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Kawamura, E.

DEVELOPMENT BANK OF LATIN AMERICA

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ABSTRACT

This paper presents the main set-up and long-run results from a simple deterministic version of a dynamic stochastic general equilibrium model of a small open economy in Kawamura (2017). The model assumes two types of households, one poor and the other non-poor. There are two types of energy used as both GDP input and consumption goods, one using a fossil-based resource (with a given international price) and another that uses public capital and that represents a non-standard, "clean" (i.e., non-fossil based) energy source. The paper reports the results from two types of policy makers. The .rst type corresponds to a benevolent and perfectly-committed government that sets complete plans of taxes, subsidies and public investment policies, including public infrastructure. The second type of policy maker is a politician that wins elections occurring in every period. Such politician implements policies promised at the electoral stage. This second policy-making process assumes that the politician can commit to policies only for the period in which she wins elections. The paper shows that a necessary condition for obtaining long-run growth in public capital, private capital, GDP and clean energy is that the international price of the resource increases steadily through time. Thus, both types of policy makers react to such increase by also steadily increasing the public investment.

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POLÍTICAS DE INFRAESTRUCTURA PÚBLICA Y SUBSIDIOS A LA ENERGÍA, ACCESO ENERGÉTICO PARA SECTORES POBRES Y PERFORMANCE MACROECONÓMICA DE LARGO PLAZO.

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RESUMEN

Este artículo presenta la estructura básica y los principales resultados de largo plazo de la versión simple y determinística del modelo de economía abierta desarrollado en Kawamura (2017). El modelo supone dos tipos de hogares, uno de pobres, el otro de no-pobres. Existen dos tipos de bienes energéticos utilizados tanto como insumos para la producción de bienes y servicios (PIB) como también bienes de consumo directos. Un tipo de bien energético ("standard") es intensivo en un recurso fósil (cuyo precio internacional se supone exógeno), mientras que el otro ("no-standard") utiliza infraestructura pública y representa el producto de fuentes energéticas no basadas en recursos fósiles incluyendo fuentes "limpias". El artículo reporta los resultados del modelo suponiendo dos tipos de decisores de política. El primer tipo de hacedor de política corresponde a un gobierno benevolente y perfectamente comprometido (con sus políticas) que fija planes completos de impuestos, subsidios y decisiones de infraestructura pública. El segundo tipo de decisor de política es un político que compite y eventualmente gana elecciones que ocurren en cada período. Tal gobierno implementa políticas que se proponen en la etapa electoral. Este segundo tipo de proceso de decisión de política supone entonces que cada político que compite electoralmente solamente por el período en el que se gana la elección. El artículo muestra que una condición necesaria para generar crecimiento de largo plazo en infraestructura pública, capital productivo, PIB y en la producción de energía limpia es que el precio internacional del recurso fósil crezca permanentemente a una tasa constante a través del tiempo. Por lo tanto, ambos tipos de políticas reaccionan a tal incremento sostenido aumentando también la inversión pública en energía limpia también de forma sostenida.

Public-infraestructure and energy-subsidy policies, energy access by the poor and long-term macroeconomic performance. *

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April 24th, 2017

Abstract

This paper presents the main set-up and long-run results from a simple deterministic version of a dynamic stochastic general equilibrium model of a small open economy in Kawamura (2017). The model assumes two types of households, one poor and the other non-poor. There are two types of energy used as both GDP input and consumption goods, one using a fossil-based resource (with a given international price) and another that uses public capital and that represents a non-standard, "clean" (i.e., non-fossil based) energy source. The paper reports the results from two types of policy makers. The first type corresponds to a benevolent and perfectly-committed government that sets complete plans of taxes, subsidies and public investment policies, including public infrastructure. The second type of policy maker is a politician that wins elections occurring in every period. Such politician implements policies promised at the electoral stage. This second policy-making process assumes that the politician can commit to policies only for the period in which she wins elections. The paper shows that a necessary condition for obtaining long-run growth in public capital, private capital, GDP and clean energy is that the international price of the resource increases steadily through time. Thus, both types of policy makers react to such increase by also steadily increasing the public investment.

1 Introduction

Latin America and the Caribbean (LAC) is one of the main regions in the world with important energy needs within the Developing and Emerging Market groups of countries.

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In particular, according to an IFC report in 2013, about 7 % of the total population in LAC has no access to electricity and 19% of the population in the region have no access to clean cooking facilities. These numbers suggest large fractions of the population in LAC using very precarious and inefficient sources of energy. Yet, the access to more efficient (and environmentally friendly) energy sources for that population clearly depends on public infrastructure and other energy-policy decisions from the respective governments[1].

Another policy-relevant energy issue almost globally is the environmental impact of energy access. In particular, one particular policy relevant question involving both issues is whether there exist trade-offs or synergies between energy poverty alleviation and policy-provided incentives to rely more on cleaner (i.e., less fossil-dependent) energy sources. For example, Ürge-Vorsatz and Tirado Herrero (2012) qualitatively describes different aspects of this relationships[2], stressing that possible synergies could arise between them when thinking policies focusing on equipment technology, building and infrastructure development. Thus, access by energy-poor households to clean energy sources seems a desirable target to get a synergy case between both policy goals.

Yet, in Developing as well as Emerging Market countries, this target seems to depend on how politics shape public policies, including energy-sector policies of course. Governance issues seems to start becoming important in energy policy discussions in recent years[3]. Indeed, the interactions between political actors, consumers (voters) and other relevant stakeholders may impose strong constraints to achieve the goals of higher energy efficiency and sustainable growth in the long run. Also, from a more general endogenous-policy perspectives, LAC countries usually present political dynamics that directly determine the quality of public policies in different dimensions[4]. In particular, the access to clean energy may involve political decisions regarding the composition of public spending, since such access often demands large amounts of infrastructure works. The composition of the electorate and the incentives of political parties trying to attract the electorate may imply biases in the public spending composition and in other fiscal policy variables that may work against the goal of increasing the supply of "clean" energy.

This paper presents a simple version of the model in Kawamura (2017) with an emphasis in long-run dynamics and its policy and institutional implications. That paper develops a dynamic stochastic general equilibrium (the standard methodology in Macroeconomic analysis) where energy-related public policy variables (including public infrastructure spending) are endogenously determined by two alternative types of policy-makers. More specifically,

[1] This access-to-energy problem is closely related to the issue of energy poverty. Although the precise meaning of the latter is not obvious the one that seems general enough is that analyzing affordability-related challenges of the provision of adequate energy services to households (Ürge-Vorsatz and Tirado Herrero (2012)). This phenomenon is clearly relevant in several LAC countries, leading to several specific interventions intending to mitigate this problem. For example, Pereira et al (2011) reports the results of several interventions consisting in rural electrification in Brazil.

[2] Chakravarty and Tavoni (2013) presents a novel method to quantify possible trade-offs between these two policy goals at the global level.

[3] See, e.g., Bazilian et al (2014).

[4] For an overview of this link see, e.g., Spiller and Tommasi (2003).

the model assumes a small open dynamic economy with two types of households, one interpreted as the *poor*, the other as the *non-poor*. The main feature of the former is their absence from any possibility of savings or borrowing. Thus, they consume all their net-of-tax income in the same period. Another salient feature of the poor household is that they offer a type of labor force interpreted as unskilled. The non-poor does participate in international asset markets (whose interest rate is exogenous, according to the small-open economy assumption), and also offers productive capital. There are three consumption goods produced endogenously in the economy. There is first a numeraire good, that represents GDP production. There are then two types of energy consumption good. The first one is produced using a non-renewable resource commodity (with a given international price) and a second that uses factors of production and public capital. The latter is interpreted as a "clean" energy good, in the sense that does not use the non-renewable resource.

In terms of each type of policy-makers, the first (and benchmark) case corresponds to a benevolent and perfectly-committed government that sets a complete plan of policies from the first period on. The latter sets tax and subsidy rates as well as the amount of public capital that maximizes a weighted average of the total utilities of the two households. The second case considers a policy-maker who wins an electoral contest occurring at the beginning of every period. In such electoral competition two identical parties offer a set of policy proposals for that period. This second alternative reflects how such competition shapes policies in regions such as LAC. The equilibrium concept used then must refer to a politico-economic equilibrium definition, in the spirit of the recent political macroeconomics literature that is commented below. Thus, the model proceeds to provide a characterization of such politico-economic equilibrium allocations and the induced prices and policies. In both cases the focus is on the long-run characteristics of the allocations including energy consumption by each type of household and GDP production.

The main findings of the paper is as follows. When the benevolent and committed government sets policies, the resulting allocation implies a long-run dynamics where public infrastructure, private capital stock, GDP output and non-fossil-based energy increase with the price of the international fossil resource, while production of traditional (fossil-based) energy decreases with such price. Thus, if the international price of the fossil resource increases steadily then the first four variables mentioned above also increases steadily, while the production of the traditional energy decreases. Under electoral competition, such positive link between the international price, on the one hand, and public infrastructure, private capital, GDP and non-fossil based energy, on the other hand, is still present, although the quantitative positive correlation differs from the solution of the benevolent government. Thus, repeated competition by parties caring about being in power (or, equivalently, caring about winning elections) may provide qualitative incentives for public investment and energy-policy setting similar to those of a benevolent planner. Such incentives induce policy-makers to provide more important impulses to public investment in non-fossil based energy when the international price of fossil resources such as oil or gas keeps increasing (mainly as a long-run trend, despite short-run oscillations).

The model presented here merges two major brands of literature that so far were not linked. The first is a recent DSGE-type of models of environmental dynamics (see, e.g., Acemoglu et al (2012), Golosov et al (2014) and Barrage (2014)). This assumption in that literature is that environmental quality depreciation leads to a decrease in TFP, while in this proposal such negative effect is absent. The purpose of this assumption is two fold. First is obviously simplicity. The second reason is that empirical evidence on the possible impact of environment on productivity is hard to find in the LAC case. The two criteria together call for abstracting from productivity effects of environment.

The second branch of literature that is used here is the one that determines the political side of the model. That literature includes models that use general versions of the probabilistic voting model of Lindbeck and Weibull (1987). The main examples of that literature is Sleet and Yeltekin (2008) in more dynamic settings. Those papers present models with heterogeneous households (voters), which is central also in this model. Heterogeneity must be an obvious ingredient since the major question is related to analyzing political constraints to energy poverty alleviation. Given the type of energy poverty present in regions such as LAC, such concept refers to an important segment of the population but not necessarily to the entire society (as it could be in very poor countries in other continents). As stressed by Azzimonti (2011) the timing of decisions here does not correspond to a model with more traditional probabilistic voting structures, the reason being the lack of commitment that the incumbent has. This approach of course also differs from other macro-political-economy modelling schemes such as Acemoglu et al (2010) and Yared (2010), which constitute political-economy extensions of the classical time-consistent fiscal policy analysis in Chari and Kehoe (1990) and Phelan and Stacchetti (2003), among others. Those papers assume representative consumers, which cannot capture the type of trade-offs that are naturally present in the discussion about energy poverty, politics and environment.

The rest of the paper is as follows. Section 2 presents the model set-up. Section 3 summarizes how individual choices look like in any equilibrium. Section 4 presents the Ramsey problem and its characterization. Section 5 presents the case where policy makers compete in elections. Section **??** characterizes the special case of deterministic fundamentals, while section 6 includes several policy and institutional suggestions from the results of the model. Finally, section 7 presents concluding remarks and suggests some venues for future research.

2 The environment

As stated in the introduction, this paper presents the deterministic version of the more general model developed in the companion technical paper (Kawamura, 2017). The model assumes an infinite-period, discrete-time economy, with time indexed by $t = 0, 1...$ In this economy there are three consumption goods: a numeraire good (whose output represents the net-of-energy GDP of the economy) and two other goods representing two types of energy services, one coming from a sector that use as an input an internationally-tradable resource interpreted as a fossil-based resource (oil, gas, carbon). This type of energy is called *traditional*. The other type of energy comes from a technology that does not use any fossil-based resource, and uses public capital as a key factor. This type of energy is called *clean*, although the most precise name would be non-traditional, since that type of energy may include forms of energy coming from hydro technologies. Paragraphs below present the details regarding households characteristics, technologies and the way policies are chosen.

2.1 Households

There is a continuum of two types of infinitely-lived (private) households, one indexed as P and the other as N. The $P-$ households present characteristics that would resemble those of lower-income segments in Latin America, while the N households represent middle to upper income agents. There is a constant fraction π of P households in the economy, while the remaining one corresponds to the share of non-poor households, with $0 < \pi < 1$. For each type of household, an intertemporal utility function represents their preferences:

$$U = \sum_{t=0}^{\infty} \beta^t u^i \left(c_t^i, e_t^{T,i}, e_t^{C,i}, l_t^i \right) \tag{1}$$

In equation (1) the function $u^i \left(c_t^i, e_t^{T,i}, e_t^{C,i}, l_t^i \right)$ denotes the typical Benourlli utility function, the coefficient β denotes the subjective discount factor, being positive and less than one (a larger value of β denotes a more patient household). That coefficient is common across the two types of households. The Bernoulli function depends on the type of household. Their common arguments include numeraire-good consumption, each energy type consumption and leisure (or, indirectly, the type of labor force that complements the consumption of leisure).

$$\begin{aligned} & u^i \left(c_t^i, e_t^{T,i}, e_t^{C,i}, l_t^i \right) \qquad (2) \\ \equiv & \left\{ \begin{array}{l} \phi \left[\theta \log c_t^P + (1-\theta) \log l_t^P \right] + (1-\phi)\, \eta \rho_t \log e_t^{T,P} + (1-\phi)(1-\eta)\, \rho_t \log e_t^{C,P} - \zeta Y_t^T, \ i = P \\ \phi \theta \log c_t^N - \phi (1-\theta) \sum_j \Theta_j L_{St}^j + (1-\phi)\, \eta \rho_t \log e_t^{T,N} + (1-\phi)(1-\eta)\, \rho_t \log e_t^{C,N}, \ i = N \end{array} \right. , \\ 0 \ < \ & \phi, \theta, \eta < 1, \ \zeta > 0 \end{aligned}$$

In expression (2) the variable c_t^i denotes the numeraire-good consumption in period t by household of type i, $e_t^{T,i}$ is the consumption of traditional energy , while e_t^C denotes the consumption of clean energy, where $0 < \eta < 1$ denoting the relative importance of traditional energy. This particular form of the utility function assumes that those two types of energy are not perfect substitutes. Instead, the elasticity of substitution between them is exactly equal to one. In both utility functions there is a time-dependent variable ρ_t. The latter is taken as exogenous by all households and represents the influence that the macroeconomic state has on the subjective valuation of energy. The reason for introducing such variable is essentially for analytical convenience. Yet, there are several possible interpretations on why the macroeconomy (mainly, the GDP) positively affects the marginal utility of energy consumption. The most basic intuition for such variable is the well-documented positive cross-country correlation between per-capita GDP and per-capita energy consumption. Introducing this externality variable in the marginal utility captures in a reduced-form such correlation.

In terms of preference asymmetries, for the P households, the variable l_t^P denotes the fraction of period-t available time not devoted to work (the details on this choice comes in the next paragraph). In this regard, parameter ϕ denotes the relative importance of both leisure and numeraire consumption while $1-\phi$ denotes the relative importance of energy consumption in preferences. Also, parameter θ denotes the relative importance of the numeraire consumption in the first combo, while $1-\theta$ denotes the importance of leisure. Finally, the last term in the utility function for P households denotes the negative effect on the P household's welfare coming from the production of traditional energy, denoted as Y_t^T[5]. This negative externality constitutes one key driving force for limiting the production of traditional energy. For N households, variable L_{St}^j denotes the labor time sold to sector j, where the latter runs over the three sectors mentioned above (numeraire good, traditional energy and clean energy). Thus, the only difference in preferences between the two types of households lies on how leisure enters into the utility function. Given that the types of labor that each household can offer in the market (described in more detail below) are different then this asymmetry does not seem too artificial.

The other dimension that identifies the type of household lies on the endowments. The P households receive a unit of labor time endowment. Also, such households cannot access either asset markets or credit institutions[6], reflecting the very low level of financial access of the lowest decile households[7]. The type of labor that P households offer is interpreted as unskilled, although the more precise meaning would be a low-productivity type of labor. This type of labor is only used in the production of the numeraire good, as described in subsection 2.2. The corresponding wage is denoted as w_t^U. Unskilled-labor income is taxed at a rate τ_t^U. On the other hand, the policy-maker sets a subsidy (or tax, depending on the sign) $\tau_t^{T,P}$ on traditional energy consumption and $\tau_t^{C,P}$ on clean energy consumption. Letting p_t^T be the price of traditional energy (measured in units of the numeraire good) and p_t^C be the price of clean energy, then the household$P$'s budget constraint in period t is

$$c_t^P + p_t^T\left(1-\tau_t^{T,P}\right)e_t^{T,P} + p_t^C\left(1-\tau_t^{C,P}\right)e_t^{C,P} = \left(1-\tau_t^U\right)w_t^U\left(1-l_t^P\right) \tag{3}$$

On the other hand, $N-$households have also a unit of time, a fraction of which is offered as a second type of labor, interpreted as *skilled* (or high productivity), to the three productive sectors in the economy. In principle, given that the marginal disutility of labor effort may differ across sectors, then skilled wages may be sector specific. This assumption of differential disutilities across sectors is not uncommon in the macroeconomic literature[8], indicating

[5] This is the "utility damage" effect in Barrage (2014).

[6] This type of consumers resembles the ones called non-Ricardians in the literature on fiscal policy rules. See Gali et al (2004) and Gali et al (2007) for examples.

[7] A growing literature on financial inclusion for the poor emphasizes this fact. See, e.g., Allen et al (2016) for an illustration of that link.

[8] See, e.g., Bouakez et al (2009).

that households may not find as perfectly substitutable working for either sector. The $N-$ households also receive an initial endowment of productive capital, $k_0 > 0$. As owners of capital, $N-$households decide in each period how much of their income to save in the form of new capital. The latter depreciates at a constant rate $\delta \in (0,1)$. Also, this type of households has access to international asset markets. The corresponding interest rate is assumed to be constant and equal to r. Let a_{t+1} be the financial investment decided in t for period $t+1$. The budget constraint for N consumers is

$$\begin{aligned} & c_t^N + p_t^T \left(1 - \tau_t^{T,N}\right) e_t^{T,N} + p_t^C \left(1 - \tau_t^{C,N}\right) e_t^{C,N} + a_{t+1} + k_{t+1} \\ = & \sum_j \left(1 - \tau_t^{S,j}\right) w_{St}^j L_{St}^j + \left(1 - \tau_t^k\right) r_t k_t^P + (1-\delta) k_t + (1+r) a_t \\ & + \Pi_t^C \end{aligned} \tag{4}$$

Here the variable a_t stands for the security paying off in the current period state. Regarding the disutility for work effort, clearly the utility function depends linearly on the labor supplied to each of the sectors described below. In principle, the marginal disutilities may differ across sectors, although the predictions when such disutilities are the same across sectors are quite straightforward special cases of those obtained here.

2.2 Technologies (goods, factors, inputs)

As stated from household preferences, the model assumes three consumption goods, the numeraire and two types of energy. At the same time, energy is also used as input to produce the numeraire good. On the other hand, the production of energy depends on either public capital (to be introduced below) or on non-renewable resources, depending on the type of energy considered here. Also from the household description it is clear that there are four primary factors: the non-renewable resource, the type of labor from the P households, labor from the N households, and capital (offered by the N households as well). Labor from P households is interpreted as "low productivity" and, less literally, as "unskilled" labor. As stated above, the type of labor that N consumers provide is interpreted as "high productivity" or, less literally, as skilled labor. Yet, the functional form assumed for the production function of the numeraire good does not allow for a more precise division between skilled and unskilled labor, given that the numeraire-good technology presented below does not allow for the empirically relevant complementarity between skilled labor and capital[9] Let L_t^U, L_t^S, K_r be the total quantity of unskilled labor, skilled labor and capital respectively used to produce the numeraire good, and let ϵ_t^T and ϵ_t^C be the quantities of traditional and clean energy used to produce the numeraire good. Thus, the production

[9] See, e.g., Krusell et al (2000).

function for the latter is

$$\begin{array}{rcl} Y_t & = & \exp(s) \left(L_t^U\right)^{\alpha_U} K_t^{\kappa\alpha_S} \left(L_t^S\right)^{(1-\kappa)\alpha_S} \left(\epsilon_t^T\right)^{\gamma(1-\alpha_U-\alpha_S)} \left(\epsilon_t^C\right)^{(1-\gamma)(1-\alpha_U-\alpha_S)} \\ 0 & < & \alpha_U < 1,\ 0 < \alpha_S < 1, 0 < \kappa < 1, 0 < \gamma < 1 \end{array} \tag{5}$$

The technologies that produce each type of energy are adaptations from those used in other papers found in the literature on Macroeconomics, energy and Environment as in, e.g., Acemoglu et al (2012) or Golosov et al (2014). In the case of the production of traditional energy, the technology uses one factor and one input. One is skilled labor and the other is the amount of the non-renewable resource that in this case is assumed to be fully imported. Although this is a clear simplification relative to what occurs in several countries in Latin America, the issue of the possible influence of reserves stock behavior and the macroeconomic aspects of energy policy is out of the scope of this paper. Thus, the production function representing the traditional-energy technology is assumed to be equal to:

$$Y_t^T = X_t^{\alpha_T^X} \left(L_{Tt}^S\right)^{1-\alpha_T^X},\ 0 < \alpha_T^X < 1 \tag{6}$$

where X_t denotes the quantity of the non-renewable resource and the amount L_{Tt}^S denotes the skilled labor used in producing traditional energy. Production of this type of energy is subject to taxation, given the negative externality that this production imposes on P households. Thus, the government imposes a tax on output equal to τ_t^{xT} units of the numeraire good per unit of T energy production. Of course, the application of this tax assumes that the policy-maker can observe and verify that level of T energy production. Therefore, the set-up of the problem of the traditional energy representative firm is

$$\max_{\left(X_t, L_{Tt}^S\right)\in\mathbb{R}_+^2} \left\{\left(p_t^T - \tau_t^{xT}\right) X_t^{\alpha_T^X} \left(L_{Tt}^S\right)^{1-\alpha_T^X} - q_t^* X_t - w_{St}^T L_{Tt}^S\right\}$$

The technology to produce clean energy uses skilled labor, private capital and public capital. Let L_{Ct}^S denote the skilled labor used to produce clean energy, K_{Ct} the stock of capital used to produce clean energy and K_{Ct}^g be the stock of public capital used to produce this type of energy. The production function for this good is then:

$$Y_t^C = \left(K_{Ct}^g\right)^{\alpha_C^{kg}} \left(K_{Ct}\right)^{\alpha_C^k} \left(L_{Ct}^S\right)^{1-\alpha_C^{kg}} \tag{7}$$

Public capital depreciates at constant rate $\delta^g \in (0,1]$. The presence of the latter assumes that the provision of this type of energy demands an important stock of public infrastructure, either to directly produce the energy from the upstream side or otherwise for distribution purposes, on the downstream side. The former is more clearly present in hydroelectric energy generation, while the former is more general and refers mostly to distributing electricity generated from more properly clean sources (eolic or solar energy types). The firm(s) producing clean energy take the stock of public capital as given. Thus, the latter presents constant returns with respect to skilled labor and capital. The problem of the representative firm in the clean energy sector is

$$\Pi_t^C \equiv \max_{\left(K_{Ct}, L_{Ct}^S\right)} \left\{ p_t^C \left(K_{Ct}^g\right)^{\alpha_C^{kg}} \left(K_{Ct}\right)^{\alpha_C^k} \left(L_{Ct}^S\right)^{1-\alpha_C^{kg}} - r_t K_{Ct} - w_{St}^C L_{Ct}^S \right\}$$

For each energy sector, markets are assumed to be perfectly competitive, in the sense that firms are price takers. Thus, prices are set equal to their respective private marginal costs.

2.3 Public-policy variables and political-economy (bureaucrats / parties)

The government decides taxes on both unskilled and skilled labor income, taxes on capital income, τ_t^k, taxes on energy production τ_t^{xT}, subsidies to each different form of energy τ_t^T and τ_t^C and public infrastructure investment, I_t^g. The latter and the depreciation rate introduced above defines the following standard law of motion for public capital

$$K_{t+1}^g = \left(1 - \delta^g\right) K_t^g + I_t^g \tag{8}$$

Also, depending on the party in power, a portion of public spending may be directed towards it, represented that spending by g_t^p, where p stands for the party in power (see the paragraphs below for details). The benchmark model assumes no access to foreign credit. A possible extension to be developed in the last sections is to add a foreign institutional lender (representing a multilateral organization that lends funds for public infrastructure). Thus, the period-t budget constraint is

$$\begin{aligned} & I_t^g + p_t^T \left[\pi \tau_t^{T,P} e_{Tt}^P + (1-\pi) \tau_t^{T,N} e_{Tt}^N\right] + p_t^C \left[\pi \tau_t^{C,P} e_{Ct}^P + (1-\pi) \tau_t^{C,N} e_{Ct}^N\right] \\ = \; & \pi \tau_t^U w_t^U L_t^U + (1-\pi) \left[\sum_j \tau_t^{S,j} w_t^{S,j} L_{St}^j + \tau_t^k r_t k_t\right] + \tau_t^{xT} Y_t^T \end{aligned} \tag{9}$$

2.4 Market clearing and other equilibrium conditions

Economic equilibrium is completed through consistency (market-clearing) conditions. In the unskilled labor market:

$$L_t^U = \pi \left(1 - l_t^P\right) \tag{10}$$

In the physical capital market the condition reads:

$$K_t + K_{Ct} = (1-\pi) k_t \tag{11}$$

Both types of energy are assumed to be non-tradeable. This assumption clearly ignores possible international trade on the downstream side of this type of energy. This assumption seems a bit restrictive considering possible trade in electricity that may occur between neighbor countries, as it is the case between Colombia and Ecuador[10]. Yet, there is a recognition that the development of such international trade is far from being fully exploited. Thus, the market clearing condition reads as follows:

$$\pi e_t^{T,P} + (1-\pi)\, e_t^{T,N} + \epsilon_t^{T} = Y_t^{T} \tag{12}$$

$$\pi e_t^{C,P} + (1-\pi)\, e_t^{C,N} + \epsilon_t^{C} = Y_t^{C} \tag{13}$$

Regarding the externality that affects the marginal utility for energy consumption, the assumption is that in equilibrium:

$$\rho_t = \frac{Y_t}{\Psi} \tag{14}$$

for a constant $\Psi > 0$. Finally, aggregating the households and government budget constraint we get

$$\begin{aligned} & Y_t - \pi c_t^P - (1-\pi)\, c_t^N + (1-\pi)\left((1+r)\, a_t - a_{t+1}\right) \\ & -(1-\pi)\left(k_{t+1} - (1-\delta)\, k_t\right) - q_t^* X_t - I_t^g \\ = \; & 0 \end{aligned} \tag{15}$$

which is the equation for the balance of payments in period t.

3 Preliminaries: individual's choices given policies in equilibrium

This section presents the household's and firm's optimal-choice characterizations in equilibrium for given policy variables. This exercise allows a better visualization of the type of trade-offs present in the setting of policy variables implemented under different types of government behavior. The paper presents such characterization for each private decision-maker. The technical paper (Kawamura, 2017) presents the details of the derivation.

3.1 Households.

Starting from the $P-$ household, their problem is essentially a sequence of static optimization problems. When introducing the period-t budget constraint into household $P's$ utility function the problem is reduced to

$$\begin{aligned} \max_{e^{T,P}, e^{C,P}, l_t^P} \; & \phi\theta \log\left[\left(1-\tau_t^U\right) w_t^U \left(1-l_t^P\right) - p_t^T \left(1-\tau_t^{T,P}\right) e_t^{T,P} - \left(1-\tau_t^{C,P}\right) p_t^C e_t^{C,P}\right] \\ & +\phi(1-\theta)\log l_t^P + (1-\phi)\,\eta\rho_t \log e_t^T + (1-\phi)(1-\eta)\,\rho_t \log e_t^C - \zeta Y_t^T \end{aligned} \tag{16}$$

[10] See CAF (2009) on a description of this market as well as the associated problem of congestion rent estimation.

whose solution is characterized by

$$l_t^P = \frac{\phi(1-\theta)}{\theta + \phi(1-\theta)} \tag{17}$$

$$c_t^P = \frac{\theta\left(1-\tau_t^U\right) w_t^U}{\theta + \phi(1-\theta)} \tag{18}$$

$$e_t^{C,P} = \frac{(1-\eta)\,\rho_t\,(1-\phi)\,\frac{\theta\left(1-\tau_t^U\right)w_t^U}{\theta+\phi(1-\theta)}}{p_t^C\left(1-\tau_t^{C,P}\right)} \tag{19}$$

and

$$e_t^{T,P} = \frac{\eta\rho_t\,(1-\phi)\,\frac{\theta\left(1-\tau_t^U\right)w_t^U}{\theta+\phi(1-\theta)}}{\left(1-\tau_t^{T,P}\right)p_t^T} \tag{20}$$

Clearly, those choices reflect the interaction between subsidies to energy consumption, prices and consumption of the numeraire good by the P households. The idea is that, to implement a higher energy consumption, higher subsidy rates may implement that, as it is obvious, but also other policies leading to lower energy prices or higher unskilled wages may also implement such higher energy consumption. Constraints that the government face may imply different degrees of use of such policy variables to allow for such higher energy consumption.

N households, unlike the P ones, face a genuinely intertemporal problem. Define an auxiliary variable

$$\begin{aligned}\iota_t^N \equiv\ & \sum_j \left(1-\tau_t^{S,j}\right) w_{St}^j L_{St}^j + \left[\left(1-\tau_t^k\right) r_t + (1-\delta)\right] k_t + a_t \\ & -\mathbf{Q}_t \cdot \mathbf{a}_{t+1} - k_{t+1}\end{aligned}$$

denoting total income net of investment in capital and international assets for next period. Then, individually optimal choices of energy consumptions given stock (state) variables are:

$$e_t^{C,N} = \frac{(1-\eta)(1-\phi)\,\rho_t\iota_t^N}{p_t^C\left(1-\tau_t^{C,N}\right)} \tag{21}$$

$$e_t^{T,N} = \frac{\eta(1-\phi)\,\rho_t\iota_t^N}{\left(1-\tau_t^{T,N}\right)p_t^T} \tag{22}$$

Then, the intertemporal problem is directly written in the following recursive way

$$\begin{aligned} & V(k_t, a_t, \sigma_t) \\ = & \max_{k_{t+1}, a_{t+1}, \left(L_{St}^j\right)_j} \log \left[\sum_j \left(1 - \tau_t^{S,j}\right) w_{St}^j L_{St}^j + \left[\left(1 - \tau_t^k\right) r_t + (1 - \delta)\right] k_t \right. \\ & \left. + \left(1 - \tau_t^{com}\right) y_t^{com} + a_t - \mathbf{Q}_t \cdot \mathbf{a}_{t+1} - k_{t+1} \right] \\ & - (1 - \phi) \eta \rho_t \log \left(1 - \tau_t^{T,N}\right) p_t^T - (1 - \phi)(1 - \eta) \rho_t \log p_t^C \left(1 - \tau_t^{C,N}\right) \\ & + \beta V(k_{t+1}, a_{t+1}, \sigma_{t+1}) \end{aligned} \tag{23}$$

where σ_t denotes the vector of realizations of all exogenous values in period t. From here the standard Euler equations are

$$\frac{c_{t+1}^N}{c_t^N} = \beta (1 + r) \tag{24}$$

and

$$1 = \beta \left[\frac{c_t^N \left[\left(1 - \tau_{t+1}^k\right) r_{t+1} + 1 - \delta\right]}{c_{t+1}^N} \right] \tag{25}$$

which implies that

$$\left(1 - \tau_{t+1}^k\right) r_{t+1} = r + \delta \tag{26}$$

Equation (24) is important when considering the policy choices below. In particular, the latter is important when the policy variables are determined through the electoral process. This equation implies that any policy maker faces the constraint that the consumption of the numeraire good by the N households cannot be manipulated between consecutive periods, given their access to international financial markets. This imposes limits to redistribution between consumption of household types, as it was stressed in the optimal fiscal policy literature. From this point on, the assumption on r is

$$\beta (1 + r) = 1 \tag{27}$$

That is, the international interest rate reflects exactly the discount rate implicit in the discount factor β. This of course implies that c_t^N is constant across time in any equilibrium for any policy chosen. On the other hand, equation (26) is the base for the determination of the capital tax rate.

3.2 Firms (factor and energy prices)

Individual firms optimality conditions are standard. For unskilled ("low-productivity") labor force:

$$w_t^U = \alpha_U \frac{Y_t}{L_t^U} \tag{28}$$

while for skilled ("high-productivity") labor in every sector:

$$w_{St}^{n} = \alpha_S (1-\kappa) \frac{Y_t}{L_t^S}; \tag{29}$$

$$w_{St}^{T} = \left(1-\alpha_T^X\right)\left(p_t^T - \tau_t^{xT}\right) \frac{Y_t^T}{L_{St}^T}; \tag{30}$$

$$w_{St}^{C} = \left(1-\alpha_C^k\right) p_t^C \frac{Y_t^C}{L_{Ct}^S} \tag{31}$$

Equation (28) equalizes the unskilled-labor wage to the marginal productivity of this type of labor in the numeraire sector. Equation (29) equalizes the numeraire-sector skilled wage to its marginal productivity, while equations (30) and (31) equalize the corresponding sector's skilled wage to their respective value of marginal products. The rental price of physical capital is equal to its value of the marginal product in both sectors:

$$r_t = \alpha_S \kappa \frac{Y_t}{K_t} = \alpha_C^k p_t^C \frac{Y_{et}^C}{K_{Ct}} \tag{32}$$

while the demand for the non-renewable resource equalizes the price of that input to the net-of-tax value of marginal product with respect to that resource in the T energy sector:

$$q_t^* = \left(p_t^T - \tau_t^{xT}\right) \alpha_T^X \frac{Y_t^T}{X_t} \tag{33}$$

Individually optimal demands of each type of energy of the numeraire-sector firms equalize the corresponding energy prices to the marginal product with respect to such energy inputs in the numeraire technology:

$$p_t^T = (1-\alpha_U-\alpha_S)\gamma \frac{Y_t}{\epsilon_t^T} \tag{34}$$

$$p_t^C = (1-\alpha_U-\alpha_S)(1-\gamma) \frac{Y_t}{\epsilon_t^C} \tag{35}$$

All these equations allow the computation of wages, rental price of capital and energy prices from the endogenous-policy allocations.

4 Benchmark-case policies: a (constrained) benevolent government with perfect commitment (constrained Ramsey problem)

4.1 Introduction to constrained Ramsey policies.

The first case considered in the paper is a benchmark where policies are in charge of a benevolent government that sets policy variables from period 0 onwards, and perfectly commits to such policy. This case corresponds to the well-known optimal fiscal (taxation) policy with commitment Ramsey problem in the macroeconomic literature [11]. Papers in the recent literature on dynamic macro models of energy and environmental quality mentioned in the introduction characterized policies under this assumption. Yet, none of those papers have considered a case of heterogeneous households and foreign-economy variables, which are novel elements introduced here.

As it is standard in the above-mentioned literature, the problem of choosing policy variables can be written in the form of a planner's problem that directly chooses the allocation. Then, prices and tax / subsidy rates are derived from the equilibrium conditions introduced in section 3. Formally, the problem can be set in the following way:

$$\max\ \bar{\varphi}\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t u_t^P\right]+(1-\bar{\varphi})\,\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t u_t^N\right] \tag{36}$$

with

$$u_t^i \equiv u^i\left(c_t^i, e_t^{T,i}, e_t^{C,i}, l_t^i\right),\ i=P,N$$

The maximization is subject to the $N-$ households' consumption of the numeraire good:

$$c_t^N = c_0^N \tag{37}$$

together with the unskilled-labor equilibrium quantity

$$L_t^U = \frac{\pi\theta}{\theta+\phi\,(1-\theta)} \tag{38}$$

obtained from equation (17), the market-clearing conditions for capital (11), for T energy

[11] For classic references on this literature see, e.g., Lucas and Stokey (1983), Chamley (1986) Chari et al (1994) and Aiyagari et al (2002), the four of which assume a unique type of households (representative-agent models) and closed economies. For extensions to economies with heterogeneous consumers see, e.g., Werning (2007) and Bassetto (2014). For an extension to small open economies see Aguiar and Amador (2016). For a textbook treatment and methodological issues see Ljungqvist and Sargent (2004).

(12) and for C energy (13), the intertemporal budget constraint by household N :

$$0 = -\left[\left(1-\tau_0^k\right)\alpha_S \kappa \frac{Y_0}{K_0} + (1-\delta)\right] k_0 + \frac{c_0^N}{(1-\beta)\phi} \tag{39}$$

coming from the time aggregation of constraints (4), the intertemporal aggregate balance of payment:

$$\begin{aligned} & 0 \\ = & \sum_{t=0}^{\infty} \beta^t \left[\pi c_t^P + (1-\pi) c_0^N - Y_t\right] \\ & + \sum_{t=0}^{\infty} \beta^t (1-\pi) \left[(k_{t+1} - (1-\delta) k_t) + q_t^* X_t + K_{t+1}^g - (1-\delta^g) K_t^g\right] \end{aligned} \tag{40}$$

After getting the allocation that solves the above-mentioned problem, factor and energy prices are obtained from equations in subsection 3.2. The tax and subsidy rates also come from the equations in section 3, meaning that subsidy rates on T energy for each type of household satisfy

$$\tau_t^{T,P} = 1 - \frac{(1-\phi)\eta\rho_t c_t^P}{\phi p_t^T e_t^{T,P}};\ \tau_t^{T,N} = 1 - \frac{(1-\phi)\eta\rho_t c_t^N}{\phi p_t^T e_t^{T,N}} \tag{41}$$

while the analogs for clean energy subsidies are:

$$\tau_t^{C,P} = 1 - \frac{(1-\phi)(1-\eta)\rho_t c_t^P}{\phi p_t^C e_t^{C,P}};\ \tau_t^{C,N} = 1 - \frac{(1-\phi)(1-\eta)\rho_t c_t^N}{\phi p_t^C e_t^{C,N}} \tag{42}$$

Finally, the P household's budget constraint allows for the explicit computation of the tax rate on unskilled labor, the tax on skilled labor supplied in each sector j comes from the equilibrium labor supply on sector j, while capital income satisfies the :

$$\tau_t^U = 1 - \frac{c_t^P}{\phi\alpha_U Y_t};\ \tau_{St}^j = 1 - \frac{\beta^t(1-\theta)\Theta_j}{\theta w_t^{S,j}};\ \tau_{t+1}^k = 1 - \frac{\left(\frac{1-\beta}{\beta} + \delta\right)}{r_{t+1}} \tag{43}$$

Kawamura (2017) provides a general characterization of the solution when all tax and subsidy rates are interior. The following proposition provides key features of the allocation coming from such characterization (the proof comes also from Kawamura, 2017).

Proposition 1 *At the solution to the Ramsey problem in (36) implies the following dynamic evolution for the main variables*

1. *The next-period stock of capital at the Ramsey allocation takes the following form*

$$\widehat{k}_{t+1} = k^{ss} \frac{\left(\bar{k}^r \left(\beta^t q_t^*\right)^{\alpha_T^X} + \varphi\zeta\right)^{\eta_{1k}}}{\beta^{\eta_{\beta k} t}} \tag{44}$$

Moreover, if the share of public capital in then production of clean energy α_C^{kg} *is sufficiently large, then the next-period stock of private capital is increasing in the international price of the fossil resource.*

2. *The next-period stock of public infrastructure takes the form:*

$$\widehat{K}_{Ct+1}^{g} = \bar{K}^{g,ss} \beta^{\eta_{\beta g} t} \left(\bar{k}^r \left(\beta^t q_t^*\right)^{\alpha_T^X} + \varphi\zeta\right)^{\eta_{1k}} \tag{45}$$

3. *The production of the numeraire good satisfies*

$$\widehat{Y}_t = \beta^{\eta_y t} \left(\bar{k}^r \left(\beta^t q_t^*\right)^{\alpha_T^X} + \varphi\zeta\right)^{\eta_{1k}} \bar{Y}^{ss} \tag{46}$$

where $\bar{Y}^{ss}$ *is a positive constant.*

4. *Consumption of each type of energy for each type of household satisfies the following equations*

$$\widehat{e}_t^{T,P} = \frac{\beta^{\eta_{TP} t}}{\left(\bar{k}^r \left(\beta^t q_t^*\right)^{\alpha_T^X} + \varphi\zeta\right)^{1-\eta_{1k}}} \bar{e}^{TP} \tag{47}$$

$$\widehat{e}_t^{T,N} = \frac{\pi (1-\varphi)}{\varphi (1-\pi)} \widehat{e}_t^{T,P}$$

$$\widehat{e}_t^{C,P} = \beta^{\bar{\alpha}_{C,P}^{e} t} \left(\bar{k}^r \left(\beta^t q_t^*\right)^{\alpha_T^X} + \varphi\zeta\right)^{\alpha_{qCP}} \tag{48}$$

$$\widehat{e}_t^{C,N} = \frac{\pi (1-\varphi)}{\varphi (1-\pi)} \widehat{e}_t^{C,P} \tag{49}$$

The first two statements of proposition 1 state that the international price of the resource is one of the main forces that govern the dynamics of both forms of capital in this model. In particular, Kawamura (2017) shows that the coefficient that affects the resource price depends on the share of this fossil resource in the production of traditional energy, on the share of unskilled labor, physical capital and non-traditional energy in the production of the numeraire good, and also on the share of capital in the production of non-traditional energy. That same set of parameters affect the correlation between the fossil resource price and the stock of public capital. The other main exogenous variable that influence both stocks of capital is the international interest rate (or, equivalently, the discount factor). The impact of this variable may differ across each of the two forms of capital. In statement 1 of this proposition, the correlation of private capital with interest rate not only depends on the same set of parameters that affect the influence of the international price of the resource on capital. It also depends on the share of traditional energy in GDP production through the coefficient tat affects the discount factor in the denominator of equation (44). In this way, the influence of the international interest rate on capital may not be unequivocally decreasing. Instead, there are constraints that such technological parameters must satisfy to generate an inverse relationship between that interest rate and the stock of capital when the benevolent and committed government sets policies. The reason for such ambiguous effect is that the interest rate not only reflects financial opportunity costs of investing in private capital but also the degree of impatience by households in this economy. However, the public capital stock is clearly decreasing with respect to the international interest rate. This asymmetry may be due to specific assumptions on technologies that may wash out certain trade-offs regarding the influence of such parameter.

The third statement shows how output (the production of the numeraire sector) evolves through time in an equilibrium under these optimal policies. It states a positive dependence of that output level with respect to both stocks of capital. How both types of capital affect GDP in the model implies that, in the equilibrium with optimally endogenous policies, the output level ends up being increasing in the international price of the fossil resource and decreasing in the international interest rate. Undoubtedly, the international price of the resource works as a growth engine for the non-energy sectors, given its positive influence not only in private capital investment, but also on the public infrastructure investment decision. The latter also gives positive impulse on GDP since non-fuel energy is an input to produce numeraire goods.

The fourth statement emphasizes the quantity of each type of energy that each household consumes in this equilibrium. By construction, the relative consumption for each energy food between the two types of households is completely fixed and determined by the social weights φ and $1-\varphi$. Thus, the higher or lower access to each energy good for the non-poor is proportional to that of the poor households. Expression (47) emphasizes that consumption of traditional energy is decreasing in the fossil-resource international price. This property just reflects the positive influence of such price in the production costs of this type of energy. The same international price enters in an increasingly monotone way in the consumption of the non-traditional energy. This is also a consequence of the optimal equilibrium policies that include a decision of public investment that is increasing in that international price. Such increase public investment increases the stock of public capital, that is a key input to produce the non-traditional energy good.

The last proposition also shows how the externality effect (coming from the parameter ζ) weighted by the policy-maker's parameter φ affects the main variables of this benevolent-government-policy allocation. In particular, it affects positively on the level of numeraire output, investment in both types of capital and consumption of non-traditional energy. On the contrary, it affects negatively the consumption of traditional (fossil-based) technology. These effects capture the fact that the benevolent government would focus on policies that tends to avoid such negative externality. Thus, policies induce to favor production of non-traditional energy (and the investments that facilitate such production) as opposed to that of traditional energy.

As stated above, the method that allows for the computation of the equilibrium allocation also provides prices and the explicit tax and subsidy policies that implement such allocation. The next proposition reports the prediction of the equilibrium prices and subsidies on each type of energy.

Proposition 2 *At the equilibrium with a benevolent government the implied prices and subsidy rates on each type of energy are as follows. The price of traditional energy is*

$$\widehat{p}_t^T = \frac{\bar{k}^r \left(\beta^t q_t^*\right)^{\alpha_T^X} + \varphi\zeta}{\Phi\beta^t} \tag{50}$$

The equilibrium price of clean energy is

$$\widehat{p}_t^C = \frac{\bar{p}^C \beta^{\eta_{\beta pC} t}}{\left(\bar{k}^r \left(\beta^{t-1} q_{t-1}^*\right)^{\alpha_T^X} + \varphi\zeta\right)^{\eta_{qpC}}} \tag{51}$$

for a positive constant $\bar{p}^C$. The subsidy rate on traditional energy consumption for the poor is

$$\widehat{\tau}_t^{T,P} = 1 - \theta \tag{52}$$

while the subsidy rate on clean energy consumption (also for the poor) is

$$\widehat{\tau}_t^{C,P} = 1 - \frac{\theta}{\Psi} \tag{53}$$

Finally, the tax on traditional energy production is

$$\widehat{\tau}_t^{xT} = \frac{\zeta}{\Phi\beta^t} \tag{54}$$

The first two expressions in proposition 2 refer to the equilibrium price of each type of energy. Their specific form reflects similar features from the optimal-policy allocations. In particular, the traditional-energy price is increasing in the international price of the fossil-based resource. This property just reflects the cost of producing traditional energy in equilibrium. On the other hand, the effect of that same resource international price on the price of non-traditional energy is undoubtedly negative, since Kawamura (2017) shows that the coefficient affecting the denominator in equation (51) denoted as η_{qpC} is strictly positive. The intuition is based on the same arguments that show its positive effect on public capital investment and private investment, which implies higher clean energy production and so lower prices of this alternative energy good. On the other hand, the effect of the international interest rate on both energy prices is ambiguous given how the discount factor affects these prices.

Regarding explicit energy policy variables, proposition 2 states that, under a benevolent government policies, the subsidy rates on both types of energy consumption by the poor are constant, and depending on preference and / or technological parameters only. In particular, they depend negatively on the value of numeraire consumption good. Thus, no exogenous variable impacts on such rates. On the other hand, the tax rate (denominated in numeraire goods) on the production of traditional energy is increasing, as it is expected, in the externality parameter ζ. Unlike the subsidy rates on energy consumption, the tax on traditional energy production is increasing over time, since such tax rate depends on a capitalization factor using international interest rate. Thus, it is immediate that such tax rate increases over time at a rate equal to the international interest rate.

This last property implies that, at least for the subsidy rates on the consumption of each type of energy, all dynamics coming from either the exogenous behavior of the international price of the resource or from the capitalization or discounting effect that depends on the international interest rate are absorbed by allocations and prices in this Ramsey equilibrium in such a way that the dynamics of prices counterbalance that of the quantities. Equilibrium relationships between prices and quantities (together with the specific forms of preferences and technologies) ensure this counterbalancing effect of exogenous dynamics, ensuring then that the policy rates for these subsidies are time invariant. Admittedly, this property may not hold with other more general forms of preferences or technologies. Yet, it states explicitly what types of parameters influence these rates, in particular, the parameter that governs the marginal utility of numeraire consumption.

The last two propositions imply the following long-run dynamics of the major endogenous variables under the Ramsey policy[12].

Corollary 3 *Suppose that the international price of the fossil-based resource grows at a constant (gross) rate $\gamma_q > 1$. Assume also that the share of public capital in the production of clean energy α_C^{kg} is sufficiently large. The following statements hold.*

1. *If*

$$\gamma_q > \beta^{1-\frac{\eta_{\beta k}}{\alpha_T^X \eta_{1k}}}$$

then the next-period stock of capital converges to a path with a constant (gross) growth rate equal to

$$\frac{\gamma_q^{\alpha_T^X \eta_{1k}}}{\beta^{\eta_{\beta k}-\alpha_T^X \eta_{1k}}}$$

2. *If*

$$\gamma_q > \beta^{-\left(1+\frac{\eta_{\beta g}}{\alpha_T^X \eta_{1k}}\right)}$$

then the next-period stock of public capital converges to a path with a constant (gross) growth rate equal to

$$\gamma_q^{\alpha_T^X \eta_{1k}} \beta^{\eta_{\beta g}+\alpha_T^X \eta_{1k}}$$

[12] See Kawamura (2017) for details.

3. If

$$\gamma_q > \beta^{-\frac{(\eta_y+\eta_{1k})}{\alpha_T^X \eta_{1k}}}$$

then the GDP (the numeraire output) converges to a path with a constant (gross) growth rate equal to

$$\gamma_q^{\alpha_T^X \eta_{1k}} \beta^{\eta_y+\alpha_T^X \eta_{1k}}$$

4. If

$$\gamma_q > \beta^{-\frac{\left(\bar{\alpha}_{C,P}^e+\alpha_{qCP}\right)}{\alpha_T^X \alpha_{qCP}}}$$

then the P households"s C energy consumption converges to a path with a constant gross growth rate equal to

$$\gamma_q^{\alpha_T^X \alpha_{qCP}} \beta^{\bar{\alpha}_{C,P}^e+\alpha_T^X \alpha_{qCP}}$$

Corollary 3 shows sufficient conditions that ensure sustained long-run growth on private and public capital, output and clean (non-fossil-based) energy consumption. This corollary emphasizes that a necessary condition for such sustained growth to occur in the long run is indeed the assumption of an international price of the fossil resource to grow. This evolution provides enough incentives to the benevolent and committed policy-maker to invest in public infrastructure and to set other policy variables that favor private capital accumulation. The other condition needed for long-run growth is that the international interest rate being not large. The latter is very intuitive, since the interest rate constitutes the opportunity cost for N households of investing in physical capital, given the international financial asset option. What varies across different variables regarding the long-run growth rate is the exponent of the discount factor and the growth rate of the international price of the resource. Such exponents depend essentially on technological parameters. In any case, the main message from this corollary is that sustained growth may be a long-run outcome of an optimal policy with perfect commitment whenever the price of an international tradable fossil fuel increases.

Propositions 1 and 2 and corollary 3 summarize the main features that arise at the solution of the Ramsey planning problem, together with the implied policies. The latter assumes a benevolent planner with a welfarist objective. As it was emphasized in the introduction, this assumption allows for a characterization of a constrained socially "optimal" policy, but it seems far from policies and allocations that arise in developing economies where the polity (in this case, electoral competition) affects incentives to implement such a constrained optimal allocation. The next section then re-introduces the political economy side of the environment to analyze the type of allocations that arise in such case.

5 The economy with political (electoral) processes

This section introduces the explicit analysis of the policy variables setting problem when one of two identical parties A or B runs the government in every period, becoming the explicit policy-maker in that period. It first introduces the main assumptions concerning the electoral competition and the preferences that each party has. Then the section introduces and studies the concept of politico-economic equilibrium where policies are set sequentially by the corresponding ruling party.

5.1 Electoral competition, timing within the period and the equilibrium concept.

This section assumes that in each period t there are two parties (that could be reduced to one politician per party) called A and B. They engage in an electoral competition at the beginning of each period. At the electoral stage, each party proposes a set of policy variables for that period. The model assumes that the winning party has a commitment technology only for that period to implement the proposed policies. Both parties have the same type of preferences in every period t. They are represented by a utility function that is linear in the probability of winning the electoral competition. This assumption is identical to that in Sleet and Yeltekin (2008)[13]. The outcome of this electoral competition is determined by the realization of random political variables that appear additively in the utility function of each type of households, as described below. The timing within the period is as follows:

1. At the beginning of the period, each party proposes the policy variables for that period. The proposal by both parties occurs simultaneously.

2. After every party makes the policy proposals, political shocks are realized and the winning party is also determined.

3. The winning party implements the proposed policy at the electoral competition stage.

4. Given policies, households and firms make decisions. The following period follows.

This timing allows for an equilibrium concept called a **politico-economic equilibrium**. The latter includes subsidies on energy consumption, taxes on traditional energy production, tax rates on unskilled and skilled labor income, on capital income, investment in public capital, prices of both types of energy and factors of production and quantities that are endogenously determined. Policies come from the electoral competition stage, while prices and quantities are consistent with households and firm's optimality and market clearing, as it will be clear below.

[13] The assumption on one-period perfect commitment for policies may be considered as a strong assumption, as stressed by, e.g., Azzimonti (2011, 2015). Yet, it allows for a smoother analytical characterization of equilibria with endogenous policy coming from this electoral competition. Instead, using other assumptions in terms of non-commitment by parties within the period demands a different type of parties preferences, probably closer to ideological parties. However, the latter may introduce more artificial oscillations, which are just direct consequences of the political volatility and the asymmetric policy goals by each party.

5.2 Specifying the policy problem.

The first step is to explicit the specific assumptions on the political shocks that determine the probability of winning the election for any party. The following subsection does so.

5.2.1 Political shocks

This paper assumes that period-t utility functions for each type of household $j \in \{P, N\}$ include an additive shock whose realization is $\widetilde{\xi}_t^j$. This variable means the bias that a household of type j has to vote in favor to politician A. That variable is assumed to follow:

$$\widetilde{\xi}_t^j = \xi_t^j + \widetilde{\psi}_t, \; j \in \{P, N\} \tag{55}$$

Here ξ_t^j is a type-idiosyncratic bias variable favoring party A, with ξ_t^j being i.i.d. (across people of type i and across time) uniformly distributed on $\left[-\bar{\xi}^j, \bar{\xi}^j\right]$, with $\bar{\xi}^j > 0$. Thus, of course, $-\widetilde{\xi}_t^j$ denotes the household j's ideological bias favoring party B. Variable ψ_t is an aggregate popularity variable towards party A, which is i.i.d. over time and uniformly distributed on $\left[-\frac{\Psi}{2}, \frac{\Psi}{2}\right]$. These assumptions then allow for an explicit characterization of the probability of winning the election, which is the step taken in the next subsection.

5.2.2 Determining the probability of winning the election

For this task it is useful to determine first the inequality that induces the P household voting for A. Let

$$\mathbf{s}_t \equiv \left(k_t, K_t^g, a_t, q_t^*\right) \tag{56}$$

be the vector of relevant state variables. Letting $V^{P,i}\left(\mathbf{s}_{t+1}\right)$ be the future utility that P obtained from the next period on when in the current period this household votes for party $i \in \{A, B\}$ then this P household votes for A instead of B if and only if

$$\begin{aligned} & u^P\left(c_t^{P,A}, e_t^{T,P,A}, e_t^{C,P,A}, \frac{\phi\left(1-\theta\right)}{\theta+\phi\left(1-\theta\right)}\right) - \zeta Y_t^{T,A} + \beta V^{P,A}\left(\mathbf{s}_{t+1}\right) + \xi_t^P + \psi_t \\ \geq \; & u^P\left(c_t^{P,B}, e_t^{T,P,B}, e_t^{C,P,B}, \frac{\phi\left(1-\theta\right)}{\theta+\phi\left(1-\theta\right)}\right) - \zeta Y_t^{T,B} + \beta V^{P,B}\left(\mathbf{s}_{t+1}\right) \end{aligned} \tag{57}$$

voting for B if the inequality (57) above is reversed. Here the term $u^P\left(c_t^{P,i}, e_t^{T,P,i}, e_t^{C,P,i}, \frac{\phi(1-\theta)}{\theta+\phi(1-\theta)}\right)$ refers to the $P-$household's period t utility evaluated at an allocation set by party i in power. Note that the fourth term denotes the quantity of leisure that P households consume in any equilibrium. Analogously, the representative N household votes for A instead of B if and only if

$$\begin{aligned}
& u^N\left(c_t^N, e_t^{T,N,A}, e_t^{C,N,A}, \left(L_{St}^{j,A}\right)_j\right) + \beta V^{N,A}\left(\mathbf{s}_{t+1}\right) + \xi_t^N + \psi_t \\
\geq \;& u^N\left(c_t^N, e_t^{T,N,B}, e_t^{C,N,B}, \left(L_{St}^{j,B}\right)_j\right) + \beta V^{N,B}\left(\mathbf{s}_{t+1}\right)
\end{aligned} \tag{58}$$

where the function u^N refers to the $N-$household's period t utility evaluated at the allocation that party i chooses, and $V^{N,i}\left(\mathbf{s}_{t+1}\right)$Both inequalities state that voting in the current period for party A provides at least as much total utility from the current period on than voting for party B. All the terms on the left of those inequalities except for the last two are the intrinsic welfare coming from voting for party A, while all terms on the right hand side of these inequalities is the same welfare but when voting for party B. The last two terms on the left hand side in each inequality is the sum of the realizations of the political shocks as introduced in the last subsection. Those inequalities determine a threshold value for the realization of the idiosyncratic component the shock, denoted as $\widehat{\xi}_t^P$ for the P households and as $\widehat{\xi}_t^N$ for the N households. Thus, the probability that party A wins the election in period t is given by

$$\begin{aligned}
\mathfrak{p}_{A,t} &= \pi \Pr\left(\xi^P > \widehat{\xi}_t^P\right) + (1-\pi)\Pr\left(\xi^N > \widehat{\xi}_t^N\right) \\
&= 1 - \frac{\pi \widehat{\xi}_t^P}{2\bar{\xi}^P} - \frac{(1-\pi)\,\widehat{\xi}_t^N}{2\bar{\xi}^N}
\end{aligned}$$

Kawamura (2017) shows that the last probability can be written as

$$\begin{aligned}
\mathfrak{p}_{A,t} = &\frac{\pi\left(u_t^{P,A} - \zeta Y_t^{T,A}\right)}{2\bar{\xi}^P} + \frac{(1-\pi)\,u_t^{N,A}}{2\bar{\xi}^N} + \beta V^A\left(\mathbf{s}_{t+1}\right) \\
&- \left[\frac{\pi\left(u_t^{P,B} - \zeta Y_t^{T,B}\right)}{2\bar{\xi}^P} + \frac{(1-\pi)\,u_t^{N,B}}{2\bar{\xi}^N} + \beta V^B\left(\mathbf{s}_{t+1}\right)\right] \\
&+1 + \left(\frac{\pi}{\bar{\xi}^P} + \frac{(1-\pi)}{\bar{\xi}^N}\right)\frac{\psi_t}{2}
\end{aligned} \tag{59}$$

where

$$V^j\left(\mathbf{s}_{t+1}\right) \equiv \frac{\pi V^{P,j}\left(\mathbf{s}_{t+1}\right)}{2\bar{\xi}^P} + \frac{(1-\pi)\,V^{N,j}\left(\mathbf{s}_{t+1}\right)}{2\bar{\xi}^N},\; j \in \{A, B\}$$

and where $u_t^{h,i}$ refers to the $h-$household's period t utility (with h being either P or N) evaluated at an allocation set by party i (either A or B) in power. Of course, the probability that party B wins the election is just $\mathfrak{p}_{B,t} = 1 - \mathfrak{p}_{A,t}$. What is important from expression (59) is that it is increasing in a linear combination of both types of households's intertemporal welfare when policies are determined by A, and it is decreasing in that same total welfare when policies are determined by B. The assumption of simultaneously choosing policy proposals by each party means that each party takes the other party's policy proposals as given. Then, given the symmetry between the two politicians, and as it occurs in the traditional probabilistic-voting model by Lindbeck and Weibull (1987), the problem of policy proposals by each party is symmetric. The next subsection shows the explicit policy proposal stage problem.

5.2.3 Policy proposals stage

Given the conditions described in the last subsection, the problem of policy proposal decision by any party can be written as follows. First, the problem is also written in the form of choosing allocations directly, computing afterwards prices and policy variables from the economic equilibrium condition. Let:

$$\omega^P \equiv \frac{\pi}{2\bar{\xi}^P},\ \omega^N \equiv \frac{(1-\pi)}{2\bar{\xi}^N}$$

These two expressions measure the electoral "weight" of each type of household under the probabilistic voting equilibrium. First, it is clear that both are increasing in their respective fraction on the total population. On the other hand, each of these weights are decreasing in the parameter $\bar{\xi}^i$. The latter measures the dispersion of the political biases of type i's households in each period. The larger the dispersion, the lower is their weight in the total population. This feature clearly reflects the idea that the electoral weight of a household type may be higher the more unanimous are their political opinions on any of the two candidates.

Therefore, the current-period public policy proposal problem is:

$$\begin{aligned}
& V^*\left(k_t, a_t, K_t^g, \sigma_t\right) \\
= \quad & \max\ \omega_P \left[\phi\theta \log c_t^{P*} + \rho_t (1-\phi) \left[\eta \log e_t^{T,P*} + (1-\eta) \log e_t^{C,P*}\right] - \zeta Y_t^{T*}\right] \\
& +\omega_N \left[-\phi(1-\theta) \sum_j \Theta_j L_{St}^{j,*} + \rho_t (1-\phi) \left[\eta \log e_t^{T,N,*} + (1-\eta) \log e_t^{C,N,*}\right]\right] \\
& +\beta V^*\left(k_{t+1}^*, a_{t+1}^*, K_{t+1}^{g*}, \sigma_{t+1}^*\right)
\end{aligned}$$

subject to the period-t constraints that include the production technology of the numeraire good (5), the market clearing conditions for private capital (11), the traditional energy (12), the non-traditional energy (13), the current-period balance of payment equation (15) and the current period N household's constraint:

$$\frac{c_t^N}{\phi} = (1+r)(k_t + a_t) - (a_{t+1} + k_{t+1})$$

From the last constraint and introducing the N household's constant consumption of the numeraire good then the last constraint is obviously written as:

$$a_{t+1} + k_{t+1} = (1+r)(k_t + a_t) - \frac{1}{\phi} c_0^N \tag{60}$$

Also, given the no-arbitrage condition generated at equilibrium between Arrow-securities and capital, then one can define

$$\widetilde{a}_t \equiv a_t + k_t$$

consumer $N's$ constraint is equivalent to

$$\widetilde{a}_{t+1} = (1+r)\,\widetilde{a}_t - \frac{1}{\phi} c_0^N$$

This leads to replace $a_{t+1} + k_{t+1} = \widetilde{a}_{t+1}$ and the physical capital market clearing condition in the balance-of-payments constraint to get:

$$\begin{aligned} & \pi c_t^{P*} + K_{t+1}^{g*} + q_t^* X_t^* \\ = Y_t^* \quad & -\frac{(1-\pi)}{\phi} c_0^{N*} + (1-\delta^g) K_t^{g*} - \left[\frac{1}{\beta} - (1-\delta)\right](K_t^* + K_{Ct}^*) \end{aligned} \tag{61}$$

5.3 Characterization of dynamic politico-economic equilibria.

The next step is to present the evolution of the major endogenous variables. As the next proposition shows, the dynamics of public capital and the P household's consumption of the numeraire good a-priori present a joint evolution through time that looks very different from that in the benevolent committed policy-maker.

Proposition 4 *Suppose that*

$$\delta^g = 1 \tag{62}$$

That is, assume full-depreciation of public capital between consecutive periods[14]*. Then the politico-economic equilibrium reduces to the following system involving the P household's consumption of the numeraire and the public capital for next period with the following form:*

$$\left(c_{t+1}^{P*}\right)^{1+\alpha_{cP'}^{PV}} = \frac{\beta \bar{K}^g \left[\bar{\omega}(1-\eta) c_{t+1}^{P*} + \alpha_C^y\right] c_t^{P*} \left(K_{Ct+1}^{g*}\right)^{\frac{\alpha_C^y \alpha_C^{kg}}{\alpha_U} - 1}}{\left[\bar{k}^{PV} \left(q_{t+1}^*\right)^{\alpha_T^X} + \omega_P \zeta \left(c_{t+1}^{P*}\right)^{\alpha_T^X}\right]^{\frac{\alpha_T^y}{\alpha_U}}} \tag{63}$$

[14] The technical paper version (Kawamura (2017)) shows a more general characterization for any arbitrary value of the public capital depreciation. This paper presents this more particular case to get cleaner expressions that may more easily generate policy implications.

$$K^{g,*}_{Ct+1} = \frac{\left\{ k^{PV}_{gcP} + \alpha^k_C \bar{\omega}(1-\eta) c^{P*}_t - \frac{\bar{c}^{PV}\left(c^{P*}_t\right)^{\alpha^X_T}\left[\frac{\bar{\omega}\eta}{\Psi}\left(c^{P*}_t\right)^{1-\alpha^X_T}+\alpha^y_T\right]}{\left[\bar{k}^{PV}\left(c^{P*}_t\right)^{-\alpha^X_T}+\frac{\omega_P\zeta}{(q^*_t)^{\alpha^X_T}}\right]} \right\} \left(K^{g*}_{Ct}\right)^{\frac{\alpha^y_C \alpha^{kg}_C}{\alpha_U}} \bar{Y}^*}{\left(c^{P*}_t\right)^{\alpha^{PV}_{cP\prime}} \left[\bar{k}^{PV}(q^*_t)^{\alpha^X_T} + \omega_P\zeta\left(c^P_t\right)^{\alpha^X_T}\right]^{\frac{\alpha^y_T}{\alpha_U}}} - \pi c^{P*}_t - (1-\pi)\frac{1}{\phi}c^N_0 \tag{64}$$

with

$$\bar{\omega} \equiv (\omega_P + \omega_N)(1-\phi)$$

where $\alpha^y_C \equiv (1-\gamma)(1-\alpha_U-\alpha_S)$ *is the share of clean energy in the production of numeraire goods,* $\alpha^y_T \equiv (1-\alpha_U-\alpha_S)\gamma$ *is the share of traditional energy in the production of numeraire goods,* α^{PV}_{kg}, $\alpha^{PV}_{cP\prime}$ *are positive coefficients and* $\bar{k}^{PV}$, k^{PV}_{gcP}, $\bar{c}^{PV}$, $\bar{K}^g$ *and* $\bar{Y}^*$ *are positive constants depending on parameters.*

The purpose of assumption in equation (62) is to provide a cleaner characterization of the public capital dynamics under probabilistic voting competition. Proposition (4) emphasizes that, under a politico-economic equilibrium with probabilistic voting, consumption of the numeraire good by the P household presents a different dynamics relative to the case of the equilibrium determined by the benevolent and committed government. Even if the P household's consumption of the numeraire good were constant, public capital may not evolve in an identical way as in the benevolent and committed policy-maker case.

The next proposition also shows the features of energy prices and energy-consumption subsidy policies and taxes on traditional energy production in the politico-economic equilibrium under probabilistic voting.

Proposition 5 *Suppose assumption in (62) holds. Then*

1. *The price of traditional energy is given by*

$$p^{T*}_t = \left[\frac{\omega_N\phi(1-\theta)\Theta_T}{(1-\alpha^X_T)}\right]^{1-\alpha^X_T}\left(\frac{q^*_t}{c^{P*}_t\alpha^X_T}\right)^{\alpha^X_T} + \omega_P\zeta \tag{65}$$

2. *The price of fossil-free energy is given by*

$$p^{C*}_t = \frac{\left(\frac{1}{\beta}-(1-\delta)\right)^{\alpha^k_C}\left(\omega_N\phi(1-\theta)\Theta_C\right)^{1-\alpha^k_C}}{\left(1-\alpha^k_C\right)^{1-\alpha^k_C}\left(\alpha^k_C c^{P*}_t\right)^{\alpha^k_C}\left(K^g_{Ct}\right)^{\alpha^{kg}_C}} \tag{66}$$

3. *The tax rate on traditional energy production is equal to*

$$\tau_t^{xT*} = \frac{\omega_P \zeta}{c_t^{P*}} \tag{67}$$

4. *The subsidy rates on consumption of traditional and non-traditional energy are both equal to*

$$\tau_t^{T,P*} = \tau_t^{C,P*} = 1 - \frac{\pi c_t^{P*}}{\phi \omega_P} \tag{68}$$

Item 1 of proposition 5 presents the traditional energy price under the politico-economic equilibrium concept. It follows a similar pattern as the same price under a Ramsey equilibrium. In particular, it is increasing in the international price of the fossil resource. It is also increasing in the negative externality parameter ζ, weighted by the P households electoral intensity. Related to this result, statement 3 of this last proposition presents the numeraire-denominated tax on traditional energy production in this politico-economic equilibrium. As expected, it is increasing in the negative externality parameter ζ, weighted by the P households electoral intensity. It is also decreasing in the P household's consumption of the numeraire. Given that the latter may not be increasing over time, then it is not obvious that this rate be decreasing over time, as it is the case in the Ramsey equilibrium. On the other hand, statement 4 presents the common subsidy rate on both the traditional and non-traditional energy consumption for the P households. It is noticeably increasing in the electoral weight of these households (an expected result given how policies are set through the political competition at the beginning of every period). It is decreasing in the numeraire consumption by the P household.

Finally, statement 2 of the same proposition predicts that the price of clean energy is decreasing in the stock of public capital. The latter is also a natural consequence of the inverse relationship between the price of this type of energy and the main force that allows for growth in the supply of this type of energy, which is the public capital.

It is possible to obtain sufficient conditions to characterize a long-run equilibrium with a constant growth for the public capital stock (and also for private capital stock and output) and where the P household's consumption of the numeraire good is constant. The following proposition states such result.

Proposition 6 *Suppose that the international price of the fossil resource grows at a constant (gross) rate equal to γ_q. Then, there exists a long-run politico-economic equilibrium with probabilistic voting with the following features.*

1. *Next-period public capital converges to the following expression*

$$K_{Ct+1}^{g*} = \left[\left[\frac{\omega_N \phi (1-\theta) \Theta_T}{(1-\alpha_T^X)} \right]^{1-\alpha_T^X} \left(\frac{q_{t+1}^*}{\alpha_T^X} \right)^{\alpha_T^X} \right]^{\frac{\alpha_T^y}{\alpha_C^y \alpha_C^{kg} - \alpha_U}} \tag{69}$$

Thus if α_C^{kg} is large enough then public capital grows at a constant rate equal to

$$\gamma_g^* = \left(\gamma_q\right)^{\frac{\alpha_T^y \alpha_T^X}{\alpha_C^y \alpha_C^{kg} - \alpha_U}} \tag{70}$$

2. *The P household's consumption of the numeraire good is a constant c^{P*} that satisfies*

$$\frac{\beta \alpha_C^{kg} \bar{K}^g \gamma_g^*}{\bar{Y}^*} \left[\bar{\omega}\left(1-\eta\right) c^{P*} + \alpha_C^y\right] \tag{71}$$
$$= k_{gcP}^{PV} + \alpha_C^k \bar{\omega}\left(1-\eta\right) c^{P*} - \frac{\bar{c}^{PV}}{\bar{k}^{PV}} \left[\frac{\bar{\omega}\eta}{\Psi}\left(c^{P*}\right)^{1-\alpha_T^X} + \alpha_T^y\right] \left(c^{P*}\right)^{2\alpha_T^X}$$

3. *Numeraire output is equal to*

$$Y_t^* = \left(\frac{q_t^*}{\alpha_T^X}\right)^{\frac{\alpha_T^y \alpha_T^X}{\alpha_C^y \alpha_C^{kg} - \alpha_U}} \left(c^{P*}\right)^{-\alpha_{cP'}^{PV}} \bar{Y}^{PV} \tag{72}$$

where $\bar{Y}^{PV}$ is a positive constant depending on parameters.

4. *The C energy consumption by the P households takes the form*

$$e_t^{C,P*} = \frac{\left(q_t^*\right)^{\alpha_{ecp}^{PV}}}{\left(c^{P*}\right)^{\alpha_{cP'}^{PV} - \alpha_C^k}} \omega_P \bar{e}_{PV}^{CP} \tag{73}$$

for positive constants α_{ecp}^{PV} and $\bar{e}_{PV}^{CP}$ (when α_C^{kg} is large enough).

5. *The T energy consumption by the P households satisfies*

$$e_t^{T,P*} = \frac{\left(q_t^*\right)^{\alpha_{eTPq}}}{\left(c^{P*}\right)^{\alpha_{cePT}^{PV} - 1}} \omega_P \bar{e}_{PV}^{TP} \tag{74}$$

being α_{cePT}^{PV} a positive constant depending on technological parameters and

$$\alpha_{eTPq} \equiv \left(\frac{\alpha_T^y}{\alpha_C^y \alpha_C^{kg} - \alpha_U} - 1\right) \alpha_T^X$$

This proposition states that there is a long-run equilibrium with balanced growth for public capital, numeraire output, and clean energy. In such equilibrium, long-run growth rates do not depend on the political weights of each type of household. Yet, the level of public capital stock does depend positively on the N household electoral weight. Kawamura (2017) in fact shows that during the transition towards the path described in (69), the level of the stock of public capital is also increasing in the product of the electoral weight of the P households and the externality parameter ζ, that measures the external cost to the P households of the production of traditional energy. Yet, given that such parameter is constant, as it occurs with the P- household consumption of the numeraire good, then the constant term tend to vanish in the very long run, at least compared to the term containing the international price of the resource. This is why the long-run growth rate of public capital does not depend on these electoral weights.

On the other hand, the levels (not the long-run rate of growth) of energy consumption by the P households do depend on the Phousehold electoral weight, as it is expected. The correlation between the traditional energy consumption and the international price of the fossil resource is not clearly negative or positive. It depends on the share of each type of energy in the production of the numeraire output. In particular, the long-run elasticity of P's traditional energy consumption with respect to the international price of the resource is negative, for example, if the share of traditional energy in the GDP production is low enough. Yet, unlike the case of the benevolent and committed policy maker, the impact of the international price of the resource on the long run consumption of traditional energy is ambiguous. Finally, it can be shown (see Kawamura, 2017 for details) that the scalar that determines the level of numeraire output, $\bar{Y}^{PV}$, is decreasing in both electoral weights.

6 Policy discussion

Results from the last sections pose several issues with rich policy dimensions. The first clear point is related to the comparison between the solution of the benevolent and committed policy-maker with the one coming from the electoral competition between the two parties. In particular, Kawamura (2017) shows that the first of those two equilibria imply a long-run faster growth in the stock of public capital than the second one if and only if the rate of growth of the fossil-resource international price is larger than a threshold value that inversely depends on the international interest rate and whose elasticity with respect to that interest rate is decreasing in the share of the fossil resource in the production of traditional energy. On the other hand, it is also shown that the numeraire output increases faster in the long-run politico-economic equilibrium with probabilistic voting than under the Ramsey allocation.

Those results above show that electoral competition may be a factor that enhances energy policies that lead to long run economic growth. Even though the transition towards that long-run path may differ from that of the Ramsey equilibrium, which seems smoother, in the long-run equilibrium this intrinsic electoral competition generates incentives to increase steadily the stock of public capital, allowing for long-run growth not only in the non-traditional energy sector but also in the numeraire sector. Part of this result relies on the assumption of perfect commitment within the period for the winning party. Of course, replacing this assumption may lead to a different outcome, although such replacement depends on how to break the indeterminacy that a no-commitment assumption implies in terms of policy choices. The best known alternative, as mentioned above, is the assumption of two parties representing each the interests of one of the two types of households, as assumed by Azzimonti (2011, 2015). Yet, such change of assumption in the electoral competition stage may introduce arbitrarily too oscillating dynamics for policy and macroeconomic performance variables. This discussion already suggests the importance of certain institutions that at least ensure a minimum of commitment levels by the parties that win elections, together with political environments that provides stronger conditions for competing in policies[15].

Another interesting point to stress is the incentive that increasing international prices of fossil resources poses on policy-makers to increase public infrastructure investment that allows growth in the non-traditional energy sector as well as in the production of general goods (GDP). A-priori, this result emphasizes that both a committed and benevolent government and a party that wins a competitive election would devote an important fraction of fiscal revenues to increase infrastructure in clean energy sources (especially, infrastructure that ensures distribution of sources like eolic and solar energy) or even in hydroelectric projects (that obviously need an important amount of capital from public sources). It is noticeable that the main force that works in favor of investing in public capital in this politico-economic equilibrium is the type of electoral competition between parties (given their preferences to be in power). The timing of this electoral competition implies that voters end up choosing the platform (policies) that induce allocations that are most preferred. Thus, the candidates (each party or politician) sets policy proposals that intends to maximize a linear combination of both households's welfare, where the weights correspond to the characteristics of the political disagreement that each type of household has between the two candidates. Comparing this type of electoral competition with others where other dimensions such as politician's charisma receive heavier weight (which seem to be more relevant in LAC countries) seems to impose some word of caution about how close the long-run performance from the election-shaped policies is relative to that from a benevolent and committed policy-maker.

In other dimensions, that long-run equilibrium result may also have implications for other sources of energy. For countries such as Argentina the existence of gigantic reservoirs of shale oil and shale gas[16], the results of public infrastructure and non-traditional energy production being increasing in the international price of the fossil resource in the model may have a different meaning[17]. As it is well-known, the extraction of those non-standard forms of oil and gas entails large previous investment. Therefore, an increase in the international price of traditional forms of oil and gas may induce policy-makers to provide such large investments from public sources to increase the production of shale-oil and shale-gas-based energy. On the other hand, as long as shale-oil and shale-gas energy sources become productive substitutes of the traditional oil and gas-based energy in GDP production, then such public investment in shale oil and gas may build conditions for an increase in the growth trend of

[15] Currently, an important dimension of political competition entails more "leadership" perceptions and "charisma" rather than more fundamental policy contents, especially in Emerging Market countries such as those in LAC. This model suggests that political reforms should emphasize such more fundamental competition rather than the "charisma" dimension. Of course, this paper is completely silent on how this change may be implemented.

[16] As it is well-known, the main reservoir of shale gas and shale oil is located in Vaca Muerta, in the north-west side of the Argentine Patagonian region.

[17] I am particularly indebted to Walter Cont, who explicitly suggested this implication for the Argentine case from the results of the model.

the economy. Of course, this implication uses the results of a model that ignores risk or uncertainty, especially regarding shocks that may impose incentives against public investment. Including lack of certainty may clearly change some of those results, since the incentives to increase public investment may compete with other uses of public funds when adverse shocks threaten current consumption by households, which may be relevant especially for the poor households. Yet, the positive correlation between output growth and public capital, on the one hand, with the international price of the fossil resource, on the other, suggests at least that for countries with important stocks of shale gas and shale oil sound political institutions may lead policy-makers to prioritize investment in those non-conventional forms of oil and gas to ensure provision of energy to consumers and producers.

Another interesting policy implication is referred to the dynamics of prices. Equations (50) and (51), on the one hand, and equations (65) and (66) on the other, provide a useful guidance for linking energy prices and other exogenous variables and parameters. This guidance is important since in most countries final-use energy prices are publicly regulated. Of course, this model does not separate between production and distribution of energy, and also assumes a perfectly competitive market. Clearly issues of natural monopolies were ignored in the model. Yet, such equations strongly suggest the convenience of linking at least a fraction of energy prices to the main upstream source of energy. It is not the same problem to price fossil-based energy than the non-fossil-based energy. These four expressions strongly suggest that the former should be clearly positively correlated to the resource price, while the latter should be negatively correlated to the same resource price. More generally, for tariff regulators, those equations may be useful to understand which other factors or parameters are important to include in such tariffs, such as the environmental (welfare) cost of fossil-based energy production.

7 Concluding remarks

This paper reported results from a macroeconomic (dynamic general equilibrium based) model with energy analysis (Kawamura (2017)) that extends a growing literature on macroeconomics and energy. The main innovations from that literature are as follows: first, the inclusion of energy as a consumption good; second, the inclusion of two types of households, one naturally interpreted as poor. The third innovation is possibly the most relevant here, which is the use of political competition under the form of probabilistic voting (with one-period commitment) in dynamic macroeconomic models as in Sleet and Yeltekin (2008). The goal of this last innovation is to understand how different allocations and energy prices and policies differ from a more idealistic constrained-optimal policy with commitment (which is the traditional benchmark of the macroeconomic literature on energy and environment issues). The main lesson so far is that actual consumption may be much more volatile (which is an obvious consequence of how the incumbent decides in the model) than at the Ramsey allocation. Another lesson is the deep asymmetry for an allocation and energy price between the governments. A change in party ruling the economy may lead to a big departure regarding how taxes and subsidies induce an allocation which is very different from what it would have been had the same incumbent remained one more period.

The main message of this model is that public investment seems to be an important fiscal tool to promote both clean-energy (or, at least, energy alternatives to fossil-based sources) production and consumption, as well as long-term GDP growth, as long as such public infrastructure constitutes a key factor in producing such type of energy. Subsidy rates on consumption of such types of energy do not seem to play a central role in the long-term trend of production of energy and GDP. It only affects each type of household's level of energy consumption. Yet, the effectiveness of public investment policies depends on the goals and implementation constraints by the policy-maker. This paper assumes both a completely benevolent, omniscient and perfectly committed policy maker and an electoral competition process between two parties that care about winning the election but where voters (households) choose candidates according to policy proposals. The model predicts that such electoral competition does provide enough incentives to these parties to set policies that induce a long-term path with growth in the non-traditional energy sector and the GDP sector, as long as fossil-resource international prices grow. Clearly, the political side of this model also abstracts from other political-economy issues related to energy production and especially on non-renewable resource extractions. Rent appropriation[18], government expropriation, taxation time inconsistency and even corruption are usually very important policy-related phenomena that are absent in this research proposal. Other possible relevant energy-related questions not addressed here are related to the possible impact of policy regulations and performance (in terms of production and international trade balance in the energy sector) such as Barril and Navajas (2015) and Kawamura (2016) in the case of Argentina. Of course, future research may include some of these issues into a model like the one proposed here, but only as an extension of a well studied model with heterogeneous households.

Some of the assumptions in this model may not be completely satisfactory. For example, the level of substitutability between energy consumption goods in households's preferences or in the GDP technology implied by the Cobb-Douglas case considered here may not fit well enough the empirical evidence available in several countries (mostly corresponding to developed ones). Departure from those and other assumptions surely implies the impossibility of getting a qualitative precision on equilibrium properties, forcing a quantitative response. Yet, quantitative work with this type of models is not easy when dealing with developing economies, as it is well known, due to the lack of information for reliable calibrations. In this regard, then, this more qualitative approach does not seem useless to start understanding how political factors affect the way energy policies and energy performance interact with more standard macro variables such as output. Also, the deterministic version of the model allowed for a qualitative analysis in the very long run, another important issue when thinking about the design of energy policies, especially public investment in the energy sector, and long run growth.

There are several other extensions (and uses) of this model. Simpler versions of this

[18]For these issues studied in different other modelling frameworks see the book by Hogan and Sturzenegger (2010), Manzano and Monaldi (2008), among others.

model assuming for example that energy is not used for producing other goods may serve as a basis for introducing different assumptions on the technology of production of different types of energy. An extension not considered here is the presence of a foreign lender that may be ready to lend funds (numeraire good) for public infrastructure investment, rather than taking funds out of tax revenues. This extension is crucial when analyzing the role of regional development banks in facilitating the road to cleaner energy sources and eventually even more growth in the long run, or else if such loans for public infrastructure should be more carefully designed to avoid possible manipulations by the policy makers, especially when the latter are either self-interested or else they only represent a subset of the population. This extension is left for future research.

Also, another dimension not considered in this simple model is the domestic extraction of the fossil resource. Several LAC countries are actually oil and gas producers. For such countries, energy policies also include the dimension of public investment and other tax / subsidy decisions on the fossil-resource extraction. Thus, future versions of this model should include some domestic extraction sector. There are several forms to include such extraction technology. Some papers such as Golosov et al (2014) assume a very simple linear extraction technology. The latter clearly differs from more complete but sophisticated models of resource extractions, such as in Campbell and Lindner (1985) and especially Deacon (1993). As of the problem of the speed of the resource extraction, papers such as Osmundsen (1998), Epaulard and Pommeret (2003), Manzano (2000), Zhang (1997) or even ideas in the classic survey by Heaps and Helliwell (1985) would serve as background for the specific microeconomic foundations for the decision of resource extraction.

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