy providers can generally observe the energy use of all economic players. Consequently, in contrast to labor taxes, which only affect the formal economy, energy taxes are a valuable instrument to tax the informal sector (Heine and Black, 2019).
Secondly, using the energy tax revenue to lower formal labor income taxes or formal bureaucratic costs per worker decreases formal labor costs. That boosts formal employment mainly at the expense of its informal counterpart leading to favorable labor market outcomes. These two measures, however, differ substantially in their impact on the labor market. This is mainly because of contrary wage effects. Decreasing the labor income tax positively affects formal wages. That, in turn, mitigates the negative impact of the measure on the formal labor costs. Thus, the labor response is relatively low. In contrast, lowering the formal bureaucratic costs per worker does not directly affect the wages. Consequently, this measure leads to an extensive labor response. This finding is in accordance with the empirical literature, which indicates that policies helping firms to overcome issues like bureaucratic costs are more promising in creating new jobs than intervening in the labor supply with wage subsidies (McKenzie, 2017).
Lastly, lump-sum redistribution schemes decrease the incentive to work and are thus, in combination with energy taxes, neither beneficial for the labor market nor utilitarian welfare. They are, however, a useful instrument to improve equality.

1.2 Relation to literature

In the last years, researchers started to develop general equilibrium search and match models to elaborate on the overall effect of climate policies on labor markets.[4] Most studies, however, focus on the developed countries, despite the high relevance for developing countries. An exception is Kuralbayeva (2018), which develops a general equilibrium model using search frictions to analyze the effect of climate policies on the labor market in Mexico. This model focuses on rural-urban migration and, therefore, belongs to the search and match models based on the seminal work of Harris and Todaro (1970).[5] The model introduced here differs substantially in three key aspects. Firstly, I consider formal and informal firms with search frictions in my model, whereas Kuralbayeva (2018) includes an urban formal sector with search frictions and an urban and rural informal sector without them. Considering that all firms are hiring workers

[4]See Aubert and Chiroleu-Assouline (2019) and Hafstead and Williams (2018).
[5]See Fugazza and Jacques (2004), Albrecht et al. (2009) and Günther and Launov (2012).

and thus have search frictions, this approach only relies on self-employment. Therefore, it leaves out the crucial role of informal firms in developing countries. Secondly, I do not differentiate between urban and rural employment. In my model, all individuals, irrespective of where they are located, can search for a job in a firm. Thus, search frictions in the labor market define labor mobility. That is in contrast to the migration mechanism used in Kuralbayeva (2018): if the expected urban wage is higher than its rural counterpart plus migration costs, then some rural individuals are incentivized to migrate to the urban sector to try their "luck" there. This assumption was first questioned by Banerjee (1984), who empirically shows that a sizable proportion of urban migrants did not just migrate to try their "luck", but rather because they already have a specific job in prospect. That indicates that not only the urban individuals engage in search activities but as well the rural individuals. Lastly, I calibrate the model to India, using extensive economic and labor data, to get a computational general equilibrium model for India.

The present paper is organized as follows. Section 2 describes the multi-sectoral model with search frictions for developing countries. Section 3 sets up the steady-state conditions and provides an analysis of the wage mechanism in a three-stage matching process. The calibration of the model with Indian data is explained in Section 4. Section 5 analyzes the effect of an energy tax and different redistribution schemes, and Section 6 concludes.

2 A multi-sectoral model with search frictions for developing countries

I build up a dynamic general equilibrium model incorporating search frictions, particularly suitable for developing countries. More specifically, I extend the search and match model of Hafstead and Williams (2018) for developed countries introducing important properties of labor markets in developing countries. The main difference to search models based on Pissarides (1985) and Mortensen and Pissarides (1994) is that the presented model is not about unemployment but about working individuals using their spare time to search for a better job. Thus, my model allows for on-the-job search. Considering that developing countries are facing an employment problem, this becomes crucial to capture labor markets in developing countries where unemployment plays a minor role.

The model is a heterogenous household framework. These households differ with respect to where they are currently working: self-employment, informal (firm) employment, or formal (firm) employment. They choose the working hours depending on the labor income. With the remaining hours of the day, they automatically search for better jobs. Consequently, the search intensity of a household, and, thus, the probability of finding a better job, depends on the choice of working hours and is household-specific.

The sectoral output is produced using three different production technologies: own-production, informal firm production, and formal firm production. Own-production uses energy, labor, and materials (EL(M)) as inputs, whereas firm production additionally uses capital (KE-L(M)). Following Anand and Khera (2016), these technologies are imperfect substitutes and mainly differ by their productivity. Formal firms are the most productive, followed by informal firms and then by own-production. Self-employed individuals are working in own-production. This technology serves as the "last resort" for the labor market. Individuals not finding a job in a firm can enter without (search) frictions, and, thus, self-employment is the outside option to firm employment. This technology is relatively labor-intensive and, as there are no frictions, has competitive wages. That is in contrast to firm production, where search frictions are present. Each period, some individuals are separating from firm employment to self-employment according to an exogenous separation rate. To counteract this outflow of workers, firms can allocate some of their labor to recruitment. Recruiters meet with all individuals searching for a better job to create matches for the next periods. Thus, my model has a three-stage matching structure with self-, informally, and formally employed individuals. I assume that self-employed individuals match with informal and formal firms and informally employed individuals with formal firms. That structure allows me to capture the flow of workers within informality (from self-employment to informal employment) and between informality and formality. Further, I include different labor strategies.[6]

The scale of the flow of workers is based on a firm-specific matching function. This function includes the search effort of the individuals, the recruitment effort of a specific firm, and the aggregated recruitment effort of all firms to determine the number of matches created by a particular firm during the matching process. The firms need to optimally distribute the stock of labor to production for today and production for tomorrow, where recruiters hire new workers for the next period (which then can be used for production). Thus, firms are solving a dynamic optimization problem, where the search costs (wage payments for recruiters) prevent wages from being competitive. Instead, I endogenize wages using a Nash-bargaining process, which divides the matching surplus of a firm and the averaged matching surplus of the households according to a bargaining power parameter.

2.1 Households

In this model, all households are equally endowed and have similar abilities. They value leisure and choose the hours they want to work to receive labor income. Additionally, they use their spare time to search for a superior job. This mechanism is similar to Pissarides (1985), where unemployed individuals enjoy their leisure and automatically search for a job. The difference is

[6]For example, self-employed individuals can climb the job-ladder stepwise going first to informal firm employment and continue searching for a job in a formal firm there, or they directly jump to formal employment, which is, however, harder to do.

that in the model of Pissarides, a household can either work or search, whereas, in this model, a household can spend some hours working and automatically search for a better job with the remaining hours.

I abstract from household savings and, therefore, households are living hand-to-mouth.[7] Although this is a simplifying assumption, the advantage of this approach is that it allows me to abstract from the usually assumed full insurance assumption within households based on Merz (1995). This assumption is reasonable for developed countries but has its limitations for developing countries, as poor households often cannot insure against transitory shocks (Blundell et al., 2008).

In the model, there are $n_{i,l}$ individuals of the same household type. They operate in sector i and are $l \in \{F, I, S\}$ employed, where F stands for formal, I for informal, and S for self. I normalize the total number of individuals to 1. They work $h_{i,l}$ hours and receive an hourly wage $w_{i,l}$. The households employed in a formal firm have to pay labor income taxes at a rate $\tau_F > 0$, whereas $\tau_I = \tau_S = 0$ holds, as households working informally do not pay labor income taxes. The period utility function is

$$U_{i,l} = Log(c_{i,l} + 1) - \psi \frac{h_{i,l}^{1+\chi}}{1+\chi} \tag{1}$$

where $c_{i,l}$ is the final good consumption, ψ the disutility from work parameter, and $\frac{1}{\chi}$ the Frisch elasticity of labor supply. The budget constraint is

$$w_{i,l} h_{i,l} (1 - \tau_l) \leq P_c c_{i,l}. \tag{2}$$

where P_c is the price of the final consumption good. Based on that, I can set up the Lagrangian according to

$$\mathcal{L}_{i,l} = Log(c_{i,l} + 1) + \lambda_{i,l}(w_{i,l} h_{i,l}(1 - \tau_l) - P_c c_{i,l}) - \psi \frac{h_{i,l}^{1+\chi}}{1+\chi} \tag{3}$$

which allows me to solve for the optimal hours and consumption. I assume that households do not account for searching when they make their labor choice, meaning that they take the job-finding probability as exogenous.

2.2 The three-stage matching process

I start by assuming that it is at best to be employed at a formal firm, then by an informal firm, and at worst to be self-employed. This pattern is typically present in developing countries.[8]

[7] I assume that households discount the future at a given discount rate Q as they are impatient.

[8] Note that, in reality, the earnings of self-employed individuals often differ and can be high. However, in developing countries, it is generally the case that individuals are self-employed to get enough to survive. Therefore, in this model, I focus on self-employment in the spirit of the "last resort" idea.

This assumption induces that self-employed households operating in sector i would prefer to work in a formal or in an informal firm. Therefore, they indiscriminately search $(T - h_{i,S})$ hours, where T is the available time per day, for a job outside of self-employment. In turn, the households employed in an informal firm would prefer to work in a formal firm, but not to be self-employed. As a consequence, they search $(T - h_{i,I})$ hours for a job at a formal firm.[9] The households employed in a formal firm, however, do not have a better option and do not engage in searching. Consequently, the self-employed household operating in sector i can match with an informal firm in sector j, $m_{i,S}^{j,I}$, or a formal firm in sector j, $m_{i,S}^{j,F}$, whereas an employee of an informal firm in sector i can match with a formal firm in sector j, $m_{i,I}^{j,F}$. Therefore, my model uses a "three-stage matching process", where I include informal employment as an intermediate step to formal employment. The flow of workers between these three stages is based on the matching function, which I describe next.

2.2.1 Matching Function

In the definition of the matching functions, I follow Hafstead and Williams (2018) setting up a matching function for multiple sectors, where a firm employs recruiters to create matches with individuals interested in the job. I extend this matching function by accounting for searching time of the individuals and the disparity of formal and informal matching based on the three-stage matching process. In my model, a $k \in \{F, I\}$ firm operating in sector i employs recruiters, $v_{i,k}$, which work $h_{i,k}$ per day. Thus, the firm has a recruitment effort of $v_{i,k}h_{i,k}$ per day. The recruiters meet with individuals interested in the job, who search for $(T - h)$ hours per day, to create matches, $m_{i,k}$, for the upcoming period. The number of matches depends positively on the firm-specific recruitment effort and the household's searching effort. Additionally, several firms want to create matches with individuals of the same household. Thus, the aggregated recruitment effort of all firms competing for a particular household negatively affects the number of matches for a specific firm with that household.

The self-employed households are searching indiscriminately for a formal and informal employment. Therefore, the number of matches, $m_{i,S}^{j,k}$, of self-employed households operating in sector i with a k firm in sector j is given by the matching function

$$m_{i,S}^{j,k} = \mu_{j,k}[(T - h_{i,S})n_{i,S}]^{\gamma_{j,k}}(v_{j,k}h_{j,k})\left(\sum_{g}\sum_{z} v_{g,z}h_{g,z}\right)^{-\gamma_{j,k}} \tag{4}$$

where $\mu_{j,k}$ is the matching efficiency and $\gamma_{j,k}$ the matching elasticity parameter. $m_{i,S}^{j,k}$ is dependent on the recruiting effort of the firm, $v_{j,k}h_{j,k}$, and the total searching effort of the respective

[9] To simplify the model, I assume that a household only searches for a better job outside of her current employment status (self-employed, informal or formal employed). Consequently, there is no job-to-job transition between sectors within the same employment status. However, if a household changes its employment status, it can change the sector it is operating in.

self-employed households, $(T - h_{i,S})n_{i,S}$. Moreover, all firms are competing for matches with the self-employed individuals. Thus, $\left(\sum_g \sum_z v_{g,z} h_{g,z}\right)$ represents the aggregate recruiting effort of all firms.

In my three-stage matching structure, the self-employed individuals are the only ones who search for a job in the informal firm. Thus, I set

$$m_{j,I} = \sum_i m_{i,S}^{j,I}, \tag{5}$$

where $m_{j,I}$ is the aggregated number of matches of the informal firm operating in sector j. For formal employment, however, self-and informally employed individuals are interested in getting a job. Consequently, a formal firm in sector j additionally creates matches with workers employed in an informal firm operating in sector i, which is given by

$$m_{i,I}^{j,F} = \mu_{j,F}[(T - h_{i,I})n_{i,I}]^{\gamma_{j,F}} (v_{j,F} h_{j,F}) \left(\sum_z v_{F,z} h_{F,z} \right)^{-\gamma_{j,F}}, \tag{6}$$

where $(T - h_{i,I})n_{i,I}$ is the search effort of an informally employed individual. The aggregate recruiting effort, $(\sum_z v_{F,z} h_{F,z})$, does not contain the recruiters of the informal firms, as only the recruiters of the formal firms are competing for informally employed households. The aggregated number of matches for a formal firm in sector j consists of matches with self-employed and informal households:

$$m_{j,F} = \sum_i (m_{i,I}^{j,F} + m_{i,S}^{j,F}) \tag{7}$$

2.2.2 Job-Finding probability

Each household faces a specific probability of finding a better job per hour, θ. The number of matches in a sector must be equal to the total searching effort times the probability of the households finding a job in this sector. Therefore, for the self-employed households in sector i, it has to hold that

$$m_{i,S}^{j,k} = ((T - h_{i,S})n_{i,S})\theta_{i,S}^{j,k}, \tag{8}$$

whereas for the households employed in an informal firm in sector i,

$$m_{i,I}^{j,F} = ((T - h_{i,I})n_{i,I})\theta_{i,I}^{j,F} \tag{9}$$

has to hold. Setting that equal to Equation (4), respectively to Equation (6), gives

$$\theta_{i,S}^{j,k} = \mu_{j,k}[(T - h_{i,S})n_{i,S}]^{\gamma_{j,k}-1}(v_{j,k}h_{j,k})\left(\sum_g\sum_z v_{g,z}h_{g,z}\right)^{-\gamma_{j,k}} \tag{10}$$

and

$$\theta_{i,I}^{j,F} = \mu_{j,F}[(T - h_{i,I})n_{i,I}]^{\gamma_{j,F}-1}(v_{j,F}h_{j,F})\left(\sum_g v_{g,F}h_{g,F}\right)^{-\gamma_{j,F}}, \tag{11}$$

which shows that the probability of getting a job is endogenous as it depends on the sector-specific labor market tightness. Furthermore, the term for aggregating recruitment effort in Equation (10) and (11) indicates that it is easier to get a job in a formal firm for households employed in an informal firm than for self-employed households. The reason for that is the assumption that the total recruiting effort negatively affects the number of matches. This effect is stronger for self-employed households than for the informally employed ones because formal and informal firms are competing for self-employed households, while only the formal firms are competing for the latter ones. That pattern is typical for developing countries, where self-employment is usually located in rural areas and informal and formal jobs are in urban areas. That makes it more difficult to find a formal job for self-employed individuals. Moreover, individuals employed in an informal firm generally gain more relevant experience for formal employment than self-employed individuals.

2.2.3 Recruiting productivity

I consider the number of matches a recruiter can create per hour as the recruiting productivity. Each firm has a recruiting productivity of $H_{j,k}$. The recruiting effort times the recruiting productivity has to equalize with the number of matches, $m_{j,k} = v_{j,k}h_{j,k}H_{j,k}$. Setting that equal to the total number of matches $m_{j,k}$ from Equation (7), respectively from Equation (5), and inserting it in Equation (4) and Equation (6) allows me to solve for $H_{j,k}$. That shows that similar to the probability of getting a job, the recruiting productivity is endogenous.

2.3 Production

The production technology of each sector is formulated as a nested constant elasticity of substitution function (CES) as shown in Figure 1. In this structure, imported goods are imperfect substitutes for domestically produced goods. Moreover, the sectoral output is produced using three production technologies: own-production, informal firm production, and formal firm production. I follow Ju-e and You-min (2009) assuming a KE-L(M) production structure for firm production. Own-production does not use capital and has an E-L(M) production structure.

Furthermore, similar to Anand and Khera (2016), I assume that informal and formal goods are substitutable. In what follows, I describe the production process nest after nest. Note that variables are written in capital and parameters in small letters. For simplicity, I omit time-subscripts.

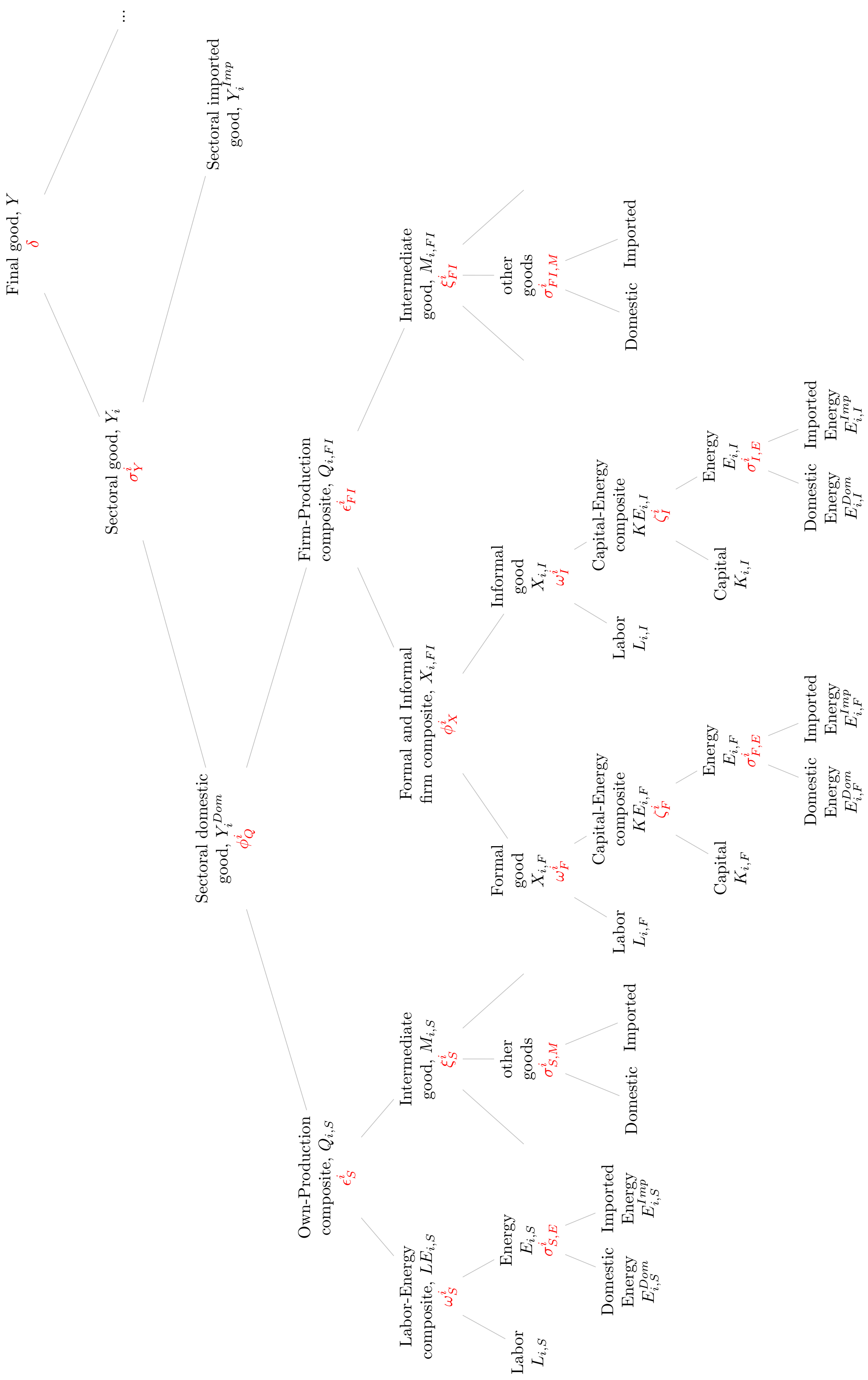

Figure 1: Production structure

Final good production

At the top level, a representative final good producer produces Y according to

$$Y = \left(\sum_i a_i Y_i^{\frac{\delta-1}{\delta}} \right)^{\frac{\delta}{\delta-1}}, \tag{12}$$

where Y_i is the sectoral good of sector i, a_i the value share of this sectoral good and δ the elasticity of substitution (EoS) between the sectoral goods. I assume perfect competition, meaning that the producer takes the prices of inputs and outputs as given. In each sector, the final good producer maximizes profits according to

$$\max_{\{Y_i\}} P_y * Y - \sum_i (P_i * Y_i) \tag{13}$$
$$\text{w.r.t. (12)},$$

where P_y is the final good price and P_i the sectoral good price of sector i. Solving Equation (13) and combining the resulting optimal demand for all sectoral goods gives the condition for the optimal input use.[10] The condition is given by

$$\frac{Y_j}{Y_i} = \left(\frac{P_i}{P_j} \right)^{\delta} \left(\frac{a_j}{a_i} \right)^{\delta}. \tag{14}$$

I define the sectoral good production as

$$Y_i = \left(a_{i,Dom} Y_{i,Dom}^{\frac{\sigma_Y^i - 1}{\sigma_Y^i}} + (1 - a_{i,Dom}) Y_{i,Imp}^{\frac{\sigma_Y^i - 1}{\sigma_Y^i}} \right)^{\frac{\sigma_Y^i}{\sigma_Y^i - 1}}, \tag{15}$$

where $a_{i,Dom}$ represents the value share of sectoral domestic goods. σ_Y^i is the EoS between sectoral domestic goods, $Y_{i,Dom}$, and sectoral imported goods, $Y_{i,Imp}$. For the sectoral domestic production, I make a distinction between a composite good of own-production, $Q_{i,S}$, which is produced by self-employed households, and a composite good of the firms, $Q_{i,FI}$. That allows me to include competition between the own- and the firm production composite. $Y_{i,Dom}$ is given as

$$Y_{i,Dom} = \left(a_{i,S}^Q Q_{i,S}^{\frac{\phi_Q^i - 1}{\phi_Q^i}} + (1 - a_{i,S}^Q) Q_{i,FI}^{\frac{\phi_Q^i - 1}{\phi_Q^i}} \right)^{\frac{\phi_Q^i}{\phi_Q^i - 1}}, \tag{16}$$

[10] Except for the informal and formal good production, I use this solving process based on the full competition assumption. Thus, given the CES production function, the producer behavior can explicitly be described as the maximization of their profits. For brevity, I describe the other nests without solving them explicitly and refer to this case for the solution method.

where $a_{i,S}$ is the value share of own-production and ϕ^i_Q the EoS between the own-production composite and the firm-production composite.

Firm Production

The firm-production composite is defined as

$$Q_{i,FI} = \left(a^X_{i,FI} X_{i,FI}^{\frac{\epsilon^i_{FI}-1}{\epsilon^i_{FI}}} + (1 - a^X_{i,FI}) M_{i,FI}^{\frac{\epsilon^i_{FI}-1}{\epsilon^i_{FI}}} \right)^{\frac{\epsilon^i_{FI}}{\epsilon^i_{FI}-1}}, \tag{17}$$

where $X_{i,FI}$ is a formal and informal firm composite, $M_{i,FI}$ the intermediate good, $a_{i,FI}$ the value share of the formal and informal firm composite, and ϵ^i_{FI} the EoS between those two goods. The intermediate good is produced using intermediates of all non-energy sectors, which can either be domestically produced, $M^{j,Dom}_{i,FI}$, or be imported, $M^{j,Imp}_{i,FI}$. Thus, the intermediate good production is defined as

$$M_{i,FI} = \left(\sum_{j \neq E} a^{j,M}_{i,FI} M^j_{i,FI}{}^{\frac{\xi^i_{FI}-1}{\xi^i_{FI}}} \right)^{\frac{\xi^i_{FI}}{\xi^i_{FI}-1}}, \tag{18}$$

where

$$M^j_{i,FI} = \left(a^{j,M,Dom}_{i,FI} M^{j,Dom}_{i,FI}{}^{\frac{\sigma^i_{FI,M}-1}{\sigma^i_{FI,M}}} + (1 - a^{j,M,Dom}_{i,FI}) M^{j,Imp}_{i,FI}{}^{\frac{\sigma^i_{FI,M}-1}{\sigma^i_{FI,M}}} \right)^{\frac{\sigma^i_{FI,M}}{\sigma^i_{FI,M}-1}}. \tag{19}$$

$a^{j,M}_{i,FI}$ represents the value share of a good j and $a^{j,M,Dom}_{i,FI}$ the value share of this good produced domestically. ξ^i_{FI} is the EoS between the different intermediate goods and $\sigma^i_{FI,M}$ the one between domestic and imported intermediates.

The formal and informal firm composite production is given as

$$X_{i,FI} = \left(a^X_{i,F} X_{i,F}^{\frac{\phi^i_X-1}{\phi^i_X}} + (1 - a^X_{i,F}) X_{i,I}^{\frac{\phi^i_X-1}{\phi^i_X}} \right)^{\frac{\phi^i_X}{\phi^i_X-1}}, \tag{20}$$

where $X_{i,F}$ is the formal good, $X_{i,I}$ the informal good, $a_{i,F}$ the value share of the formal good, and ϕ^i_X the EoS between the two goods. Thus, similar to Anand and Khera (2016), I allow for competition between the formal and informal good. For the firm production of the informal and formal good, I follow Ju-e and You-min (2009) who finds that a KE-L nesting structure is appropriate in the case of China.[11] As I calibrate my model to India which is relatively close to China in Section 4, I assume that firms have a KE-L nesting structure. A k firm in sector i produces good $X_{i,k}$ according to

$$X_{i,k} = A_{i,k} \left(a^L_{i,k} (L_{i,k})^{\frac{\omega^i_k - 1}{\omega^i_k}} + (1 - a^L_{i,k}) KE_{i,k}^{\frac{\omega^i_k - 1}{\omega^i_k}} \right)^{\frac{\omega^i_k}{\omega^i_k - 1}}, \tag{21}$$

where $A_{i,k}$ is the firm-specific technology factor, $L_{i,k}$ the labor input, $KE_{i,k}$ the capital-energy composite, $a^L_{i,k}$ the value share of labor and ω^i_k the EoS between Labor and the capital-energy composite. I follow Hafstead et al. (2018b) for the description of the labor input. Each period a firm inherits a stock of workers, $n_{i,k}$. The firm then has to allocate the workers between recruitment, $v_{i,k}$, and labor for production, $L_{i,k} \equiv (n_{i,k} - v_{i,k})h_{i,k}$. I assume that, in each period, some individuals are separating from the firm according to an exogenous separation rate $\beta_{i,k}$ and go back to self-employment. That means that firms face a trade-off between using labor to produce more goods today and using labor to hire more individuals for the next period. Consequently, firms are solving a dynamic problem. They choose the distribution of labor and the capital-energy composite good to maximize the value of the firm. As firms are owned by their corresponding households discounting the future at a given discounting rate of Q, the future profits of the firm are discounted at this factor. Based on that, I can set up the Bellman equation for a firm in sector i as

$$J(n_{i,k}) = \max_{\{KE_{i,k}, v_{i,k}\}} P_{i,k}X_{i,k} - ((1 + \tau_{p,k})h_{i,k}w_{i,k} + b_{i,k})n_{i,k} - P^{KE}_{i,k} KE_{i,k} + \mathbb{E}\left[QJ(n'_{i,k})\right] \tag{22}$$

where $P_{i,k}$ is the selling price, $\tau_{p,k}$ the labor tax, $w_{i,k}$ the wage per hour, $P^{KE}_{i,k}$ the price of the capital-energy composite good and $b_{i,k}$ a bureaucratic cost per worker. Bureaucratic costs are an important determinant of informality in developing countries that can create barriers to enter formal employment (Perry et al., 2007). Moreover, India‘s bureaucracy is perceived as one of the worst in Asia, making it necessary to include such costs in the model. Note that only the formal firm has to pay labor taxes, which means that $\tau_{p,F} > 0$ and $\tau_{p,I} = 0$ holds.
The law of motion for formal employment is defined as

$$n'_{i,F} = (1 - \beta_{i,F})n_{i,F} + H_{i,F}h_{i,F}v_{i,F} \tag{23}$$

and for informal employment as

$$n'_{i,I} = (1 - \beta_{i,I})n_{i,I} + H_{i,I}h_{i,I}v_{i,I} - (T - h_{i,I})n_{i,I}(\sum_j \theta^{j,F}_{i,I}), \tag{24}$$

[11] See Burniaux and Truong (2002) and Van der Mensbrugghe (1994) for models with a KE-L production structure.

where $(T - h_{i,I}) n_{i,I} (\sum_j \theta_{i,I}^{j,F})$ is the outflow of workers from the informal firm to the formal firms. It is assumed that the firms take the recruiter productivity and the probability that a worker finds a job as given. The first order constraint with respect to the capital-energy composite good leads to

$$P_{i,k} \frac{\partial X_{i,k}}{\partial KE_{i,k}} = P_{i,k}^{KE}. \tag{25}$$

Furthermore, the condition

$$P_{i,k} \frac{\partial X_{i,k}}{\partial L_{i,k}} = H_{i,k} \mathbb{E}\left[Q \frac{\partial J(n'_{i,k})}{\partial n'_{i,k}} \right] \tag{26}$$

is derived from the first-order condition with respect to the number of recruiters, $v_{i,k}$, where $\mathbb{E}\left[Q \frac{\partial J(n'_{i,k})}{\partial n'_{i,k}} \right]$ is the current value of an additional employee in the next period. This condition induces that a firm is adding recruiters until the marginal cost of an additional recruiter is equal to the expected value of recruitment. Using the envelope condition with respect to the number of workers, $n_{i,k}$, leads to the following condition for the marginal value of an additional worker for a formal firm

$$\frac{\partial J(n_{i,F})}{\partial n_{i,F}} = P_{i,F} \frac{\partial X_{i,F}}{\partial n_{i,F}} - (1 + \tau_{p,F}) h_{i,F} w_{i,F} - b_{i,F} + (1 - \beta_{i,F}) \mathbb{E}\left[Q \frac{\partial J(n'_{i,F})}{\partial n'_{i,F}} \right]. \tag{27}$$

This condition equalizes the value of an additional worker to its marginal revenue subtracting its compensation and adding the expected value of the worker in the next period if the worker does not separate from the firm. The informal firms do not only have to consider the separation rate but as well the possibility that a worker changes to a formal firm. Therefore, the condition for the informal firms slightly changes to

$$\frac{\partial J(n_{i,I})}{\partial n_{i,I}} = P_{i,I} \frac{\partial X_{i,I}}{\partial n_{i,I}} - h_{i,I} w_{i,I} - b_{i,I} + (1 - \beta_{i,I} - (T - h_{i,I})(\sum_j \theta_{i,I}^{j,F})) \mathbb{E}\left[Q \frac{\partial J(n'_{i,I})}{\partial n'_{i,I}} \right]. \tag{28}$$

The capital-energy composite good is produced according to

$$KE_{i,k} = \left(a_{i,k}^K K_{i,k}^{\frac{\zeta_k^i - 1}{\zeta_k^i}} (1 - a_{i,k}^K) E_{i,k}^{\frac{\zeta_k^i - 1}{\zeta_k^i}} \right)^{\frac{\zeta_k^i}{\zeta_k^i - 1}}, \tag{29}$$

where $a_{i,k}^K$ is the value share parameter of capital, $K_{i,k}$ the capital input, $E_{i,k}$ the energy input and ζ_k^i the elasticity of substitution between capital and energy. As my model focuses on labor, I make the simplifying assumption that capital is rented in each period from the rest of the world and is, therefore, imported.[12] Energy $E_{i,k}$ is produced using domestic and imported energy according to

$$E_{i,k} = \left(a_{i,k}^{E,Dom} E_{i,k}^{Dom} {}^{\frac{\sigma_{k,E}^{i}-1}{\sigma_{k,E}^{i}}} + (1 - a_{i,k}^{E,Dom}) E_{i,k}^{Imp} {}^{\frac{\sigma_{k,E}^{i}-1}{\sigma_{k,E}^{i}}} \right)^{\frac{\sigma_{k,E}^{i}}{\sigma_{k,E}^{i}-1}}, \tag{30}$$

where $a_{i,k}^{E,Dom}$ is the value share of domestic energy, $E_{i,k}^{Dom}$, and $\sigma_{k,E}^{i}$ the elasticity of substitution between domestic energy and imported energy.

Own-Production

In contrast to firm production, own-production does not use capital as an input and has an E-L(M) production structure. The reason for that is that my model focuses on low productive self-employed individuals. In developing countries, these individuals traditionally do not rely on capital for production. Moreover, own-production does not have search frictions. The own-production composite good $Q_{i,S}$ is produced according to

$$Q_{i,S} = \left(a_{i,S}^{LE} LE_{i,S}^{\frac{\epsilon_{S}^{i}-1}{\epsilon_{S}^{i}}} + (1 - a_{i,S}^{LE}) M_{i,S}^{\frac{\epsilon_{S}^{i}-1}{\epsilon_{S}^{i}}} \right)^{\frac{\epsilon_{S}^{i}}{\epsilon_{S}^{i}-1}}, \tag{31}$$

where $LE_{i,S}$ represents the labor-energy composite, $M_{i,S}$ the non-energy intermediates, $a_{i,S}^{LE}$ the value share of labor-energy composite and ϵ_{S}^{i} the EoS between the two goods. $M_{i,S}$ is produces similar to Equation (18) and (19), and given by

$$M_{i,S} = \left(\sum_{j \neq E} a_{i,S}^{j,M} M_{i,S}^{j}{}^{\frac{\xi_{S}^{i}-1}{\xi_{S}^{i}}} \right)^{\frac{\xi_{S}^{i}}{\xi_{S}^{i}-1}} \tag{32}$$

where

$$M_{i,S}^{j} = \left(a_{i,S}^{j,M,Dom} M_{i,S}^{j,Dom} {}^{\frac{\sigma_{S,M}^{i}-1}{\sigma_{S,M}^{i}}} + (1 - a_{i,S}^{j,M,Dom}) M_{i,S}^{j,Imp} {}^{\frac{\sigma_{S,M}^{i}-1}{\sigma_{S,M}^{i}}} \right)^{\frac{\sigma_{S,M}^{i}}{\sigma_{S,M}^{i}-1}}. \tag{33}$$

The labor-energy composite is produced using labor, $L_{i,S}$, and energy, $E_{i,S}$, according to

$$LE_{i,S} = \left(a_{i,S}^{L} L_{i,S}^{\frac{\omega_{S}^{i}-1}{\omega_{S}^{i}}} + (1 - a_{i,S}^{L}) E_{i,S}^{\frac{\omega_{S}^{i}-1}{\omega_{S}^{i}}} \right)^{\frac{\omega_{S}^{i}}{\omega_{S}^{i}-1}}, \tag{34}$$

[12] A different method is to include a "capitalist" in the model which owns the capital and has savings. However, focusing on labor effects, the inclusion of a capitalist is not needed.

where $a_{i,S}$ is the value share of Labor and ω_S^i the EoS between labor and energy. Own-production does not need recruiters as there are no search frictions. Therefore, labor is given as $L_{i,S} = n_{i,S}h_{i,S}$. Similar to Equation (30), energy production is defined as

$$E_{i,S} = \left(a_{i,S}^{E,Dom} E_{i,S}^{Dom}{}^{\frac{\sigma_{S,E}^i - 1}{\sigma_{S,E}^i}} + (1 - a_{i,S}^{E,Dom}) E_{i,S}^{Imp}{}^{\frac{\sigma_{S,E}^i - 1}{\sigma_{S,E}^i}} \right)^{\frac{\sigma_{S,E}^i}{\sigma_{S,E}^i - 1}}. \tag{35}$$

International trade

In the model, import goods are imperfect substitutes for domestically produced goods. Regarding exports, I assume that the final good, Y, is divided into exports, EX, and domestically supplied goods, D. The producer maximizes its profits according to the transformation function

$$\max_{\{EX,D,Y\}} = P_{EX}EX + P_c D - P_y Y \tag{36}$$

subject to the transformation technology

$$Y = \left(a_{EX} EX^{\frac{\rho_{EX}-1}{\rho_{EX}}} + (1 - a_{EX}) D^{\frac{\rho_{EX}-1}{\rho_{EX}}} \right)^{\frac{\rho_{EX}}{\rho_{EX}-1}}. \tag{37}$$

P_{EX} is the price of the export good in terms of the domestic currency, P_y is the final good price, a_{EX} the value share of exports, and ρ_{EX} is the transformation elasticity between exports and domestic supplied goods. The domestic prices for exports, P^{EX}, and imports, P^{Imp} are given as $P_{EX} = PFX * P_{EX}^{world}$ and $P_{Imp} = PFX * P_{Imp}^{world}$. PFX is the exchange rate, P_{EX}^{world} the given export price in foreign currency, and P_{Imp}^{world} the given import price in foreign currency.[13] Furthermore, I assume that trade is balanced in each period. Consequently,

$$P_{EX}^{world} * EX = P_{Imp}^{world} * Imp \tag{38}$$

has to hold.[14]

2.4 Wage bargaining

I follow the standard search and match literature based on Pissarides (1985) and assume a Nash-bargaining for wages in each period. That induces that optimized wages are such that the matching surplus is maximized. The standard search and matching literature incorporates the matching surplus from a firm and a particular household in the Nash-Bargaining. I extend

[13] I follow the common small country assumption, meaning that the country can not influence the world market prices.

[14] Note that I set up Equation (38) in general form. In my model, different sectors and firms are importing goods facing potentially different import prices. For simplicity, I summarize that here to $P_{Imp}^{world} * Imp$.

that by including an "averaged" matching surplus between different households. In my three-stage matching structure, multiple households differing in their matching surpluses can get a job in a specific firm. Taking into account that the wage bargaining between firms and labor unions considers the aggregated needs of the workforce, the equilibrium wages are derived from

$$\max_{\{w_{i,k}\}} \left(\frac{\partial J(n_{i,k})}{\partial n_{i,k}}\right)^{\eta_{i,k}} V_{n_{i,k}}^{1-\eta_{i,k}} \tag{39}$$

where $\eta_{i,k}$ is the bargaining power of the employer, $\frac{\partial J(n_{i,k})}{\partial n_{i,k}}$ is the marginal value of an additional worker for the firm and $V_{n_{i,k}}$ is the average matching surplus for the households. It holds that

$$V_{n_{i,k}} = W_{i,k} - O_{i,k}^{avg}, \tag{40}$$

where $W_{i,k}$ is the value of employment for a worker at a specific firm and $O_{i,k}^{avg}$ is the averaged outside option of the different households participating in the wage bargaining. I first derive the value of employment for a worker at a specific firm, which depends on the periodic utility of the current job and the probability to get a different job in the next period times the value of employment in the new position. In my three-stage matching structure, a formal worker can either keep her current job or lose it and go to self-employment. Thus, the value of formal employment in sector i is given as

$$W_{i,F} = \mathcal{L}_{i,F} + Q\Delta_{i,F} \tag{41}$$

where the expected value of employment in the next period, $\Delta_{i,F}$, is

$$\Delta_{i,F} = \sum_j \left(\beta_{i,F}^j W'_{j,S} + (1-\beta_{i,F})W'_{i,F}\right). \tag{42}$$

$\beta_{i,F}^j$ is the probability to lose the job and to go to self-employment in sector j, $W'_{j,S}$ the next periods value of self-employment in sector j, $\beta_{i,F} = \sum_j \beta_{i,F}^j$ the total (exogenous) separation rate of the specific formal firm and $(1-\beta_{i,F})$ the probability of staying in the job and receiving the next periods value of the current job, $W'_{i,F}$.

An informal worker can either stay in her current position or switch to self- or formal employment. Thus, the value of informal employment includes the probability to get a formal job, $(T-h_{i,I})\theta_{i,I}^{j,F}$, and can be defined as

$$W_{i,I} = \mathcal{L}_{i,I} + Q\Delta_{i,I}, \tag{43}$$

where

$$\Delta_{i,I} = \sum_j \left(\beta_{i,I}^j W'_{j,S} + (T - h_{i,I})\theta_{i,I}^{j,F} W'_{j,F} + (1 - \beta_{i,I} - (T - h_{i,I})\theta_{i,I}^{j,F}) W'_{i,I}\right) \tag{44}$$

holds. Finally, self-employed individuals can either stay or switch to formal or informal employment. Consequently, the value of self-employment is given as

$$W_{i,S} = \mathcal{L}_{i,S} + Q\Delta_{i,S} \tag{45}$$

where

$$\Delta_{i,S} = \sum_j \left(\sum_k \left((T - h_{i,S})\theta_{i,S}^{j,k} W'_{j,k} + (1 - (T - h_{i,S})\theta_{i,S}^{j,k}) W'_{i,S}\right)\right) \tag{46}$$

holds. The next step is to set up the outside option of a household which is simply the value of its original employment. To get the averaged outside option, I need to include the share of matches of a particular household type to the total number of matches of a specific firm given by Ω. A formal firm operating in sector i has matches with the self-employed households and with the informally employed households. Therefore, its averaged outside option is given as

$$O_{i,F}^{avg} = \sum_j \left(\Omega_{j,S}^{i,F} W_{j,S} + \Omega_{j,I}^{i,F} W_{j,I}\right), \tag{47}$$

where $\Omega_{j,S}^{i,F} = \frac{m_{j,S}^{i,F}}{m_{i,F}}$ and $\Omega_{j,I}^{i,F} = \frac{m_{j,I}^{i,F}}{m_{i,F}}$. As the informal firm in sector i only matches with self-employed households, its averaged outside option is defined as

$$O_{i,I}^{avg} = \sum_j \left(\Omega_{j,S}^{i,I} W_{j,S}\right), \tag{48}$$

where $\Omega_{j,S}^{i,I} = \frac{m_{j,S}^{i,I}}{m_{i,I}} = 1$ holds.
This allows me to maximize the averaged matching surplus and to solve for the after-tax total wage that an employed worker receives:

$$\begin{aligned} w_{i,k} h_{i,k}(1 - \tau_k) = \frac{\eta_{i,k}}{\lambda_{i,k}} &\left(O_{i,k}^{avg} + c_{i,k} P_c \lambda_{i,k} + \psi \frac{h_{i,k}^{1+\chi}}{1+\chi} - Log(c_{i,k} + 1) - Q\Delta_{i,k}\right) \\ + (1 - \eta_{i,k}) \frac{1 - \tau_k}{1 + \tau_{p,k}} &\left((1 - \beta_{i,k})\mathbb{E}\left[Q \frac{\partial J(n'_{i,k})}{\partial n'_{i,k}}\right] + P_{i,k} \frac{\partial X_{i,k}}{\partial n_{i,k}} - b_{i,k}\right) \end{aligned} \tag{49}$$

Equation (49) induces a division of the average matching surplus according to a constant share rule. Similar to Hafstead and Williams (2018), I find that workers need to be compensated for the opportunity costs they are facing, which are displayed by the first term on the right-hand side. The second term includes the marginal revenue of an additional worker, which positively affects the after-tax total wages due to the bargaining mechanism.[15] The wage mechanism in my model is further discussed in Section 3.

2.5 Government

The government is assumed to run a balanced budget and to use its revenues to consume the final good according to the following condition

$$\sum_i ((\tau_F + \tau_{p,F}) w_{i,F} h_{i,F} n_{i,F} + \tau_E E) = P_c c_{gov} \tag{50}$$

where τ_E is a tax on energy, E the total energy consumption and c_{gov} the governmental consumption.[16]

3 Steady-State conditions and wage mechanism

In a steady-state, the variables need to be constant over time, meaning that they are equal in period t and period $t+1$. Therefore, for the value of an additional worker for a firm,

$$\frac{\partial J(n^*_{i,k})}{\partial n^*_{i,k}} = \frac{\partial J({n_{i,k}}'^*)}{\partial {n_{i,k}}'^*}, \tag{51}$$

has to hold and employment needs to be constant

$$n^*_{i,k} = {n_{i,k}}'^*, \tag{52}$$

as well as the value of employment for the individuals:

$$W^*_{j,l} = {W_{j,l}}'^* \tag{53}$$

I can now derive the steady-state using the Equations (1) - (50) in Section 2 solving for working hours, quantities, and prices which satisfy the first-order conditions of households and firms and clear the goods and factor markets.

The wage mechanism is the most important driver of the outcome of search and match models with Nash-Bargaining. In this section, I analyze the wage mechanism in a three-stage matching process. Moreover, I explain differences to the two-staged matching process used in the standard literature. To do so, I build on Equation (49) in Sections 2 and add the steady-

[15] See Shimer et al. (2010) and Hafstead and Williams (2018) for a more detailed explanation.
[16] τ_E is assumed to be zero in the baseline case.

state conditions.[17] I assume that the steady-state conditions (51), (52), and (53) hold and solve for the wages w_F^* and w_I^*.[18] In this section, I ignore the employment and households decision, assuming that they are independent of wages and, thus, exogenously defined. Under these conditions, the wages in the different stages are interlinked such that a specific status quo with respect to employment and working hours is maintained. Specifically, this induces that a firm adjusts its wage to keep the average matching surplus of households constant, meaning that potential workers have unchanged incentives to join the firm. That enables me to explicitly analyze the wage mechanism in the three-stage matching process by disentangling it from other effects. To compare the wage response in my model with the standard two-stage matching process, I elaborate on the effect of changing the wage of self-employed individuals on w_F^* and w_I^*. Thus, I derive w_F^* and w_I^* with respect to w_S which results into

$$\frac{\partial w_F^*}{\partial w_S}\Big|_{\frac{\partial n_l}{\partial w_S}=0} = \frac{\left(\frac{h_S\lambda_S}{1+Q(-1+Q(\Gamma_I^F-\Gamma_S^F)\Gamma_S^I)}\right)}{\left(\frac{h_F\lambda_F(1-\tau_F)}{1-Q}\right)} \tag{54}$$

and

$$\frac{\partial w_I^*}{\partial w_S}\Big|_{\frac{\partial n_l}{\partial w_S}=0} = \frac{\left(\frac{h_S\lambda_S}{1+Q(-1+Q(\Gamma_I^F-\Gamma_S^F)\Gamma_S^I)}\right)}{\left(\frac{h_I\lambda_I}{1+Q(-1+Q(1-\beta_I-\Gamma_I^F)(\Gamma_I^F-\Gamma_S^F)}\right)} \tag{55}$$

where $\Gamma_S^F = (T-h_S)\delta_S^F$, $\Gamma_I^F = (T-h_I)\delta_I^F$ and $\Gamma_S^I = (T-h_S)\delta_S^I$. The Γs represent the different job finding probabilities per day. Equations (54) and (55) show how wages need to change in response to an increase in w_S to maintain similar incentives to switch to firm employment, meaning that the average matching surplus $V_{n_{i,k}}$ remains constant.

It is helpful to distinguish between three effects to understand the wage mechanism: the "direct outside option effect", the "indirect outside option effect" and the "feedback effect". The direct outside option effect captures the initial increase of the outside option, whereas its indirect counterpart incorporates the change in the outside option caused by the feedback effect.[19] Increasing w_S results in a higher outside option for firm employment. Formal and informal firms respond to that by increasing their wages to maintain similar incentives for self-employed individuals to switch to firm employment. Consequently, firms enhance the value of their employment due to the direct outside option effect, which then causes the feedback effect: a higher value of firm employment rebounds positively to the corresponding value of the lower stages of the matching process. For example, increasing W_F boosts W_S through Γ_S^F and W_I

[17] For simplicity, I assume that there is only one sector for this exercise. I replace $\frac{\partial J(n'_{i,k})}{\partial n'_{i,k}}$, $\Delta_{i,l}$ and $O_{i,k}^{avg}$ by their full-terms displayed in Equations (27), (28), (42), (44), (46), (47) and (48).

[18] The solutions are displayed in Appendix A.

[19] Although the direct and indirect outside option effect works similarly, a distinction between these two is necessary to understand the differences between the wage mechanism in a two - and three-stage matching structure.

through Γ_I^F (see Equation (43) and (45)). That feedback effect enhances the outside option and triggers the indirect outside option effect. The latter works similarly to its direct counterpart: firms respond to it by adjusting their value of employment, which, in turn, affects the size of the feedback effect, rebounding back to the outside option again. This process continues until the prior average matching surplus is reached. While the indirect outside option and feedback effect offset each other in a two-stage matching process, these two effects are decisive for the wage mechanism in a three-stage matching process, where the Γs capture their size as displayed in (54) and (55).

Proposition 1. *If $\Gamma_I^F = \Gamma_S^F$ holds, then the feedback and indirect outside option effect offset each other, and the wage mechanism only depends on the direct outside option effect.*

In that case, Equation (54) simplifies to $\partial w_F^* / \partial w_S = h_S\lambda_S / (h_F\lambda_F)(1-\tau_F)$ and Equation (55) to $\partial w_I^* / \partial w_S = h_S\lambda_S / (h_I\lambda_I)$. Changing w_S has a positive impact on firm wages through the outside option resulting in a change of the value of formal and informal firm employment. Based on that, there is a feedback effect of the increase of W_F on W_I through Γ_I^F. In addition, the feedback effect of W_F also increases W_S through Γ_S^F, which indirectly raises the outside option for informal firm employment. If $\Gamma_I^F = \Gamma_S^F$ holds, then the indirect outside option and feedback effect offset each other and, thus, the wage response coincides with the wage mechanism in standard two-stage matching processes.

Proposition 2. *If $\Gamma_I^F \neq \Gamma_S^F$ holds, then the wage mechanism is based on the direct outside option effect, the indirect outside option effect, and the feedback effect.*

In that case, the size of the feedback and the indirect outside option effect differs in a three-stage matching process and affects the wage response as a consequence. The term $(1 - \beta_I - \Gamma_I^F)(\Gamma_I^F - \Gamma_S^F)$ in Equation (55) captures the weighted feedback effect on the value of employment minus the increase of the outside option for informal firm employment due to the feedback effect on self-employment. $(1-\beta_I-\Gamma_I^F)$ is the chance to stay in informal employment, Γ_I^F the direct effect of W_F on W_I and Γ_S^F the impact of W_F on the outside option of informal employment through W_S. The term $(\Gamma_I^F - \Gamma_S^F)\Gamma_S^I$ represents the weighted feedback effect for self-employment. Different from the feedback effect on the informal firm, $(\Gamma_I^F - \Gamma_S^F)$ is multiplied by Γ_S^I, which is the chance for self-employed individuals to get into informal employment. If, for example, $\Gamma_I^F > \Gamma_S^F$ and hours and the λs are equal, then, according to Equation (54) and (55), $\frac{\partial w_F^*}{\partial w_S} > \frac{\partial w_I^*}{\partial w_S}$ holds. In this case, the formal wage affects the value of informal employment more than the corresponding outside option. Thus, an informal firm becomes relatively more attractive and changes its wage less as a response to an increase of w_S.

This simplified illustration shows that the wage mechanism in the three-stage matching process differs structurally from its two-stage counterpart. In the latter, changes in one stage affect the other stage one-dimensionally, where only the initial increase in the outside option is relevant for the wages. In contrast, the triangular nature of the former induces that changes in one stage affect the remaining two stages, which, in turn, impact each other. Consequently, the effect is multi-dimensional, meaning that the feedback and indirect outside option effect do not have to offset each other. In addition to the wage mechanism described before, the model described in Section 2 encompasses other effects: first, increasing wages raise the cost of labor, incentivizing firms to lower employment as a response. Second, firms of different sectors are competing not only on the goods market but also for potential workers (see the last term on the right-hand side of Equation (4) and (6)). Considering that an increase in a firm‘s wage decreases its incentive to employ recruiters (as labor becomes relatively more expensive), this positively affects the matchings of firms operating in other sectors. Third, the households decide, for example, on the hours dependent on the wages. Assuming a positive Frisch elasticity of labor supply, an increase in the wage incentivizes to work more. That, in turn, decreases the searching effort resulting in a negative impact on the corresponding $\Gamma(s)$.

4 Calibration

This section starts with a brief background of the labor market in India. According to Mehrotra et al. (2019), India had a low unemployment rate of 2.2% in 2011/2012. The reason for that is mainly the insufficient unemployment benefit scheme. The agricultural sector is still the predominant employer in India. In the last thirty years, however, its labor share declined substantially and continues to shrink. The output of the service sector surpassed the agricultural sector many years ago. This ongoing development is perceived as the "Service revolution" of India (e.g. Gordon and Gupta (2005)). Despite that structural change, informality continues to play a crucial role in Indian's economy for decades. With around 90% of informal workers, India has a relatively extensive informal economy compared to other developing countries. Furthermore, more than half of the workforce is self-employed (Mehrotra et al., 2019). Researchers argue that the significant and persistent role of the informal economy in India is also a result of various policies in the past favoring informality. Consequently, the Indian informal sector is multidimensional and complex, making it hard to tackle it without harming the vast majority of Indian workers.

I calibrate the model to India for the year 2011/2012, disaggregating the economy into three sectors: agriculture, industries, and services. Energy is treated as an industrial product and is thus part of the industry sector. I use employment data disaggregated into formal, informal, and self-employed workers per sector from Mehrotra et al. (2019). Furthermore, I take the sectoral economic data of the input-output table from the Asian Development Bank (2012). Those data, however, do not contain the division into formality and informality (and own-production). To overcome that shortcoming, I rely on three main assumptions for my calibration strategy.

Firstly, I assume that there are only self-employed workers in the agricultural sector.[20] Secondly, self-employed individuals produce in the same way in all the sectors. These two assumptions allow me to calibrate the own-production separately from firm-production. And lastly, I assume that the production functions of the sub-nests of the formal and informal firms operating in the same sector are similar. Based on that, the division of the economic data is a result of the model. As a consequence, the standard "nest-after-nest" calibration method for CGEs is not feasible. Instead, I calibrate the model in a step-wise approach, where I use the output of a step as an input for its subsequent.
Table 1 summarizes the benchmark parameters. The asterisk indicates calibrated steady-state values. The time period of the model is one month.

4.1 Household

I consider seven different household types; the self-employed households in each sector, and the formal and informal employed households in the industry and the service sector. Their discount rate Q is calibrated to replicate an average annualized interest rate of 7 percent. The Frisch-elasticity of labor supply is $\frac{1}{\chi} = 0.5$ which is similar to Tapsoba (2014). The disutility of work parameter ψ is calibrated such that the self-employed agricultural individuals work $h_{Agr,S} = 0.4$. This induces a 48-hours week which is consistent with the estimates of the Annual report on Periodic Labor Force Survey (PLFS) (2019) for the rural workforce in India. According to Gandullia et al. (2012) the labor income tax in India is on average $\tau_F = 0.118$.

4.2 Matching and Nash Bargaining

Following Hafstead and Williams (2018), I set the matching elasticity γ to 0.5 and the recruiter productivity H to 25 (in the initial steady state) for all sectors and firms. As employment is constant in the steady-state, I can set $n_{i,k} = n'_{i,k}$. Based on that, I use Equation (23) and (24) to solve for the recruitment effort in each sector. I then use Equation (5) and (7) to solve for the match efficiency $\mu_{i,k}$.[21]

For the Nash-bargaining process, I fix the Nash-bargaining parameter of the informal service sector to 0.5 as a benchmark. The remaining Nash-bargaining- parameters are calibrated such that the daily wages for the employed household match with the data.[22] Note that the calibrated Nash-bargaining parameters of formal employers are smaller than the ones of informal employers. Considering that employment unions are stronger for formal employees in India,

[20] According to the labor data, almost every worker in the agriculture sector is operating informally, and a vast majority of them are self-employed. Additionally, only 2.3% of the non-self-employed workers are regular workers, whereas the others are generally low earning casual workers.

[21] This approach is similar to Hafstead and Williams (2018). Therefore, I omit a more detailed description here.

[22] Own calculation based on Singhari and Madheswaran (2017) and Employment and Unemployment situation in India (2014).

Households				
Discount Factor	Q	0.994		
Disutility of work parameter	ψ	3.38*		
Taxes on formal labor income	τ_F	0.118		
Production		**Industry**	**Service**	**Agriculture**
Formal firm productivity	A_F	3.43*	4.03*	
Informal productivity relative to formal productivity	z_I	2/3	2/3	
Own-Production productivity	A_S	0.72*	0.72*	0.72*
Formal firm employment	n_F	0.0198	0.0536	
Informal firm employment	n_I	0.1489	0.0852	
Self-employment	n_S	0.1297	0.0737	0.4891
Payroll tax for formal firm	$\tau_{p,F}$	0.143	0.143	
Nash-Bargaining and Wages		**Industry**	**Service**	
Formal wage relative to informal industry wage	$\frac{w_F h_F}{w_{I,Ind} h_{I,Ind}}$	1.87	2.48	
Informal wage relative to informal industry wage	$\frac{w_I h_I}{w_{I,Ind} h_{I,Ind}}$	1	1.06	
Formal bargaining power	η_F	0.14*	0.05*	
Informal bargaining power	η_I	0.35*	0.5	
Matching				
Matching elasticity	γ	0.5		
Formal matching efficiency	μ_F	0.65*		
Informal matching efficiency	μ_I	3.04*		
Formal separation rate	β_F	0.1		
Informal separation rate	β_I	0.6		

Table 1: Calibration Table

this structure is reasonable.

4.3 Production

I calibrate the production-side in a stepwise approach starting with own-production. Based on the outcome of own-production, it becomes possible to calibrate the firm-production in a second step. Lastly, I calibrate the remaining nests using a nest-after-nest approach. Table 4 in Appendix B displays the underlying elasticities of substitutions, which I assume to be the same in formal and informal firm production.[23]

4.3.1 Own-Production

To calibrate the own-production, I start by calibrating the agriculture sector. I assume that only self-employed individuals are operating in the agriculture sector. Based on that, I can calibrate the agriculture sector in the standard way using the labor and economic data. Further, as I assume that the production structure of own-production is the same for all sectors, I can use the disaggregated labor data to calibrate the own-production of the other sectors.

4.3.2 Firm Production

Taking the calibrated own-production into account, I can distinguish between own-production and firm-production in the input-output table. To differentiate between the output of the formal and informal firms, I set them equal in the initial steady-state.[24] I then use Equation (25) to set up the share per firm of the sectoral aggregated capital-energy composite received from the data.[25] As a next step, I calibrate the bureaucratic costs per worker such that it is coherent with the firm-specific labor input and the wage distribution received from the data.

According to Gandullia et al. (2012) the payroll tax paid by the formal firms is on average $\tau_p = 0.143$. I assume that the exogenous separation rate for the formal firm, $\beta_{i,F}$, is 0.1 while the exogenous separation rate of the informal firm, $\beta_{i,I}$, is 0.6.[26] Similar to Ulyssea (2010) and Anand and Khera (2016), I further assume that the productivity of the informal firm is $A_{i,I} = \frac{2}{3} * A_{i,F}$. Considering the inputs and outputs evaluated before, this allows me to get an expression for the formal technology $A_{i,F}$. I then use the steady-state condition, $\frac{\partial J(n_{i,k})}{\partial n_{i,k}} = \frac{\partial J(n'_{i,k})}{\partial n_{i,k}}$, to calibrate for the firm-specific value share parameters.

Finally, the priorly stated assumption for similar sub-nests for firms in the same sector allows me to calibrate the sub-nests using the ratio of the capital-energy composite inputs between the formal and informal firms.

[23] Note that I assume that own-production in each sector has the same elasticity of substitution as agriculture.
[24] This is similar to Anand and Khera (2016).
[25] I take the sectoral data for capital from Timmer et al. (2015).
[26] Empirical evidence finds that the separation rate of informal firms is higher than of formal firms (e.g. Maloney (1999)).

5 Climate policy

In this section, I simulate the impact of a climate policy decreasing the energy use of India up to 20%. In my framework, I implement a tax on energy use to achieve an exogenously defined climate target. I assume that all the agents (including the informal ones) have to pay energy taxes.[27] Moreover, the revenue of the energy tax can be redistributed according to four scenarios: in "Scenario 1", the revenue is equally distributed across all individuals as a lump-sum transfer, whereas in "Scenario 2", the lump-sum only goes to the self-employed households. In "Scenario 3", the revenue is used to decrease the labor income taxes, and in "Scenario 4", to lower the formal bureaucratic costs per worker. In the first step, I provide a detailed analysis of the effects in each scenario separately. Building on that, I evaluate the optimal climate policy mix combining all four measures for different climate targets. I assume that pre-tax governmental consumption is needed to run the government. Therefore, this level has to be reached in all scenarios. Additionally, I neglect the transition and only analyze the steady-state values.

5.1 Comparison of the Scenario Results

Figure 2 shows the effect on the labor market considering the employment status. The results in "Scenario 1" are based on two effects: firstly, the lump-sum transfer to everyone increases the outside option of the worker due to the concavity of the utility function. Secondly, the lump-sum transfer decreases the incentive to work, which results in lower working hours, as shown in Figure 3. These two effects make labor relatively more expensive for firms. Thus, firm employment decreases while self-employment increases. In "Scenario 2", the second effect cancels out for firm employment. However, the first effect is amplified as the lump-sum transfer only goes to self-employed individuals. Compared to "Scenario 1", this is particularly detrimental for informal firms as they only hire self-employed individuals. The last two scenarios commonly put the focus on strengthening the formal firms. In "Scenario 3" and partially in "Scenario 4", the green job effect outweighs the job killer effect not only in quantitative terms but also in qualitative terms as formal firm employment increases at expenses on its informal counterpart.[28] The different impact on the labor market can be accounted to contrary wage effects, as shown in Figure 7 in Appendix C. In "Scenario 3", decreasing the labor income taxes directly affects the wage-bargaining-process, pushing up the wages substantially, which keeps the labor response

[27]Thus, I treat energy taxes differently than labor income taxes in my model. In developing countries, the informal employment relationship does not rely on an official contract. That makes it difficult for the government to observe and tax labor income. Energy consumption, however, is observable for the government. All the agents (including the informal ones) acquire the energy from the market. As the energy in India is usually provided by large, often state-owned (and formal) companies, it becomes possible to tax all energy providers, which can pass on the tax to the consumers.

[28]I consider firm-employment as jobs and self-employment as no jobs to analyze the well-known green job versus job killer effect of a climate policy.

relatively small. In "Scenario 4", lowering the bureaucratic costs is not connected to wages but to the number of workers. Therefore, wages remain constant. Consequently, formal employment increases by up to 20%, mainly at the expense of informal employment.

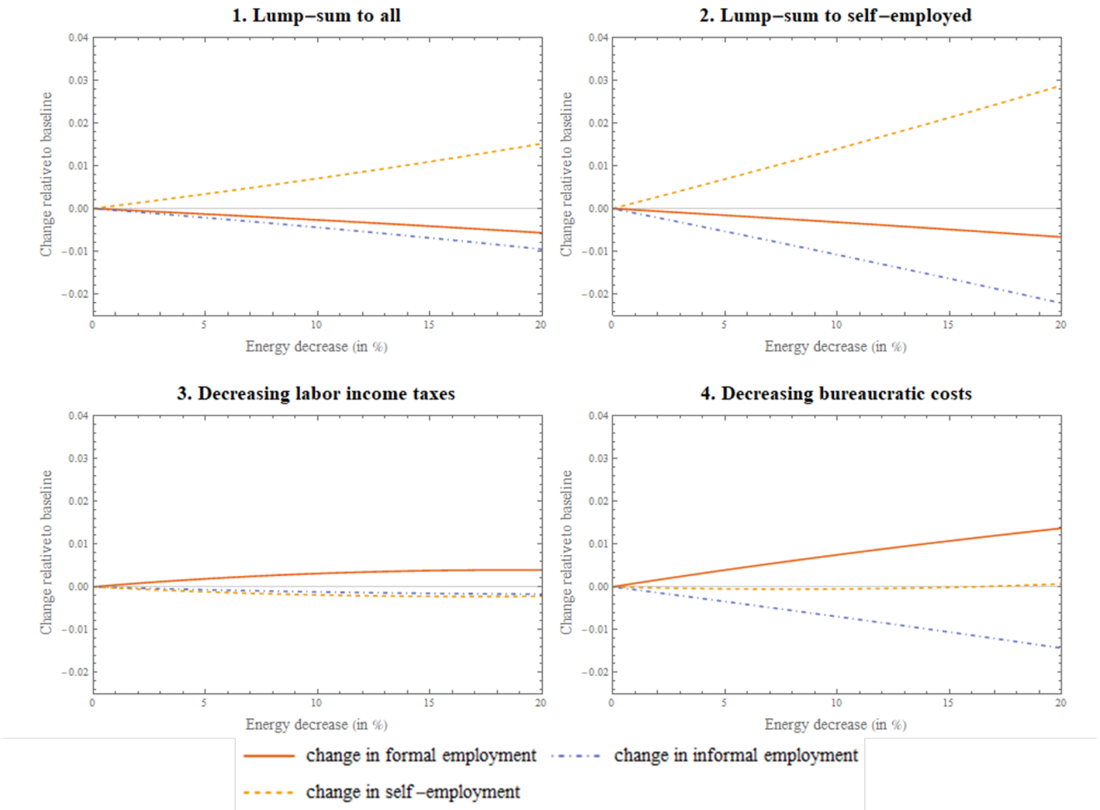

Figure 2: Effect on formal and informal employment

These results are in line with McKenzie (2017), who examines multiple empirical evaluations of various labor market policies in developing countries. He finds that wage subsidies lead to a relatively small labor response while helping the firm to overcome obstacles, as onerous regulations and labor laws is more promising.[29] Lastly, Figure 8 in Appendix C shows that supporting the formal labor force especially favors the formal service sector due to its high labor intensity.

[29] Alternatively, the revenue of the energy tax could be used to enhance the enforcement of regulations for informal firms which increases $b_{i,I}$. Different from decreasing the formal bureaucratic costs, this would not only boost formal but also self-employment and, thus, lead to less favorable labor market results. That finding is similar to Ulyssea (2010) using Brazilian data.

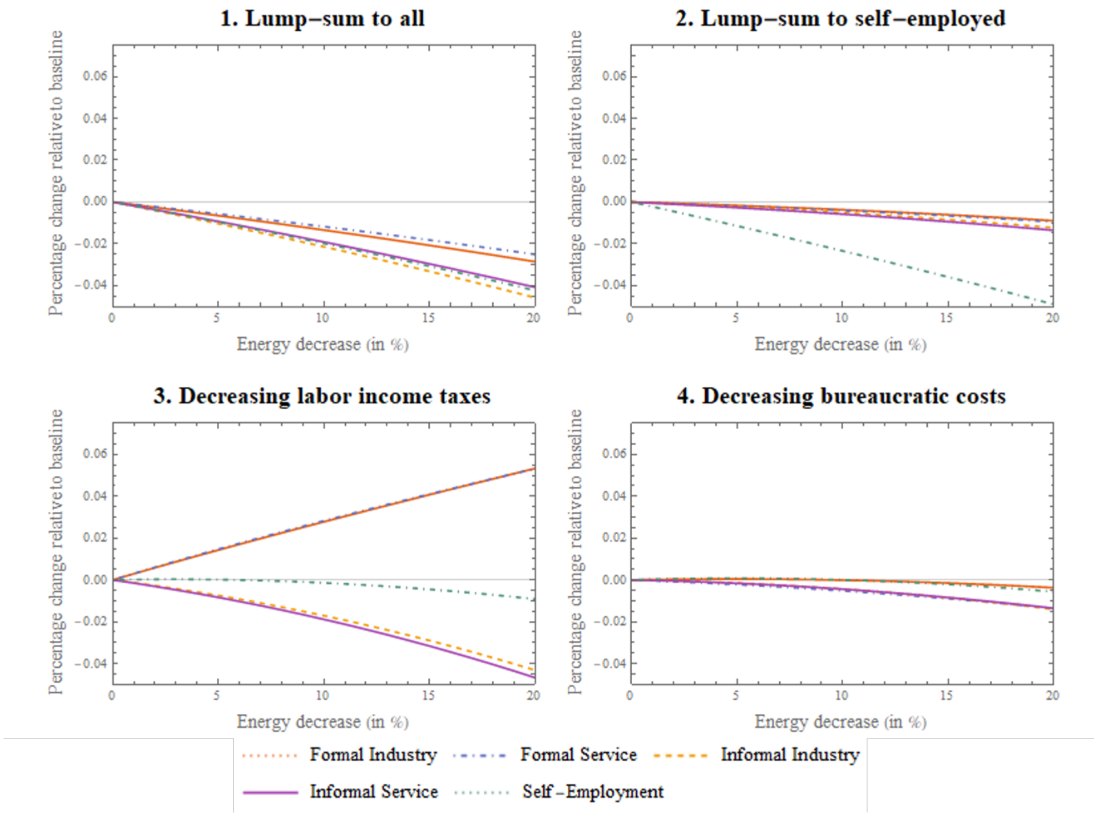

Figure 3: Effect on working hours per day

Figure 4 shows the development of utilitarian welfare and the Gini coefficient in the four different scenarios.[30] In "Scenario 1", the share of self-employment, which is relatively unproductive, increases. Furthermore, the lump-sum transfer decreases the incentive to work for everyone, which results in less "productive hours" in formal and informal firms. Based on that, "Scenario 1" decreases welfare the most. In "Scenario 2", the lump-sum transfer only lowers the incentive to work for self-employed individuals, leaving the "productive hours" nearly untouched. In addition, the transfer to the self-employed individuals has maximum impact due to the concavity of the utility function. As a result, "Scenario 2" harms welfare less as the effects described before outweigh the impact of a higher share of self-employment in "Scenario 2". Concerning inequality, both lump-sum scenarios slightly decrease the Gini-coefficient and, therefore, improve equality. In "Scenario 3", the policy includes a subsidy for formal workers, which are the top earners in the economy. Consequently, inequality increases substantially. In contrast, "Scenario 4" enhances the formal labor share keeping the formal wages constant, which results in a small increase in inequality.

[30]Note that the Gini coefficient only considers the income of the working individuals, which are included in my model. Therefore, the level differs from the Gini coefficient in India received from the data.

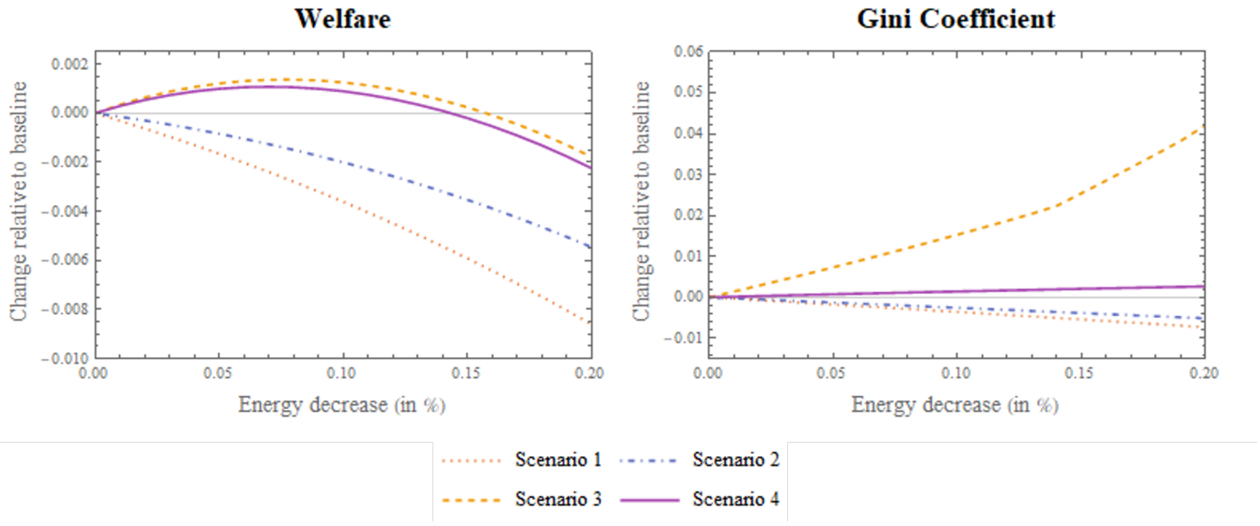

Figure 4: Comparison of welfare and the Gini-coefficient of different Scenarios

The boost of the formal sector in "Scenario 3" and "Scenario 4" gives rise to a triple dividend effect: next to reducing the energy consumption, they increase the formal labor share and, for a moderate energy tax, enhance welfare. Note that "Scenario 3" exceeds "Scenario 4" in terms of welfare. The main reason for that is that the wage increase in "Scenario 3" positively affects the formal working hours. In both scenarios, the welfare declines sharply towards 20%. The reason for this is twofold: after surpassing a specific threshold for the energy decrease, the positive effect on the formal sector decreases, and the negative one on the non-formal sectors increases.

5.2 Optimal policy mix

In this section, I evaluate the optimal climate policy mix for India. I impose a tax on energy use and assume that its revenue can be redistributed according to an optimal combination of the redistribution schemes of the four scenarios. Figure 5 displays how the net-energy tax revenue (policy expenditure) needs to be distributed to maximize utilitarian welfare. Up to 7%, it is optimal to decrease the formal labor income tax with the revenue from the energy tax. Between 7% and 15%, the revenue partially goes to decreasing the labor income tax and to decreasing the bureaucratic costs. From 15% onwards, the optimal policy mix additionally includes a lump-sum to self-employed individuals.[31]

[31] The kink at an energy decrease of 15% is due to the lump-sum transfers to self-employed individuals. Up to 15%, boosting the formal sector means that the redistribution scheme favors the energy-intensive firms in the economy. Thus, a higher energy tax is needed to reach the climate target. After 15%, the lump-sum transfers to self-employed negatively affect the formal sector, which, in turn, decreases their energy demand. Consequently, a lower tax is needed to reach the climate target.

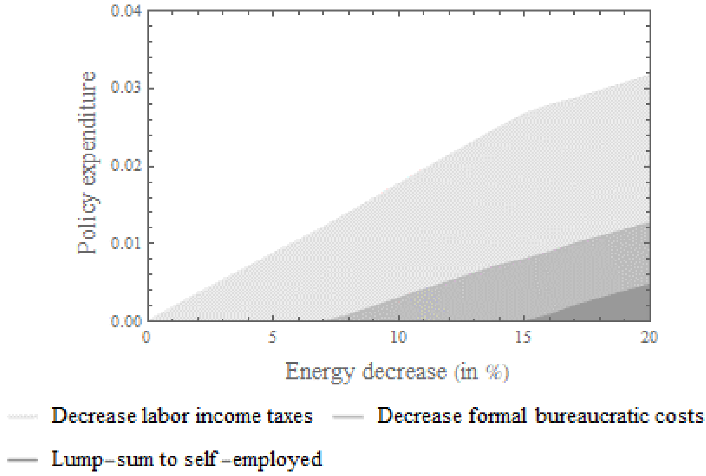

Figure 5: Optimal Redistribution Scheme

Table 2 shows the optimal climate policy mix and the outcome for different climate targets regarding energy usage up to a decrease of 20%. Decreasing energy up to 15% enhances formal employment, whereby the formal service sector benefits most due to high labor intensity and productivity, while self-and informal employment shrinks. From 15% until 20%, the optimal mix incorporates a lump-sum redistribution to self-employed individuals. That, in turn, increases self-employment mainly at the expense of informal employment. The optimal climate policy mix leads to a triple dividend effect for an energy decrease up to 13.4%: next to reducing the emissions, the optimal climate policy mix increases the formal labor share and enhances welfare (see Figure 9 in Appendix C). Moreover, in this range, the green job effect outweighs the job killer effect qualitatively (up to 7.5% more formal jobs) and quantitatively (up to 0.25% less self-employment).

The optimal climate policy mix, however, negatively affects equality.[32] That could prevent specific climate policies from being accepted by the population in developing countries. Therefore, I additionally evaluate the optimal policy mix* keeping the Gini coefficient constant.

Figure 6 displays how the net-energy tax revenue needs to be distributed to maximize utilitarian welfare keeping the Gini-coefficient constant. The optimal policy mix* consists of lowering bureaucratic costs combined with lump-sum transfers to self-employed individuals. Thus, the policy decreases the formal labor costs while boosting the incentive to be self-employed.

[32] The Gini-coefficient in my model only incorporates the income of the agents considered in my model. Thus, the percentage change of the Gini-coefficient in Table 2 should be seen in the sense of an ordinal scale.

Energy	**0%**	**-5%**	**-10%**	**-15%**	**-20%**	**-13.4%***
Optimal Climate Policy mix						
Energy tax	0%	+10.3%	+21.4%	+33.6%	+42.5%	+29.6%
Distribution of the tax revenue						
Scenario 1	0%	0%	0%	0%	0%	0%
Scenario 2	0%	0%	0%	0%	15%	0%
Scenario 3	0%	100%	83%	71%	60%	73%
Scenario 4	0%	0%	17%	29%	25%	27%
Outcome						
Formal employment	0.0734	0.0752 (+2.54%)	0.0772 (+5.21%)	0.0792 (+7.97%)	0.0776 (+5.74%)	0.0787 (+7.2%)
Industry	0.01981	0.01984 (+0.13%)	0.01987 (+0.23%)	0.01986 (+0.22%)	0.01926 (-2.82%)	0.01989 (+0.34%)
Service	0.05355	0.05539 (+3.43%)	0.05733 (+7.05%)	0.05936 (+10.84%)	0.05833 (+8.91%)	0.05877 (+9.74%)
Informal employment	0.2341	0.2334 (-0.29%)	0.232 (-0.9%)	0.23 (-1.75%)	0.2245 (-4.13%)	0.2306 (-1.5%)
Industry	0.1489	0.1488 (-0.10%)	0.1482 (-0.49%)	0.1473 (-1.1%)	0.1438 (-3.46%)	0.1475 (-0.94%)
Service	0.0852	0.847 (-0.63%)	0.0838 (-1.61%)	0.0827 (-2.9%)	0.0807 (-5.3%)	0.0831 (-2.48%)
Self-employment	0.6925	0.6913 (-0.169%)	0.6908 (-0.248%)	0.6908 (-0.252%)	0.698 (+0.788%)	0.6907 (-0.255%)
Gini-coefficent	0%	+7.78%	+13.98%	+19.04%	+18.23%	+17.22%
Welfare	0%	+0.46%	+0.35%	-0.24%	-1.17%	0%

Table 2: Optimal Policy mix

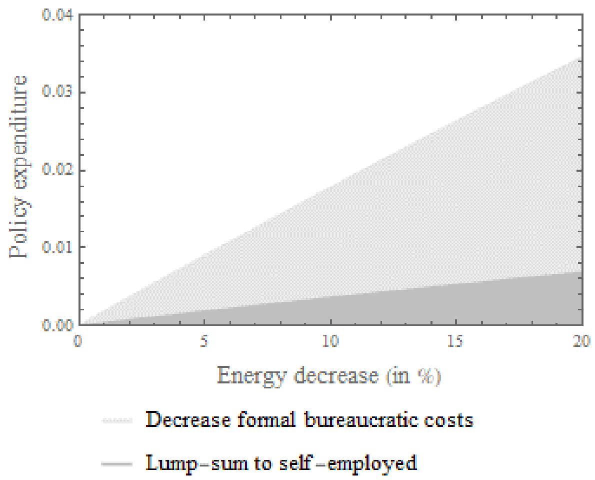

Figure 6: Optimal Redistribution Scheme with fixed Gini-coefficient

Table 3 shows the optimal climate policy mix* and the outcome for different climate targets regarding energy usage. Decreasing the use of energy increases self-and formal employment at the expense of informal employment. Keeping the Gini-coefficient constant lowers the effect of the policy on utilitarian welfare. As a consequence, the optimal climate policy mix* leads to a triple dividend effect for an energy decrease up to 8.53% instead of 13.4%. Moreover, due to the lump-sum transfers to self-employed individuals, the green job effect outweighs the job killer effect qualitatively (more formal jobs), but not quantitatively (more self-employment) anymore.

Energy	**0%**	**-5%**	**-10%**	**-15%**	**-20%**	**-8.53%***
Optimal Climate Policy mix* (constant Gini-coefficient)						
Energy tax	0%	+9%	+18.9%	+29.8%	+41.8%	+15.9%
Distribution of the tax revenue						
Scenario 1	0%	0%	0%	0%	0%	0%
Scenario 2	0%	20.3%	20.1%	19.9%	19.7%	20.2%
Scenario 3	0%	0%	0%	0%	0%	0%
Scenario 4	0%	79.7%	79.9%	80.1%	80.3%	79.8%
Outcome						
Formal employment	0.0734	0.0754 (+2.73%)	0.0772 (+5.25%)	0.0789 (+7.6%)	0.0805 (+9.76%)	0.07669 (+4.53%)
Industry	0.01981	0.01994 (+0.63%)	0.02 (+0.92%)	0.01999 (+0.86%)	0.01991 (+0.46%)	0.01999 (+0.87%)
Service	0.05355	0.05542 (+3.5%)	0.05723 (+6.86%)	0.059 (+10.09%)	0.06062 (+13.2%)	0.0567 (+5.88%)
Informal employment	0.2341	0.23 (-1.76%)	0.2258 (-3.57%)	0.2214 (-5.42%)	0.217 (-7.32%)	0.227 (-3.03%)
Industry	0.1489	0.1461 (-1.86%)	0.1434 (-3.71%)	0.1407 (-5.55%)	0.1379 (-7.34%)	0.1442 (-3.17%)
Service	0.0852	0.0839 (-1.59%)	0.0824 (-3.31%)	0.0808 (-5.19%)	0.0791 (-7.21%)	0.0828 (-2.79%)
Self-employment	0.6925	0.6946 (+0.31%)	0.697 (0.65%)	0.6966 (1.03%)	0.7025 (+1.44%)	0.6963 (0.54%)
Welfare	0%	+0.12%	-0.1%	-0.66%	-1.58%	+0%

Table 3: Optimal Policy mix with fixed Gini-coefficient

6 Conclusion

I investigate the economic effect of climate policies on developing countries characterized by a large informal economy. The analysis is conducted using a dynamic general equilibrium model with a search and match mechanism. The framework includes the three prevalent working-groups in developing countries: informal self-employment, informal employment, and formal employment. I calibrate the model to India, which has the largest informal workforce worldwide and contributes substantially to global emissions, making it particularly interesting to study. That allows me to evaluate the optimal climate policy mix for India, where I impose a tax on energy with an optimal redistribution scheme of its revenue. The results show that India can benefit from a triple dividend effect for an energy decrease up to 13.4%: next to reducing the emissions, the optimal climate policy mix increases the formal labor share and enhances welfare. Moreover, the green job effect outweighs the job killer effect qualitatively (more formal jobs) and quantitatively (less self-employment). Two main mechanisms are decisive for that outcome: (1) energy taxes need to be paid by the informal (and the formal) economy, and (2) the revenue of that energy taxes can be used to boost the formal economy. Consequently, the optimal climate policy mix favors formally employed individuals, which, in turn, magnifies inequality. Such an effect on inequality could hamper the political viability of the climate policy. Thus, I additionally evaluate the optimal climate policy mix holding inequality constant. In that case, the range of an energy decrease, where India could benefit from a triple dividend effect, decreases to 8.53%. The reason for that is the need for lump-sum transfers for self-employed individuals, which negatively affect the labor market outcome, to keep inequality constant.

In general, I highlight that developing countries with large informal economies can utilize climate policies to deal with environmental problems *and* informality. Designing such climate policies requires incorporating their impact on the most prevalent formal and informal working groups in developing countries. Therefore, the general equilibrium model with a search and match mechanism suggested in this paper provides a tool for developing countries to design climate policies considering labor market effects.

The model opens up many promising directions for future research. Firstly, one can consider disaggregating the energy sector into clean and dirty energy. That would potentially lead to a more positive effect of climate policies on the economy as dirty energy could be substituted with its clean counterpart. Secondly, the model can be applied to a wide range of developing countries, and it would be fruitful to compare the results of other countries with those of India. Thirdly, analyzing the transitions phase would allow for an evaluation of the optimal policy mix considering time. Lastly, one can consider extending the model proposed here to elaborate on the effects of, for example, trade policies or minimum wages.

References

Albrecht, J., Navarro, L., and Vroman, S. (2009). The effects of labour market policies in an economy with an informal sector. *The Economic Journal*, 119(539):1105–1129.

Anand, R. and Khera, P. (2016). *Macroeconomic impact of product and labor market reforms on informality and unemployment in India*. International Monetary Fund.

Annual report on Periodic Labor Force Survey (PLFS) (2019). July 2017-June 2018, Ministry of Statistics and Programme Implementation, Government of India.

Asian Development Bank (2012). India: Input-Output Economic Indicators. https://data.adb.org/dataset/india-input-output-economic-indicators.

Aubert, D. and Chiroleu-Assouline, M. (2019). Environmental tax reform and income distribution with imperfect heterogeneous labour markets. *European Economic Review*, 116:60–82.

Banerjee, B. (1984). Information flow, expectations and job search: Rural-to-urban migration process in india. *Journal of Development Economics*, 15(1-3):239–257.

Bigsten, A., Kimuyu, P., and Lundvall, K. (2004). What to do with the informal sector? *Development Policy Review*, 22(6):701–715.

Blundell, R., Pistaferri, L., and Preston, I. (2008). Consumption inequality and partial insurance. *American Economic Review*, 98(5):1887–1921.

Burniaux, J.-M. and Truong, T. P. (2002). Gtap-e: an energy-environmental version of the gtap model. *GTAP Technical Papers*, page 18.

De Soto, H. et al. (1989). The other path.

Employment and Unemployment situation in India (2014). July 2011-June 2012, NSS 68th Round, Ministry of Statistics and Programme Implementation, Government of India.

Fields, G. S. (2009). Segmented labor market models in developing countries.

Fields, G. S. (2011). Labor market analysis for developing countries. *Labour economics*, 18:S16–S22.

Fugazza, M. and Jacques, J.-F. (2004). Labor market institutions, taxation and the underground economy. *Journal of Public Economics*, 88(1-2):395–418.

Gandullia, L., Iacobone, N., and Thomas, A. (2012). Modelling the tax burden on labour income in brazil, china, india, indonesia and south africa. (14).

Gordon, J. and Gupta, P. (2005). Understanding india's services revolution. In *India's and China's recent experience with reform and growth*, pages 229–263. Springer.

Günther, I. and Launov, A. (2012). Informal employment in developing countries: Opportunity or last resort? *Journal of development economics*, 97(1):88–98.

Hafstead, M., Williams, R. C., Golub, A., Meijer, S., Narayanan, B. G., Nyamweya, K., and Steinbuks, J. (2018a). *Effect of climate policies on labor markets in developing countries: review of the evidence and directions for future research*. The World Bank.

Hafstead, M. A. and Williams, R. C. (2018). Unemployment and environmental regulation in general equilibrium. *Journal of Public Economics*, 160:50–65.

Hafstead, M. A., Williams, R. C., and Chen, Y. (2018b). Environmental policy, full-employment models, and employment: A critical analysis. Technical report, National Bureau of Economic Research.

Harris, J. R. and Todaro, M. P. (1970). Migration, unemployment and development: a two-sector analysis. *The American economic review*, 60(1):126–142.

Heine, D. and Black, S. (2019). Benefits beyond climate: environmental tax reform. *Fiscal Policies for Development and Climate Action*.

Ju-e, L. Z.-d. G. and You-min, X. (2009). Econometric estimate and selection on china energy ces production function. *China Population Resources and Environment*, (4):31.

Kuralbayeva, K. (2018). Unemployment, rural–urban migration and environmental regulation. *Review of Development Economics*, 22(2):507–539.

La Porta, R. and Shleifer, A. (2014). Informality and development. *Journal of Economic Perspectives*, 28(3):109–26.

Loayza, N. V. (2016). *Informality in the Process of Development and Growth*. The World Bank.

Maloney, W. F. (1999). Does informality imply segmentation in urban labor markets? evidence from sectoral transitions in mexico. *The World Bank Economic Review*, 13(2):275–302.

McKenzie, D. (2017). How Effective Are Active Labor Market Policies in Developing Countries? A Critical Review of Recent Evidence. *The World Bank Research Observer*, 32(2):127–154.

Mehrotra, S. K. et al. (2019). Informal employment trends in the indian economy persistent informality, but growing positive development. Technical report, International Labour Organization.

Merz, M. (1995). Search in the labor market and the real business cycle. *Journal of monetary Economics*, 36(2):269–300.

Mortensen, D. T. and Pissarides, C. A. (1994). Job creation and job destruction in the theory of unemployment. *The review of economic studies*, 61(3):397–415.

Okagawa, A. and Ban, K. (2008). Estimation of substitution elasticities for cge models. *Discussion Papers in Economics and Business*, 16.

Perry, G. E., Arias, O., Fajnzylber, P., Maloney, W. F., Mason, A., and Saavedra-Chanduvi, J. (2007). *Informality: Exit and exclusion*. The World Bank.

Peter, A., Ruane, C., et al. (2018). The aggregate importance of intermediate input substitutability. Technical report, Working Paper January.

Pissarides, C. A. (1985). Short-run equilibrium dynamics of unemployment, vacancies, and real wages. *The American Economic Review*, 75(4):676–690.

Prado, M. (2011). Government policy in the formal and informal sectors. *European Economic Review*, 55(8):1120–1136.

Shimer, R. et al. (2010). *Labor markets and business cycles*. Princeton University Press Princeton, NJ.

Singhari, S. and Madheswaran, S. (2017). Wage structure and wage differentials in formal and informal sectors in india. *The Indian Journal of Labour Economics*, 60(3):389–414.

Tapsoba, S. J.-A. (2014). Options and strategies for fiscal consolidation in india. *Economic Modelling*, 43:225–237.

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R., and De Vries, G. J. (2015). An illustrated user guide to the world input–output database: the case of global automotive production. *Review of International Economics*, 23(3):575–605.

Ulyssea, G. (2010). Regulation of entry, labor market institutions and the informal sector. *Journal of Development Economics*, 91(1):87–99.

Van der Mensbrugghe, D. (1994). Green-the reference manual.

A Steady-State wages

$$w_F^* =(H_I(m_I^F + m_S^F)P_F((-1+Q)(1+Q(-1+\beta_F+\delta_S^F)) + Q^3\beta_F(-\delta_I^F+\delta_S^F)\delta_S^I)$$
$$(-1+\eta_F)\eta_I\lambda_F(-1+\tau_{p,F})(1+\chi)\frac{\partial X_F}{\partial L_F} - H_F\eta_F(1+\tau_{p,F})(H_I(m_I^F+m_S^F)Q$$
$$\eta_I(c_Fpc(1+Q(-1+Q(\delta_I^F-\delta_S^F)\delta_S^I))\lambda_F(1+\chi)+h_F^{1+\chi}(1+Q(-1+Q(\delta_I^F$$
$$-\delta_S^F)\delta_S^I))\psi + (-1+Q)((c_Spc-h_Sw_S)\lambda_S(1+\chi)+h_S^{1+\chi}\psi) - (1+Q(-1$$
$$+Q(\delta_I^F-\delta_S^F)\delta_S^I))(1+\chi)Log[1+c_F] - (-1+Q)(1+\chi)Log[1+c_S]) + P_I$$
$$(m_I^F(-1+Q)(1+Q(-1+\beta_F+\delta_S^F)) + m_S^F(-1+Q)Q\delta_S^I + m_I^FQ(-1+Q$$
$$+Q^2\beta_F(-\delta_I^F+\delta_S^F))\delta_S^I)(-1+\eta_I)\lambda_I(1+\chi)\frac{\partial X_I}{\partial L_I}))/(h_FH_FH_I(m_I^F+m_S^F)Q$$
$$(1+Q(-1+Q(\delta_I^F-\delta_S^F)\delta_S^I))\eta_F\eta_I\lambda_F(-1+\tau_{p,F}^2)(1+\chi))$$

$$w_I^* =-((-H_I\eta_I(h_Sw_S\lambda_S - h_SQw_S\lambda_S + h_SQ^2w_S\delta_I^F\lambda_S - h_SQ^2w_S\beta_I\delta_I^F\lambda_S - h_S$$
$$Q^2w_S(\delta_I^F)^2\lambda_S - h_SQ^2w_S\delta_S^F\lambda_S + h_SQ^2w_S\beta_I\delta_S^F\lambda_S + h_SQ^2w_S\delta_I^F\delta_S^F\lambda_S + h_S$$
$$w_S\lambda_S\chi - h_SQw_S\lambda_S\chi + h_SQ^2w_S\delta_I^F\lambda_S\chi - h_SQ^2w_S\beta_I\delta_I^F\lambda_S\chi - h_SQ^2w_S(\delta_I^F)^2$$
$$\lambda_S\chi - h_SQ^2w_S\delta_S^F\lambda_S\chi + h_SQ^2w_S\beta_I\delta_S^F\lambda_S\chi + h_SQ^2w_S\delta_I^F\delta_S^F\lambda_S\chi + c_Ipc(1+Q$$
$$(-1+Q(\delta_I^F-\delta_S^F)\delta_S^I))\lambda_I(1+\chi) + c_Spc(-1+Q+Q^2(-1+\beta_I+\delta_I^F)(\delta_I^F$$
$$-\delta_S^F))\lambda_S(1+\chi) - h_S^{1+\chi}\psi + h_S^{1+\chi}Q\psi - h_S^{1+\chi}Q^2\delta_I^F\psi + h_S^{1+\chi}Q^2\beta_I\delta_I^F\psi + h_S^{1+\chi}$$
$$Q^2(\delta_I^F)^2\psi + h_S^{1+\chi}Q^2\delta_S^F\psi - h_S^{1+\chi}Q^2\beta_I\delta_S^F\psi - h_S^{1+\chi}Q^2\delta_I^F\delta_S^F\psi + h_I^{1+\chi}(1+Q(-1$$
$$+Q(\delta_I^F-\delta_S^F)\delta_S^I))\psi - (1+Q(-1+Q(\delta_I^F-\delta_S^F)\delta_S^I))(1+\chi)Log[1+c_I]$$
$$+Log[1+c_S] - (-\chi+Q(1+Q(-1+\beta_I+\delta_I^F)(\delta_I^F-\delta_S^F))(1+\chi))Log[1$$
$$+c_S]) + 1/(H_F\eta_F(1+\tau_{p,F}))H_IP_F(\delta_I^F-\delta_S^F)(1+Q(-2+\beta_I+\delta_I^F+Q(-1$$
$$+\beta_I+\delta_I^F)(-1+\delta_S^F)+\delta_S^I+Q(-1+\delta_I^F)\delta_S^I))(-1+\eta_F)\eta_I\lambda_F(-1+\tau_{p,F})$$
$$(1+\chi)\frac{\partial X_F}{\partial L_F} - 1/((m_I^F+m_S^F)Q)P_I(m_S^F(-1+Q)(1+Q(-1+\beta_I+\delta_I^F))$$
$$+m_S^FQ(-1+Q(1-\delta_I^F+\delta_S^F))\delta_S^I + m_I^F(-1-Q(-2+\beta_I+\delta_S^F+\delta_S^I)+Q^2$$
$$(-1+\beta_I-\delta_I^F+\beta_I\delta_I^F+(\delta_I^F)^2+2\delta_S^F-(\beta_I+\delta_I^F)\delta_S^F+\delta_S^I)+Q^3(\delta_I^F-\delta_S^F)$$
$$((-1+\beta_I+\delta_I^F)(-1+\delta_S^F)+(-1+\delta_I^F)\delta_S^I)))(-1+\eta_I)\lambda_I(1+\chi)\frac{\partial X_I}{\partial L_I})$$
$$/(h_IH_I(1+Q(-1+Q(\delta_I^F-\delta_S^F)\delta_S^I))\eta_I\lambda_I(1+\chi)))$$

B Calibration

Parameter	Value	Source
δ	0.75	Hafstead and Williams (2018)
ϕ_X	1.5	Anand and Khera (2016)
ϕ_Q	0.75	Own assumption
σ	1.15	Anand and Khera (2016)
ρ_{EX}	4.5	Anand and Khera (2016)
ϵ_S^{Agr}	0.998	Okagawa and Ban (2008)
ϵ_{FI}^{Ind}	0.9	Okagawa and Ban (2008)
ϵ_{FI}^{Ser}	0.94	Okagawa and Ban (2008)
ω_S^{Agr}	0.55	Okagawa and Ban (2008)
ω_k^{Ind}	0.4	Okagawa and Ban (2008)
ω_k^{Ser}	0.49	Okagawa and Ban (2008)
ζ_k^{Ind}	0.2	Okagawa and Ban (2008)
ζ_k^{Ser}	0.41	Okagawa and Ban (2008)
ξ	0.9	Peter et al. (2018)

Table 4: Elasticities of Substitution and Sources

I assume that $\phi_Q < \phi_X$ holds. Therefore, I implement a lower EoS between own-and firm produced goods than between formal and informal firm goods in my model. A reason for that is that own-produced goods often end-up in the rural market while firm-produced goods in the urban one. Consequently, own-and firm goods are less substitutable.

C Results

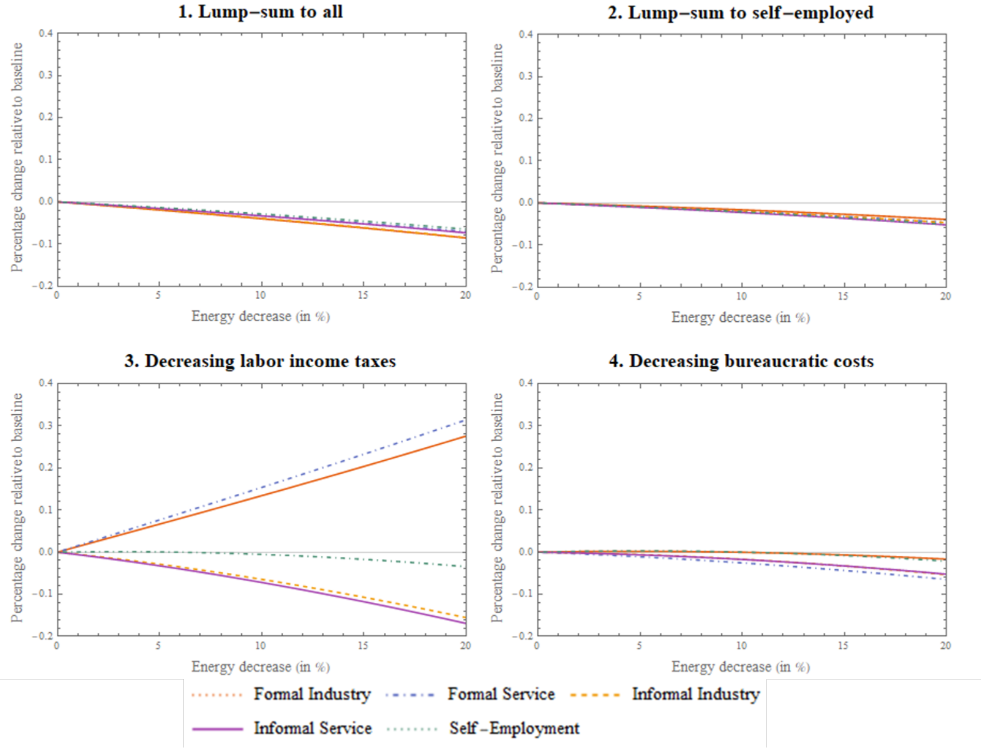

Figure 7: Effect on real income per day

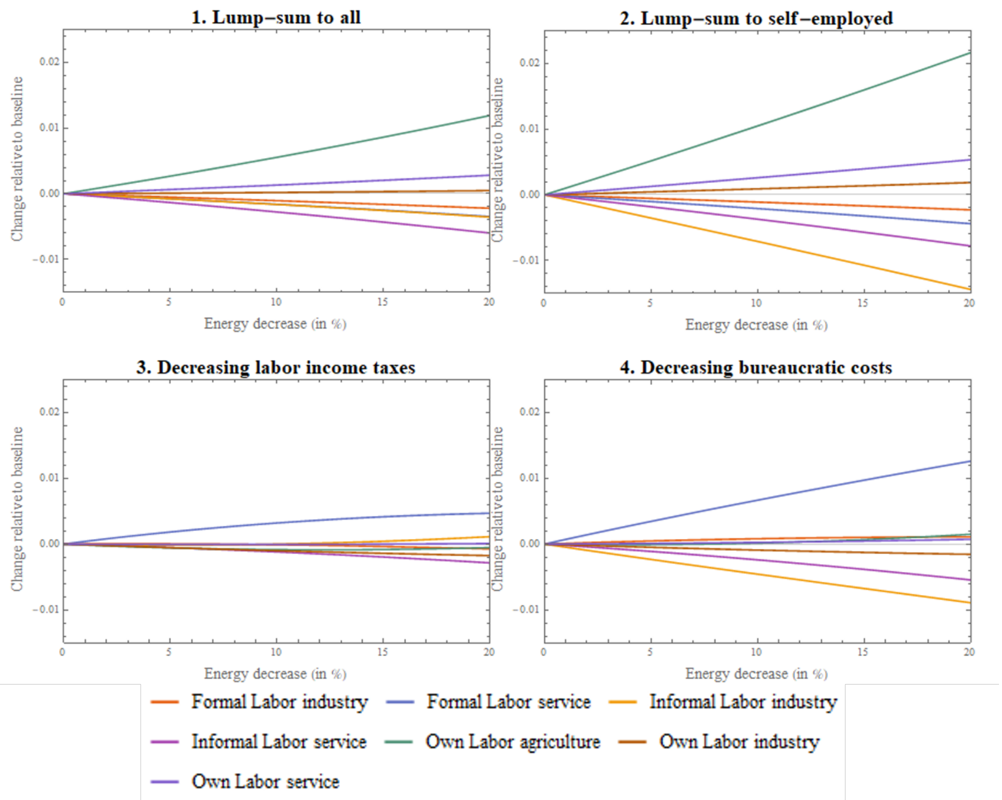

Figure 8: Sectoral Labor effect

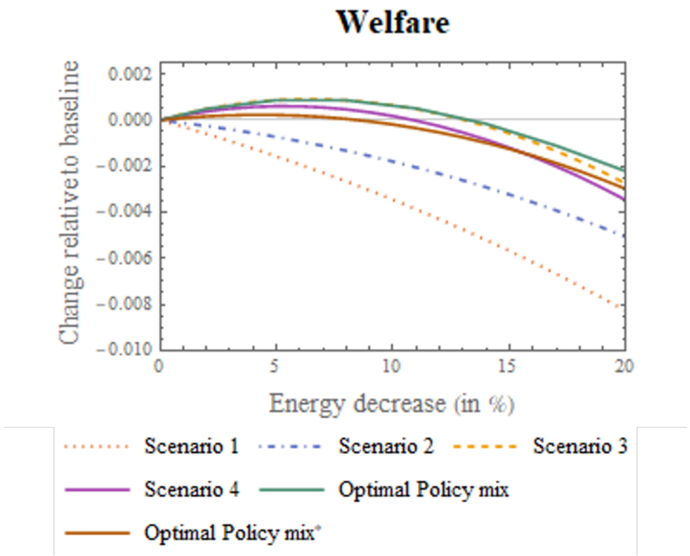

Figure 9: Optimal welfare with fixed Gini coefficient

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