ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

DEPARTMENT OF ECONOMICS

ISSUES IN PUBLIC POLICY

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Athens, June 2014

A dissertation submitted to the Department of Economics of the Athens University of Economics and Business in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics

To my beloved family

CONTENTS

INTRODUCTION

The economic research on public policy is the study of the effect of government policy on economic welfare, efficiency, and equity. It builds on the theory of welfare economics and is ultimately used as a tool to improve social welfare. The premise is whether or not the government should intervene, and to what extent, in the various economics markets. Inherently, this study involves the analysis and implementation of government policies on taxation and revenues, as well as on expenditures, which are policies collectively referred to as public finance. The study of the governmental role in market failures, externalities, and redistribution policies is also central in this strand of research.

The literature on economic public policy is particularly popular and its seeds are found in the genesis of the principle of economics as a social science. Adam Smith and Ricardo present different elements of taxation in the Wealth of Nations (1776) and the Principles of Political Economy and Taxation (1817), respectively. This vast literature has ever since been mixed with many, if not with all, other mainstream aspects of economic literature and includes research of both theoretical and empirical nature.

The purpose of this thesis is to analyze three novel questions on public policy in a way that these cover all four main aspects of public economics (Musgrave, 2008), namely (i) the theory and application of public finance, (ii) the analysis and design of public policy, (iii) the distributional effects of taxation and government expenditures, and (iv) the analysis of market and government failure. Specifically, in the first chapter we analyze the role of taxation in a Ramsey-type model with endogenous labor, where there exists a negative environmental externality. In the second chapter we examine the impact of environmental awareness on the households' labor supply decisions and consumption of polluting goods. Finally, the third chapter deals with the effect of labor, consumption and capital tax rates on income inequality. The emphasis is place on the mere effect of the levels of these tax rates in isolation from each other, but rather on the effect of their ratios (relative tax rates) on income inequality.

In the following paragraphs we describe in detail each chapter, by offering our motivation and the main results. We also briefly discuss the interconnection between the three chapters.

I. Endogenous labor in a Ramsey model with environmental externality

In the recent years, there is a growing literature on macroeconomic dynamic models examining the effect of environmental externalities in a standard neoclassical economy. This strand of literature assumes that households maximize their consumption-based utility, by internalizing the effect of the environmental externalities of the production process (see e.g., Angelopoulos, Economides, and Philippopoulos, 2013; Vella, Dioikitopoulos, and Kalyvitis, 2014).

A common characteristic of these models is that the labor/leisure decisions of households are exogenous. We suggest that endogenizing the labor/leisure choices of households is important for two reasons that motivate our work. The first concerns the increased wave of public interest for environmental quality. Examples for this interest can be found in the workings of labor unions even from the late 1960s. However, these movements have significantly intensified after the Fukushima disaster in 2011 and took the form of protests against the supply of labor in polluting jobs (e.g., in nuclear factories). The second motivational factor is related to social status. In a world of increasing concern about environmental quality, especially in high-income economics, having a heavily polluting job can be adversely related to status. Thus, there could be a positive correlation between social-status and labor supply for greener jobs.

To this end, in the first chapter of this thesis we examine the long-run properties of a dynamic general equilibrium model with endogenous labor and a negative environmental externality in a Ramsey-type economy. The endogeneity of labor creates an additional channel of substitution between environmental quality and labor, besides the channel of substitution between environmental quality and consumption. This characteristic of our model allows studying the impact of a change in the relative weights of the variables in the utility function on households' decision variables.

We find that a positive shock in the weight on environmental quality, which we define as the household's environmental awareness, improves environmental quality and could lead to either an increase or decrease in output, consumption, and labor. This is mainly based on whether there is an associated change in the weight on consumption or labor by households.

An interesting feature of the model is that the existence of the environmental externality gives a non-zero capital tax in the long run. This happens because capital tax constitutes a way for the benevolent Ramsey planner to extract revenues generated by a polluting activity and use these revenues for abatement policy to improve environmental quality. When the pollution is zero, the model is equivalent to the standard model of optimal dynamic taxation (Chamley, 1985; Judd, 1986). Hence, in our model with an environmental externality, we obtain a second-order Chamley-Judd result, where the capital tax is always positive and responds only to changes in environmental parameters.

II. Environmental awareness, labor supply, and consumption: Empirical evidence from micro data.

In the second chapter, we examine empirically two of the interesting theoretical predictions of the model of the first chapter. Specifically, we opt to identify whether there is a causal relation running from environmental awareness to (i) the consumption and (ii) the labor supply of households.

The motivation for this empirical chapter is twofold. The first factor is related to the anecdotal evidence, suggesting an increasing role for the environmental concerns/awareness on the consumption, spending, and working habits of individuals and households. For example, we will show in Chapter 2 that in numerous Eurobarometer issues on the European public opinions, the consumption patterns of European citizens are increasingly affected by environmental concerns. Further, the citizens, especially in the high-income economies, are switching their labor and leisure attitudes toward greener activities that are substantially less destructive for the environment. In many cases, such as the recent call of the German government to close down all the nuclear factories by 2022, the social planners adopt such policies.

The second motivational factor is related to the predictions of the theoretical model of the first chapter. Indeed, the relevant impulse response functions of the Ramsey economy reveal that an increase in the weight placed by households on environmental quality (i.e. a rise in environmental awareness), along with an accompanied decline in the weight on consumption, leads to a decline in the supply of labor, even when the weight on labor/leisure is constant.

Overall, Chapter 2 is the first study that examines, using household-level survey data from the United States, the effect of environmental awareness on the labor supply and consumption of households. We measure environmental awareness with the decision to make environmental donations and we have explicit data on the hours of labor offered by individuals and their levels of consumption for both polluting and less polluting goods. Further, the richness of our sample allow us to utilize the properties of a multilevel cross-sectional data set and control for all the macroeconomic, policy, institutional, and regulatory elements that might similarly affect households, through the use of regional fixed effects.

We find that environmental awareness has a negative and economically significant effect on labor supply. The respective impact on consumption of polluting goods is also negative, but less robust in terms of statistical significance. Our results highlight the importance of understanding the microeconomic foundations of household behavior related to environment and verify the theoretical considerations of the first chapter, especially with respect to the labor/leisure decisions of households.

Importantly, environmentally aware households choose to work less because they internalize the harmful effects of their jobs on the environment and are willing to tradeoff work hours with environmental quality. Moreover, we find that whether the agent is occupied in a polluting industry or not does not change the effect of environmental awareness on both work hours and polluting consumption.

III. Relative effective taxation and income inequality: Evidence from OECD countries

In the third chapter, we empirically study the effect of labor, consumption, and capital tax rates on income inequality. There exists a very large literature on the determinants of income inequality, with fiscal policy being a significant part of this. For example, in the 1980s there was growing recognition among global organizations like the World Bank and the IMF that structural adjustment programs should have an inequality flavor (e.g., IMF, 1995; IMF, 2014). In Chapter 3 we review the related literature on taxation and income inequality and show that the main conclusion concerns the redistributive nature of the income taxes and the regressive nature of the consumption taxes.

A natural extension of this line of research is to look into the relative taxes, i.e. the ratios between capital, income, and consumption taxes. Indeed, at the theoretical level, a number of studies show that what matters for the redistribution of income is the relative level of different taxes and not the various forms of taxes independently from each other. This has been the essence of the early work of Harberger (1962), but more recent studies (e.g., Freitas, 2012) explicit model economies where the policy maker chooses optimally between at least two tax instruments.

To the best of our knowledge there is no empirical literature on the effect of relative taxes on income inequality. This is probably due to the severe difficulty in comparing homogeneous types of taxation between different countries. Thus, we contribute to this literature by using a panel data set of effective tax rates that are directly comparable across OECD countries. This is a unique sample that covers the years 1970-2001. We also use a carefully selected measure of income inequality that combines information from both the Gini and Theil indices.

We find that only the effective labor tax rate exerts a negative impact on income inequality, a result stemming primarily from the redistributional effects of the incorporated social contributions. In contrast, the relative tax rates play an important role in determining income inequality. Specifically, increasing the tax burden on labor relative to capital leads to higher income inequality. This finding is amplified when social contributions are excluded from the effective labor tax rate. Similar findings are obtained when (i) the labor to consumption tax rate ratio declines and (ii) the ratio of consumption to capital tax rate ratio increases. The most important reduction in income inequality comes from an increase in the labor to consumption tax ratio. Finally, we find that as countries become more economically developed and, thus, institutionally stronger, the impact of the relative tax rates on income inequality declines or even reverses in sign.

The third chapter is not directly related to the two preceding chapters of this thesis, but is has a significant indirect relation with them, especially with the first chapter. Specifically, understanding empirically the link between the tax rate structure and income inequality can help design optimal tax policies that pursue the increase of economic activity and restrain the growth of income inequality. Our findings indicate that this dual objective is particularly challenging for the less wealthy countries as they show that any attempt to increase the relative tax burden on labor or consumption (to counterbalance the decline in capital tax rates) are likely to increase income inequality. Our results also point to the crucial role of institutions, in the sense that the quality of institutions can increase the efficiency of redistributive policies, thereby alleviating any undesirable effects of tax rate changes on income distribution. Therefore, policy makers should aim for a more efficient use of relative taxation by enhancing its reach and making sure spending is not wasted.

Chapter 1
Endogenous labor in a Ramsey model with environmental externality

1.1 Introduction

Considering the role of environmental quality as a public good in dynamic macroeconomic models is gaining a lot of ground over the last two decades. The premise is that governments levy an environmental tax to, inter alia, prevent environmental degradation. Moreover, the increasing environmental awareness of citizens pressures the governments to reconsider their environmental policies. For example, the Fukushima nuclear disaster in 2011 strengthened considerably the share of people opposing the use of nuclear power (BBC, 2011). The German government decided to shut down all nuclear plants by 2022, despite the obvious impact of this decision on output and employment, especially given the surging economic turmoil in the European Union during the same period. Such decisions place inevitably the role of environmental awareness in a central position within the labor decisions of households and fiscal decisions of governments.

The purpose of this chapter is to study the relation between the weight economic agents place on environmental quality (environmental awareness) and on their decision-making regarding consumption and labor. Our setup augments the seminal models of Chamley (1986) and Judd (1985), henceforth Chamley-Judd, by adding an environmental externality to an economy in which both labor and consumption are determined endogenously.

The representative economy consists of a large number of identical infinitely-lived households, whose utility depends on private consumption, labor, and the stock of environmental quality. The households consume, save, and produce a single good. Output produced yields environmental pollution and this worsens environmental quality, which is assumed to be a public good. In other words, private agents do not internalize the effects of their actions on environmental quality. The decentralized equilibrium is inefficient and policy intervention is justified. A Ramsey-type planner intervenes and chooses the best competitive equilibrium for this problem.

The main novelty of our model is that the labor-leisure decision of households is included in the consumer preferences. Indeed, to the best of our knowledge, there is no other study that examines the interplay between an environmental externality and labor-leisure decisions in a model similar to that of Chamley-Judd. Our novelty is important for two main reasons.

First, our analysis allows examining the response of labor supply to changes in the beliefs and attitudes of households with respect to environmental awareness. This is quite important in light of the developments in many countries against production activities that are particularly harmful for the environment. The response of many European countries to the Fukushima disaster and the response of multiple labor unions even from the 1960s further motivate our theoretical model, as they are suggestive of a reduced labor supply to environmentally harmful jobs.

Second, the relation between labor supply and environmental awareness is possibly related to the employees' social status, i.e. the nature of the job is placing the employee in a particular cast. This idea is central in theories of social stratification and class at least since the times of Marx and Weber. In other words, as environmental awareness increases, the labor supply linked to environmentally harmful activities is lower because of the lower social status given to such production activities.

The Chamley-Judd result, which is particularly relevant for our analysis, states that in a steady state there should be no wedge between the intertemporal rate of substitution and the marginal rate of transformation, i.e. the optimal tax on capital is zero. In our framework, individuals face two types of trade-offs, one between consumption and environmental quality and another between labor-leisure and environmental quality. This is mostly observed in the real business cycle (RBC) literature, where labor is endogenous, and creates an additional choice for intratemporal substitution (see e.g., Kydland and Prescott, 1982; Plosser, 1989).

Our economy yields a unique steady state, which we shock to obtain the paths of our endogenous variables. We are mainly interested in the parameters characterizing the impact of environmental awareness of households on environmental quality, consumption, and labor-leisure decisions. The benevolent Ramsey planner can choose the best competitive equilibrium implied by the tax policies. We find that an increase in environmental awareness always leads to higher environmental quality irrespective of whether higher environmental awareness comes at the expense of less weight on consumption or labor. Using simple indicators of environmental quality and awareness, we show that the model is realistic in terms of stylized facts. In particular, our model is consistent with recent trends in environmental awareness and agrees with the data describing the relation between environmental quality (measured by concentration of sulfur dioxide) and awareness (measured by indices constructed on the basis of information from the World Values Survey). A qualitatively similar effect on environmental quality also prevails when increases in the weight on consumption are accompanied by a decrease in the weight on labor and constant environmental awareness. The same shocks have interesting implications for the actual levels of consumption and labor. Indeed, an increase in households' environmental awareness can have either a positive or a negative effect on consumption and labor. When environmental awareness is accompanied by a decrease in the weight on consumption, consumption and labor decrease. In contrast, when the increase in environmental awareness comes at the expense of a lower weight on labor, consumption and labor increase.

We also show that the capital tax is determined in equilibrium, among others, by the environmental parameter of our model related to pollution. More specifically, in the case where the pollution externality is zero, the capital tax is also zero and our result is identical to the Chamley-Judd result. In contrast, in the presence of a negative environmental externality, the tax on capital is positive and the Chamley-Judd result does not hold. We could say that in our model with an environmental externality, we obtain a second-order Chamley-Judd result, where the capital tax is always positive. The same result is derived by Guo and Lansing (1999) under imperfect competition, Economides and Philippopoulos (2008) for environmental externalities and Kocherlakota (2010) under uncertainty.

The rest of the chapter is organized as follows. In the next section we describe our model. In Section 1.2 we present the related literature and in Section 1.3 we describe the economy. In Section 1.4 we solve for the decentralized competitive equilibrium, check for its stability, and compare our model with the equivalent model with endogenous labor using impulse responses and stylized facts. In Section 1.6 we solve for the Ramsey equilibrium and check for its stability. Moreover, we compare our result with the Chamley-Judd result, offer some numerical examples, and illustrate the dynamic responses to permanent shocks in some of the parameters of interest in our model. Section 1.6 concludes.

1.2 Related Literature

Our work is related to a flourishing literature on growth and environmental quality. In this section we aim to discuss mainly the most relevant for our objectives theoretical papers and subsequently link our work to a larger literature on endogenous growth models with fiscal policy and other models on macroeconomic dynamics that produce a zero capital tax rate in the long run.

Sandmo (1975) was probably the first to consider a general equilibrium model involving commodity taxation with one of the commodities having an externality. Bovenberg and Goulder (2002) review this literature by offering an analysis of a wide range of models where environmental quality is a central element. Bovenberg and Smulders (1995) were among the first to explore the link between environmental quality and economic growth in an endogenous growth model that incorporates pollution-augmenting technological change. In their model, the natural environment is included as a renewable resource. In particular, they model how technological improvements enable production to occur with lower levels of pollution and with a more effective use of renewable resources. They show that, within this framework, environmental quality and cleaner technology represent good reasons for policy intervention, as both have a public good character. Further, the revenues from pollution taxes (or pollution permits) exceed public expenditures on the development of pollution-enhancing technology, and that the optimal size of the government budget tends to increase when environmental awareness increases.

In their recent work, Angelopoulos, Economides, and Philippopoulos (2010) use a micro-founded dynamic stochastic general equilibrium (DSGE) model with exogenous labor to rank different environmental policy instruments under uncertainty. By comparing second-best environmental policies using taxes, permits, and numerical rules for emissions, they find that permits, despite their popularity among politicians, are always the worst regime. Moreover, taxes are better under economic uncertainty, while rules are better under the presence of high environmental uncertainty.

In turn, Xepapadeas (2005) proposes a number of relevant models to study the effects of environmental concerns on economic growth. The important assumptions in these models relate to the choice of emissions in an optimal way and to the devotion of resources to pollution abatement. In the former case, a Ramsey model with emissions as an input in the production process can generate economic growth with constant pollution. In the latter case the nexus between economic growth and environmental quality depends on the type and productivity of the particular abatement policy.

Economides and Philippopoulos (2008) study the case where the government imposes distorting taxes on polluting activities and then uses the revenues to finance infrastructure services and cleanup policy. The findings of this paper are quite interesting from our point of view, as environmental awareness is positively linked with growth-enhancing fiscal policies by the social planner.

Vella, Dioikitopoulos, and Kalyvitis (2014) study the allocation of tax revenues between infrastructure and environmental investment in a general-equilibrium growth model with endogenous subjective discounting. They show that when the government increases environmental spending, environmental quality improves and economic growth increases, although production technology is not affected by the environment. Moreover, when the agents' environmental awareness increases, it is optimal to perform green spending reforms.

A common characteristic of these papers is that the utility function is independent from the labor/leisure decision of households. This is quite important in our view, given the movement over at least the last fifty years of households to demand higher environmental quality. This demand should be translated to increased environmental awareness, which in turn can have a bearing on the labor/leisure decision of households, in addition to the consumption decisions that are studied in the aforementioned models.

In fact, in the endogenous-growth model literature with fiscal policy (but without environmental quality) many studies indeed treat labor supply as inelastic. This treatment limits certain aspects of fiscal policy (Turnovsky, 2000). More precisely, De Hek (2006) studies an endogenous growth model with physical capital and suggests that the flexibility of the labor supply induces agents to spend more or less time on leisure activities, depending on the relative sizes of the substitution and income effects. Flores and Graves (2008) argue that exogeneity of labor generally results in undervaluation of utility due to increases in the provision of a public good. Phrased differently, if the labor supply is exogenously fixed, the Le Chatelier-Samuelson principle holds. Intuitively, this follows from the fact that an increase in the cost of the public good will result in a higher marginal valuation of ordinary private goods, as their quantities are reduced to pay for the public good, and this in turn will result in a higher marginal cost of leisure.

Our model is also related to an important literature on macroeconomic dynamics. Of particular interest in our case is the class of models predicting the existence of a zero capital tax rate in the long run. The seminal contributions in this literature are the studies by Chamley (1986) and Judd (1985). In similar settings, these studies show that if equilibrium has an asymptotic steady state, then the optimal policy is to set the capital tax rate equal to zero. In other words, any positive capital income tax does not help in any efficiency or redistributive goals in the steady state.

However, a more recent literature shows that the optimal factor taxation may involve positive tax rates on both capital and labor incomes (e.g. Correia, 1996; Stiglitz, 1987; Jones, Manuelli, and Rossi, 1997; Acemoglu, Golosov, and Tsyvinski, 2011). Debortoli and Gomes (2012), examine the case where the choice between capital vs labor income taxation can be intrinsically related to the allocation of expenditure across different public goods. In their model, taxing profits constitutes a way to extract the private rents generated by public capital. As a result, corporate taxes are positive also in the long-run, as opposed to the optimality of zero capital taxation in Judd (1985) and Chamley (1986). Evidently, in all of these papers, a non-zero capital tax arises due to constraints on the government to impose taxes.

In our model, to be presented in the following section, these constraints are not needed; the mere existence of an environmental externality yields this result. It is precisely with this issue in mind, as well as the fact that no previous study has examined the role of environmental awareness on the labor/leisure decisions of households (as we suggested above), that we proceed with our model.

1.3 Description of the economy

We study and economy where households, firms, and the government In this section we describe our basic framework, placing particular emphasis on the fact that labor decisions are endogenous in the individual's preferences and their weight in the utility function is proportional to the weight placed on consumption and environmental quality. Subsequently, we describe the decisions of firms, the laws of motion of natural resources, the resources constraint, and we close the model with the government budget constraint. We opt to model a Ramsey-type economy within a framework, which assumes that consumption, labor, and environmental quality decisions are derived in the context of intertemporal utility-maximizing households and perfectly-competitive, profit-maximizing firms (Gradus and Smulders, 1993; Beltratti, 1996; Xepapadeas, 2005).[1]

[1] Instead, we could use an endogenous growth model. In this case, the endogenously-determined growth rates can remain positive if the productivity of capital does not approach zero in the long run or, in a model

1.3.1 Households

We assume that the population size is constant and equal to one. The representative infinitely-lived household maximizes the intertemporal utility

$$\sum_{t=0}^{\infty} \beta^t U(c_t, lt, Q_t), \tag{1.1}$$

where c is the private consumption, l is leisure, Q is the stock of environmental quality, and $\beta \in (0,1)$ is the time discount factor. Following Angelopoulos, Economides and Philippopoulos (2010) and Ladron-de-Guevara, Ortigueira, Santos (1997), the utility function has the form[2]:

$$U(c_t, l_t, Q_t) = \frac{[(c_t)^{\mu_1}(l_t)^{\mu_2}(Q_t)^{1-\mu_1-\mu_2}]^{1-\sigma}}{1-\sigma}, \tag{1.2}$$

where $\mu_1, \mu_2, \mu_3 = 1 - \mu_1 - \mu_2 \in (0,1)$ are preference parameters that assign weights to consumption, leisure, and environmental quality, respectively, and $\sigma \geq 0$ is the intertemporal elasticity of substitution. The household is endowed with one unit of time that can be used for leisure l_t or labor n_t, thus $n_t + l_t = 1$. Each household can save in the form of capital k_t, receiving a rate of return r_t. Also, households supply labor services and receive labor income $w_t n_t$. Further, they receive dividends π_t. Each household has to pay a portion of its income to the government in the form of linear taxes. τ_t^k is the tax on capital income and τ_t^l is the tax on labor income. The flow budget constraint of the household is

$$k_{t+1} - (1-\delta^k)k_t + c_t = y_t = (1-\tau_t^l)w_t n_t + (1-\tau_t^k)r_t k_t + \pi_t, \tag{1.3}$$

where k_{t+1} is the end-of-period capital stock, k_t is the beginning-of-period capital stock, and $\delta^k \in$[0,1] is the rate of capital depreciation.

with human capital, the production of knowledge is characterized by decreasing returns (see e.g., Smulders, 2000).

[2]This is a Constant Relative Risk Aversion (CRRA) utility function which is broadly used by the relevant literature as it is increasing and concave in consumption, labor and environmental quality to ensure interior solutions (see Xepapadeas, 2005; Angelopoulos, Economides, and Philippopoulos, 2013; Vella, Dioikitopoulos, and Kalyvitis, 2014).

From all the above it follows that the household's problem is to

$$\max_{\{c_t,l_t,k_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \frac{[(c_t)^{\mu_1}(1-n_t)^{\mu_2}(Q_t)^{1-\mu_1-\mu_2}]^{1-\sigma}}{1-\sigma},$$

$$s.t. k_{t+1} - (1-\delta^k)k_t + c_t = (1-\tau_t^l)w_t n_t + (1-\tau_t^k)r_t k_t + \pi_t,$$

taking w_t, r_t, Q_t, and the policy as given. The problem expressed in a Langrangian form is given by:

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \{ \frac{[(c_t)^{\mu_1}(1-n_t)^{\mu_2}(Q_t)^{1-\mu_1-\mu_2}]^{1-\sigma}}{1-\sigma}$$
$$+\lambda_t[(1-\tau_t^l)w_t n_t + (1-\tau_t^k)r_t k_t + (1-\delta^k)k_t + \pi_t - c_t - k_{t+1}]\}$$

The FOCs for this problem with respect to c_t, n_t, and k_{t+1} respectively are

$$U_{c_t} = \lambda_t, \tag{1.4}$$

$$\frac{c_t}{1-n_t} = \frac{\mu_1}{\mu_2}(1-\tau_t^l)w_t, \tag{1.5}$$

$$U_{c_t} = \beta U_{c_{t+1}}[(1-\tau_{t+1}^k)r_{t+1} + 1 - \delta^k]. \tag{1.6}$$

The first equation gives us the marginal utility of consumption and the second equation is the FOC with respect to labor. The last equation is the Euler equation for capital. It tells us that along an optimal path, the marginal utility from consumption at any point in time is equal to the opportunity cost of consumption. More specifically, the Euler equation says that, on the one hand, the household must be indifferent between consuming one more unit today and, on the other, saving that unit and consuming in the future. If the household consumes today, it gets the marginal utility of consumption today, i.e. the left-hand side of the equation, U_{c_t}. If, in contrast, the household saves that unit, it gets to consume

$[(1-\tau^k_{t+1})r_{t+1} + 1 - \delta^k]$ units in the future, each giving him $U_{c_{t+1}}$ extra units of utility. Because this utility comes in the future, it must be discounted by the weight β. That's the right side of the Euler equation. The fact that these two sides must be equal is what guarantees that the household is indifferent to consuming today versus in the future.

1.3.2 Firms

The production function of the representative firm is a neoclassical function with constant returns to scale of the form

$$y_t = Ak_t^a n_t^{1-a} = f(k_t, n_t), \tag{1.7}$$

where $a \in (0,1)$ is the output elasticity of private capital and $1-a \in (0,1)$ is the private elasticity of labor.[3] A is total factor productivity or the index of production technology, which is assumed to be constant. In each period, the representative firm takes w_t and r_t as given[4] and uses capital and labor services from households. The objective of the firm is to

$$\max_{\{l_t, k_{t+1}\}_{t=0}^{\infty}} \pi_t = y_t - w_t n_t - r_t k_t. \tag{1.8}$$

The FOCs for this problem are

$$r_t = a\frac{y_t}{k_t}, \tag{1.9}$$

$$w_t = (1-a)\frac{y_t}{n_t}, \tag{1.10}$$

so that $\pi = 0$.

[3] In our model pollution does not enter the production function. There is a large literature that introduces pollution in the production function by assuming that pollution or environmental quality affects amenities and productivity (Brock, 1973; Xepapadeas, 2005; Aznar and Ruiz-Tamarit, 2005).

[4] As firms are price takers, our model assumes perfect competition in the product market. This is a usual assumption in the Ramsey literature; however, one can alternatively assume an imperfectly competitive product market in the fashion of Bilbiie, Ghironi, and Melitz (2012) and Colciago (2013). Models of imperfect competition are also very common the micro literature involving environmental regulation (e.g. Fowlie, 2009).

1.3.3 Laws of motion of natural resources

The evolution of the stock of environmental quality is given by

$$Q_{t+1} = (1-\delta^q)\bar{Q} + \delta^q Q_t - p_t + \nu g, \tag{1.11}$$

where $\bar{Q} \geq 0$ is the environmental quality without pollution, p_t is the current pollution flow, $\delta^q \in$[0,1] is the degree of environmental persistence. g is the exogenous public spending that also includes spending on abatement activities and $\nu \geq 0$ shows how public abatement spending is transformed into units of renewable resources. The flow of pollution is caused by the production of output and is given by

$$p_t = \phi A k_t^a n_t^{1-a}, \tag{1.12}$$

where ϕ is an index of pollution technology and reflects the emissions per unit of output.[5]Note that we assume a linear relation among economic activity, pollution, cleanup policy, and the change in natural resources (e.g. John and Pecchenino, 1994; Jouvet, Michel, and Rotillon, 2005).[6]

1.3.4 Government budget constraint

The government collects revenues from the taxes on labor and capital.[7] On the expenditure side, it finances an exogenous stream of government purchases, $\{g_t\}_{t=0}^{\infty}$, that include spending

[5]In our setting we assume that the index of pollution technology is a parameter. Instead, it could be assumed to depend on private or public investment in greener technology, or to follow a stochastic process. If the latter is the case then our model would be stochastic as in Angelopoulos, Economides, and Philippopoulos (2013).

[6]We could instead assume that the environmental impacts of pollution and abatement are not separable. See Palivos and Varvarigos, 2010.

[7]We could additionally assume that the model includes government debt. This would imply that on the expenditure side of the government budget constraint there would be a term associated with the reimbursement of the debt contracted in the previous period (the rate of debt times the level of the debt), while on the revenue side there would be a term associated with the financing of new debt. In addition, the household's budget constraint (1.3) will be formatted accordingly (Economides and Philippopoulos, 2008; Ljungqvist and Sargent, 2004).

on abatement policy. Assuming a balanced budget, we have

$$g_t = Ak_t^a n_t^{1-a}[a\tau_t^k + (1-a)\tau_t^l]. \tag{1.13}$$

1.3.5 Resource constraint (technology)

Output can be consumed by households, used to increase the capital stock, and/or used by the government. Therefore, the resource constraint is

$$c_t + g_t + k_{t+1} = y_t + (1-\delta^k)k_t. \tag{1.14}$$

1.4 Decentralized competitive equilibrium (DCE)

We solve the problem described in Section 2 for a Decentralized Competitive Equilibrium (DCE) in which (i) households maximize welfare, (ii) firms maximize profits, (iii) all constraints are satisfied and, (iv) all markets clear. The DCE of the above economy is given by the following equations:

$$\frac{c_t}{1-n_t} = \frac{\mu_1}{\mu_2}(1-\tau_t^l)w_t, \tag{1.15}$$

$$U_{c_t} = \beta U_{c_{t+1}}[(1-\tau_{t+1}^k)r_{t+1} + 1 - \delta^k], \tag{1.16}$$

$$Q_{t+1} = (1-\delta^q)\bar{Q} + \delta^q Q_t - \phi A k_t^a n_t^{1-a} + \nu g_t, \tag{1.17}$$

$$g_t = Ak_t^a n_t^{1-a}[a\tau_t^k + (1-a)\tau_t^l], \tag{1.18}$$

$$c_t + k_{t+1} = Ak_t^a n_t^{1-a} - g_t + (1-\delta^k)k_t. \tag{1.19}$$

This is a four-equation system in $\{c_t, n_t, Q_{t+1}, k_{t+1}\}_{t=0}^{\infty}$. The DCE holds for given initial conditions for the stock variables k_0 and Q_0, the FOCs of the representative firm's problem, the exogenous variables A and ϕ, for given policy (which is summarized by the tax rates τ^l, τ^k), and provided that $r_t = aAk_t^{a-1}n_t^{1-a}$, $w_t = (1-a)Ak_t^a n_t^{-a}$. Therefore, we have a system of five equations in $\{c_t, n_t, k_{t+1}, Q_{t+1}\}_{t=0}^{\infty}$. We can obtain the long-run DCE if we simply drop the time subscripts.

We can obtain the long-run DCE if we simply drop the time subscripts:

$$\begin{aligned}
\frac{c}{1-n} &= \frac{\mu_1}{\mu_2}(1-\tau^l)(1-a)Ak^a n^{-a} \\
1 &= \beta[(1-\tau^k)aAk^{a-1}n^{1-a} + 1 - \delta^k] \\
0 &= (1-\delta^q)\bar{Q} - (1-\delta^q)Q - \varphi Ak^a n^{1-a} + \nu g \\
c + \delta^k k &= Ak^a n^{1-a} - g
\end{aligned}$$

1.4.1 Steady state

To find the steady state we solve the above system for c^*, n^*, Q^*, k^*, where the asterisk denotes the steady state value of each variable.

$$\begin{aligned}
\frac{c^*}{1-n^*} &= \frac{\mu_1}{\mu_2}(1-\tau^l)(1-a)A(k^*)^a(n^*)^{-a} \\
1 &= \beta[(1-\tau^k)aA(k^*)^a(n^*)^{1-a} + 1 - \delta^k] \\
0 &= (1-\delta^q)\bar{Q} - (1-\delta^q)Q^* - \varphi A(k^*)^a(n^*)^{1-a} + \nu g \\
c^* + \delta^k(k^*)^a &= A(k^*)^a(n^*)^{1-a} - g
\end{aligned}$$

Therefore, we have that

$$c^* = \frac{\mu_1}{\mu_2}(1-\tau^l)(1-a)AX^{\frac{a}{a-1}}(1 - X^{\frac{1}{1-a}}k^*), \tag{1.20}$$

$$n^* = X^{\frac{1}{1-a}}k^*, \tag{1.21}$$

$$Q^* = \bar{Q} - k^*\frac{AX}{(1-\delta^q)}[\phi - \nu a\tau^k - \nu(1-a)\tau^l], \tag{1.22}$$

where

$$k^* = \frac{\frac{\mu_1}{\mu_2}(1-a)AX^{\frac{a}{a-1}}(1-\tau^l)}{\delta^k - [\frac{\mu_1}{\mu_2}(1-a) + a(1-\tau^k) + (1-a)(1-\tau^l)]AX} \tag{1.23}$$

and

$$X = \frac{(1-\beta+\beta\delta^k)}{a\beta A(1-\tau^k)}. \tag{1.24}$$

1.4.2 Linearization

By substituting Eq. (1.18) in the rest of the equations of the DCE, the DCE becomes:

$$c_t + k_{t+1} = Ak_t^a n_t^{1-a} - Ak_t^a n_t^{1-a}[a\tau_t^k + (1-a)\tau_t^l] + (1-\delta^k)k_t, \tag{1.25}$$

$$\frac{c_t}{1-n_t} = \frac{\mu_1}{\mu_2}(1-\tau_t^l)(1-a)Ak_t^a n_t^{-a}, \tag{1.26}$$

$$U_{c_t} = \beta U_{c_{t+1}}[(1-\tau_{t+1}^k)aAk_{t+1}^{a-1}n_{t+1}^{1-a} + 1 - \delta^k], \tag{1.27}$$

$$Q_{t+1} = (1-\delta^q)\bar{Q} + \delta^q Q_t - \phi Ak_t^a n_t^{1-a} + \nu Ak_t^a n_t^{1-a}[a\tau_t^k + (1-a)\tau_t^l]. \tag{1.28}$$

We linearize the system of Eqs. (1.25)-(1.28) around the steady state, using Taylor's Theorem. We assume that the exogenous stream of government spending, $\{g_t\}_{t=0}^{\infty}$, and the exogenous tax rates, τ^l and τ^k, in the long run take the values from the respective Ramsey optimization problem. We find that the model is stable (for the proof, see Appendix 1.A).

1.4.3 Parameter values

To shock the DCE we use the parameter values usually found in the literature (e.g., Angelopoulos, Economides, and Philippopoulos, 2013; Vella, Dioikitopoulos, and Kalyvitis, 2014; King and Rebelo, 1999) and reported in Table 1. The value used for the capital share in production, α, is 0.33 and the annual depreciation rate of capital is 0.1 (equivalent to 0.025 on a quarterly basis. For the curvature parameter in utility function, σ (*i.e.* the intertemporal elasticity of substitution), we use a value equal to 2. There is considerable uncertainty regarding the true value of σ, with Hansen and Singleton (1983) estimating it to be between 0 and 2. Our results are qualitatively the same when using values equal to

0.9 or 1.1. The time discount factor is set equal to 0.97, a value obtained by setting the long-term government bond yield, r_b, equal to 0.03, which is the approximate value for the U.S. economy at the end of 2013. β is then obtained from the formula $r_b = (1-\beta)/\beta$. We set the long-run total factor productivity, A, is normalized to one (e.g. King and Rebelo, 1999).

Regarding the parameters in the motion for environmental quality we choose a relatively high persistence parameter, $\delta^q = 0.9$, and normalize the level of environmental quality without economic activity, $\bar{Q}$, to be equal to one (e.g. Angelopoulos, Economides, and Philippopoulos, 2013). Using a much lower value equal to 0.15 (Vella, Dioikitopoulos, and Kalyvitis, 2014) the model produces qualitatively similar results. Moreover, we set $\phi = 0.5$ based on OECD statistics, the CO_2 emissions (kg per PPP$ of GDP) equal to 0.4 for the U.S. economy in the period 2009-2013. Given that this concerns only the CO_2 emissions, we believe that our value off 0.5 is quite realistic.

We assume that $\nu[\alpha\tau^k + (1-\alpha)\tau^l] - \phi < 0$, which is a non-trivial solution area (when $\nu[\alpha\tau^k + (1-\alpha)\tau^l] - \phi < 0$, we have a "too good to be true" economy in the sense that effective cleanup policy, $\nu[\alpha\tau^k + (1-\alpha)\tau^l]$, is stronger than the polluting effect of production, ϕ). We study various values for ν, which reflect different levels of public sector efficiency with respect to abatement policy. For example, we set $\nu = 0.7$, 0.75, and 1 and the results are qualitatively the same. Finally, we assume that the weight on environmental quality is equivalent to that of the previous literature on public goods (e.g. Debortoli and Gomez, 2012) and equal to 0.4, while we give an equal weight of 0.3 to consumption and leisure. We carry out an extensive sensitivity analysis in this respect, which we mostly discuss in the relevant impulse responses of the Ramsey model below.

1.4.4 Impulse responses

To see how the endogeneity of labor affects the equilibrium results, we compare the impulse responses due to permanent unitary changes in the weights of the variables in the utility function for the models with exogenous and endogenous labor. This allows studying the impact of changing weights on the households' decision variables. For the model with exogenous labor, where labor is set equal to one, there are two variables in the utility function and two respective weights, one on consumption and one on environmental quality. Under the assumption of constant returns to scale, a permanent unitary increase (decrease) in the weight on environmental quality results to an equivalent decrease (increase) in the weight on consumption. This has a permanent positive (negative) effect only on welfare because this weight is not included in the steady state equations characterizing the rest of the variables. The rest of the parameters of our model, i.e. ϕ, ν, σ, and β, affect all the endogenous variables.

By introducing endogenous labor in the utility function an extra channel of substitution is created between environmental quality and the leisure-labor decision. This allows studying the impact of changes in the respective weights on households' decision variables for both consumption-environmental awareness and labor-environmental awareness. Given that these weights now affect all endogenous variables in our model, we can examine the relevant impulse responses. We take all three possible combinations when consumption and leisure are substitutes (i.e., an increase in the one variable decreases the other). Initially, all variables are at their steady-state levels.

Figures 1 to 3 show how the decentralized competitive equilibrium with endogenous labor reacts to a (i) 1% increase in the weight on environmental quality with a simultaneous 1% decrease in the weight on consumption (labor remains unchanged), (ii) 1% increase in the weight on environmental quality with a simultaneous 1% decrease in the weight on labor-leisure (consumption remains unchanged), and (iii) 1% increase in the weight on consumption with a simultaneous 1% decrease in leibor-leisure (environmental awareness remains unchanged).

We find that an increase in the weight on environmental quality with a relative decrease in the weight on consumption (leisure-labor decision), keeping the third weight steady, leads to a higher (lower) environmental quality and a higher level of welfare. In the case where we change the weights on consumption and leisure-labor decision in opposite directions all endogenous variables increase except from environmental quality and welfare. Note that these findings are the result of the competitive equilibrium, where agents do not internalize the effect of their actions. Therefore, the economy could move to a better state and policy intervention is justified. This naturally leads to the relevant Ramsey-type model, which we examine in the next section.

1.5 The Ramsey problem with an environmental externality

There are many competitive equilibria, indexed by different government policies. The Ramsey problem is to choose the competitive equilibrium that maximizes the expression

$$\sum_{t=0}^{\infty} \beta^t \frac{[(c_t)^{\mu_1}(1-n_t)^{\mu_2}(Q_t)^{1-\mu_1-\mu_2}]^{1-\sigma}}{1-\sigma}$$

subject to the DCE. Therefore, the Ramsey planner chooses the best competitive equilibrium, taking as given $\{g_t\}_{t=0}^{\infty}$, k_0, Q_0, and bounds on taxes, i.e. $0 \leq \tau_t^k < 1$ and $0 \leq \tau_t^l < 1$. Moreover, the period zero tax rates, $0 \leq \tau_0^k < 1$ and $0 \leq \tau_0^l < 1$ are also taken as given, otherwise the government would be able to impose lump-sum taxes which would make the policy problem first-best.

Ramsey taxation provides a compelling argument against taxing capital income in the long run in dynamic macroeconomic models. Here we show how this result changes when we consider a negative environmental externality. Following Chamley (1986), we replace r_t and w_t with net factor prices $\widetilde{r}_t$ and $\widetilde{w}_t$, where

$$\widetilde{r}_t = (1-\tau_t^k) r_t, \quad (1.29)$$

$$\widetilde{w}_t = (1-\tau_t^l) w_t. \quad (1.30)$$

In this way, the four instruments $\tau_t^k, \tau_t^l, r_t, w_t$ reduce to two.[8] Thus, the DCE is given by

$$\frac{c_t}{1-n_t} = \frac{\mu_1}{\mu_2}\widetilde{w}_t, \tag{1.31}$$

$$U_{c_t} = \beta U_{c_{t+1}}(\widetilde{r}_{t+1} + 1 - \delta^k), \tag{1.32}$$

$$Q_{t+1} = (1-\delta^q)\bar{Q} + \delta^q Q_t - \phi A k_t^a n_t^{1-a} + \nu g, \tag{1.33}$$

$$g = A k_t^a n_t^{1-a} - \widetilde{w}_t n_t - \widetilde{r}_t k_t, \tag{1.34}$$

$$c_t + k_{t+1} - (1-\delta^k)k_t + g = A k_t^a n_t^{1-a}. \tag{1.35}$$

The Ramsey problem in a Langrangian form becomes:

$$\begin{aligned}
\mathcal{L} = &\sum_{t=0}^{\infty} \beta^t \{U(c_t, n_t, Q_t) \\
&+\lambda_t(\frac{\mu_1}{\mu_2}\widetilde{w}_t - \frac{c_t}{1-n_t}) \\
&+\psi_t[\beta U_{c_{t+1}}[\widetilde{r}_{t+1} + 1 - \delta^k] - U_{c_t}] \\
&+\zeta_t[(1-\delta^q)\bar{Q} + \delta^q Q_t - \varphi A k_t^a n_t^{1-a} + \nu g - Q_{t+1}] \\
&+\xi_t(A k_t^a n_t^{1-a} - \widetilde{w}_t n_t + \widetilde{r}_t k_t - g) \\
&+\chi_t[A k_t^a n_t^{1-a} - c_t - k_{t+1} + (1-\delta^k)k_t - g]\}
\end{aligned}$$

where $\{\lambda_t, \psi_t, \zeta_t, \xi_t, \chi_t\}_{t=0}^{\infty}$ are sequences of Langrange multipliers or the the shadow prices associated with the households' first order condition with respect to capital, the Euler equation, government budget constraint, household budget constraint, and law of motion of environmental quality, respectively. The FOCs of the above problem with respect to c_t, n_t, Q_{t+1}, k_{t+1}, $\tilde{r}_t$, $\tilde{w}_t$, λ_t, ψ_t, ζ_t, ξ_t, and χ_t respectively are:

$$U_{c_t} = \frac{1}{1-n_t}\lambda_t + \chi_t - \partial U_{c_t}/\partial c_t[\psi_{t-1}(\widetilde{r}_t + 1 - \delta) - \psi_t], \tag{1.36}$$

[8] This approach, where tax rates are the government decision variables, is known as the dual approach. The primal approach would be to do the exact opposite, i.e. eliminate all prices and taxes so that the government could use quantities as controls (Lucas and Stokey, 1989; Jones, Manuelli, and Rossi, 1997). Both approaches yield the same results for policies and allocations (Economides, Philippopoulos, and Vassilatos, 2008).

$$U_{n_t} = \frac{c_t}{(1-n_t)^2}\lambda_t - (1-a)Ak_t^a n_t^{1-a}(\xi_t - \zeta_t\phi + \chi_t)$$
$$+\xi_t\widetilde{w}_t + \partial(U_{c_t}/\mu_1)/\partial n_t[\psi_t - \psi_{t-1}(\widetilde{r}_t + 1 - \delta)], \tag{1.37}$$

$$U_{Q_t}[\psi_t(\widetilde{r}_{t+1} + 1 - \delta^k) - \psi_{t+1}] = \frac{\zeta_t}{\beta} - U_{Q_{t+1}} - \zeta_{t+1}\delta^q, \tag{1.38}$$

$$\chi_t = \beta[\chi_{t+1}(f_{k_{t+1}} + 1 - \delta^k) + \xi_{t+1}(f_{k_{t+1}} - \widetilde{r}_{t+1}) - \zeta_{t+1}\phi f_k], \tag{1.39}$$

$$\xi_t k_t = \psi_{t-1}U_{c_t}, \tag{1.40}$$

$$\lambda_t\frac{\mu_1}{\mu_2} = \xi_t n_t, \tag{1.41}$$

$$\frac{\mu_1}{\mu_2}\widetilde{w}_t = \frac{c_t}{(1-n_t)}, \tag{1.42}$$

$$U_{c_t} = \beta U_{c_{t+1}}[\widetilde{r}_{t+1} + 1 - \delta^k], \tag{1.43}$$

$$Q_{t+1} = (1-\delta^q)\bar{Q} + \delta^q Q_t - \phi Ak_t^a n_t^{1-a} + \nu g_t, \tag{1.44}$$

$$Ak_t^a n_t^{1-a} - \widetilde{w}_t n_t - \widetilde{r}_t k_t = g_t, \tag{1.45}$$

$$c_t + k_{t+1} = Ak_t^a n_t^{1-a} + (1-\delta^k)k_t - g_t \tag{1.46}$$

Some considerations are in order. Eq. (1.39), the Euler equation, tells us that a marginal increase of capital investment in period t increases the amount of available goods in period $t+1$ by $(f_k + 1 - \delta)$, with social marginal value χ_{t+1}. Moreover, tax revenues increase by $(f_k - \widetilde{r}_{t+1})$, which enables the government to reduce its debt on other taxes by the same amount. This increase has a social marginal value equal to ξ_{t+1}, which is interpreted as the extra burden imposed to the society due to the existence of distortionary taxation. β is the discount factor in period $t+1$ and χ_t is the social marginal value of investment good in period t. Therefore, χ_t and ξ_t are positive for all t. Finally, we can see that the increase of capital investment worsens environmental quality by ϕf_k with social marginal value ζ_{t+1}.

We obtain the long-run conditions by dropping the time subscripts. To simplify the FOCs we set $\sigma = 1$ in the utility function $U(c_t, l_t, Q_t)$, which then limits to

$$U(c_t, l_t, Q_t) = \mu_1 \ln(c_t) + \mu_2 \ln(l_t) + (1 - \mu_1 - \mu_2) \ln(Q_t). \tag{1.47}$$

As we did with the DCE, we linearize the system of Eqs. (1.36)-(1.46) around the steady state using Taylor's Theorem. We use the same values for the parameters and we find that the model is stable (for details see Appendix 1.B). Once again there is a unique equilibrium and the economy converges to this through a saddle path.

1.5.1 The Chamley-Judd approach to the Ramsey problem

Eq. (1.39) reduces in the long run to

$$\beta[(r - \widetilde{r})\xi + (r + 1 - \delta)\chi - r\phi\zeta] = \chi. \tag{1.48}$$

From Eq. (1.43) it holds in the long run that $(1 - \delta) = \frac{1}{\beta} - \widetilde{r}$. By replacing this result into (1.48) and rearranging we have

$$(r - \widetilde{r})(\chi + \xi) - r\phi\zeta = 0. \tag{1.49}$$

We now consider two cases, where $\phi = 0$ and $\phi \neq 0$. In the first case the environmental externality is zero, and Eq. (1.49) becomes

$$\tau^k(\chi + \xi) = 0. \tag{1.50}$$

The marginal social value of goods χ is strictly positive and the marginal social value of reducing government taxes ξ is nonnegative, therefore r must be equal to $\widetilde{r}$, so that τ^k is equal to zero. This is the result of the papers by Chamley (1986) and Judd (1985).

We can see this result using a simple numerical example. In Table 1 we provide the parameter values and in Column I of Table 2 the results. The values used for the parameters are as in the DCE shocks introduced above. The findings show that $\tau^k = 0$ and the discounted welfare for $t = 100$ is

$$U^*(c,n,Q) = \frac{(1-\beta^t)}{(1-\beta)} U(c,n,Q) = \frac{(1-\beta^{100})}{(1-\beta)} \frac{(c^{\mu_1}(1-n)^{\mu_2} Q^{(1-\mu_1-\mu_2)})^{(1-\sigma)}}{(1-\sigma)}$$
$$= -53.76943282$$

In the case where $\phi \neq 0$ the first term of Eq. (1.49) is exactly the same with the Chamley-Judd result. The second term of Eq. (1.49) appears because of the positive environmental externality. By substituting $\widetilde{r}$ with $r(1-\tau^k)$ and by rearranging the terms we have that

$$\tau^k = \frac{\phi\zeta}{\chi + \xi}. \tag{1.51}$$

which is always positive. It must hold that $\tau^k < 1 \Leftrightarrow \frac{\phi\zeta}{\chi+\xi} < 1$, or $\phi\zeta < \chi + \xi$.[9]

In Column II of Table 1.2 we provide the results from the numerical example where ϕ is positive and equal to 0.5. The values of the parameters are as before. Evidently, τ^k is positive and discounted welfare in this case for $t = 100$ is given by

$$U^*(c,n,Q) = \frac{(1-\beta^t)}{(1-\beta)} U(c,n,Q) = \frac{(1-\beta^{100})}{(1-\beta)} \frac{(c^{\mu_1}(1-n)^{\mu_2} Q^{(1-\mu_1-\mu_2)})^{(1-\sigma)}}{(1-\sigma)}$$
$$= -86.12491269,$$

The presence of the environmental externality worsens environmental quality. Taxes increase and this leads to a lower level of utility, compared to the case where the environmental externality is equal to zero.

In our model with an environmental externality, taxing capital constitutes a way for the government to extract revenues generated by a polluting activity and use these revenues for abatement policy to improve the public good, i.e. the environmental quality. Thus, we obtain a second-order Chamley-Judd result, where the capital tax is always positive.

[9] This result remains the same even if we assume that the weight on environmental quality in the utility function of the agents is equal to zero.

1.5.2 Impulse response functions and stylized facts for the Ramsey economy

In this section we illustrate the dynamic response of the Ramsey economy to permanent unitary increases in certain parameters of our model. We begin by the equivalent shocks to the ones we present for the DCE in Section 1.3.3. Moreover, we study the responses due to a 1% increase in the weight on the pollution parameter ϕ and a 1% increase in the abatement technology ν.

Figure 4 shows how the economy responds to a 1% increase in the weight on environmental quality with a simultaneous 1% decrease in the weight on consumption. We observe that, in the long-run, output, consumption, and labor decrease. Therefore, there is a channel of substitution running from consumption to environmental quality. Agents care more about environmental quality, therefore they produce and consume less. For the same reason, they substitute labor supply with leisure or, in other words, the substitution effect dominates the income effect. In contrast capital increases, also given the decrease in capital tax. Further, to finance the exogenous government spending, there is an increase in the labor tax. Overall, these findings are robust to the changes in the parameters discussed in Section 1.4.3.

In turn, Figure 5 shows how the economy responds to a 1% increase in the weight on environmental quality with a simultaneous 1% decrease in the weight on labor-leisure. We observe that, in the long-run, consumption and labor increase, while capital and output fall. Intuitively, the labor tax falls while the capital tax rises. Once more, the increase in households' environmental awareness increases environmental quality, which leads to an increase in welfare. We should mention that small changes in the relative weights on consumption vs leisure produces a difference in the long-run level of consumption. Specifically, using a weight on leisure smaller that the weight on consumption (0.25 and 0.35, respectively) yields a decrease in the long-run consumption. This analysis might be more in line with the idea that households consume less when they become more environmentally aware.

Figure 6 shows how the economy responds to a 1% increase in the weight on consumption with a simultaneous 1% decrease in the weight on labor-leisure. We observe that, in the long-run, output, consumption, and labor increase. The increase of the output production increases pollution, environmental quality deteriorates and so does welfare. Capital tax increases and this is in line with the lower level of capital, while the lower labor tax is in line with the higher labor supply.

Figure 7 shows what happens when the pollution parameter ϕ increases by 1%. Firms use a more polluting technology for their production and, therefore, they care less for the environment. The social planner intervenes and increases the labor and capital taxes. This is the only case in our study where there is an actual decrease in the capital tax rate in the long run. This reduces the return on labor and, therefore, households choose to work more and consume less. The government spending for abatement policy increases, but this increase is not enough to offset the negative effects of the higher pollution externality. Thus, the environmental quality and welfare decrease.

The last parameter related to environmental awareness is the abatement technology ν (Figure 8). A positive 1% shock to this parameter implies that public abatement spending is transformed more effectively into units of renewable resources. Households spend more time in leisure activities and consume more. This increases the production of the polluting output, but the improvement of abatement technology completely offsets this negative effect. Moreover, with a more effective abatement policy, less government spending is needed to compensate for the negative effects of output production. Thus, the social planner reduces the labor tax. Environmental quality increases and the economy moves to a higher-welfare steady state.

Two main results become apparent from this exercise. First, an increase in the households' environmental awareness always leads to a higher environmental quality. Second, an increase in the households' environmental awareness can have both a positive and a negative effect on output, consumption, and labor, based on whether there is an associated change in the weight on consumption or labor. This provides further evidence that endogenizing labor is important to study the impact of environmental awareness on households' decisions.

These results are further supported by the stylized facts relating environmental awareness of households and environmental quality. Figure 9 illustrates this bivariate relationship using data from the World Values Survey and Yale's Environmental Performance Index. We measure environmental quality with the concentration of sulfur dioxide (SO_2). This is the measure most commonly employed in the related empirical literature for a number of reasons. First, air quality is one of the most important indicators of environmental quality and SO_2 is one of the "Criteria Air Contaminants" used by the United States Environmental Protection Agency, the World Bank, the OECD, and other authorities to describe air quality. Second, SO_2 is a major air pollutant and has significant effects on human health, ecosystems, and the economy. Third, SO_2 emissions can be controlled by altering the techniques of production. Fourth, reliable data are available for a large number of countries and over long time periods. Finally, Bernauer and Koubi (2009) show that most forms of air pollution (such as SO_2, CO_2, N_2O, and NO_x) behave quite similarly across countries and, thus, SO_2 captures general trends in overall air pollution.

As a measure of environmental awareness we use the relative information from the World Values Survey. More specifically, we an index by aggregating the responses to the following question:

- Income provision: would give part of my income for the environment, with variable/question code b001, for the years 2005-2007

An increase in the index constructed from this question implies that people are less willing to give part of their income for the environment, reflecting a decreasing environmental awareness. From Figure 9 we note that the relation between this aspect of environmental awareness and SO_2 is positive. The slope from this simple regression with robust standard errors is 14.3 and statistically significant at the 5% level. This means that as environmental awareness increases, the emissions of SO_2 decrease and, therefore, environmental quality increases.

6 Conclusions

This chapter builds on the literature of taxation of capital and labor to study a dynamic general equilibrium model with an environmental externality. In our model the households decide between consumption, labor, and environmental quality. Thus, there are two channels of substitution for environmental quality: that of consumption (as in previous literature) and that of labor-leisure.

Our model predicts that an increase in households' environmental awareness improves environmental quality and the same also holds when environmental awareness remains constant and the weight on consumption increases at the expense of the weight on labor. Using simple indicators of environmental quality and awareness, we show that this finding is in line with stylized facts. Moreover, an increase in environmental awareness yields lower consumption and labor when it is accompanied by a decrease in the weight on consumption, *ceteris paribus*. In contrast, an increase in environmental awareness has the exact opposite effect on consumption and labor when it is accompanied by a decrease in the weight on labor, *ceteris paribus*. Phrased differently, an increase in environmental awareness can have both positive or negative effects on consumption and labor based on the type of trade off in households' decisions.

We also find that, in our Ramsey model with an environmental externality, the optimal capital tax in the long run is non-zero. This happens because capital tax constitutes a way for the benevolent Ramsey planner to extract revenues generated by a polluting activity and use these revenues for abatement policy to improve environmental quality. As pollution decreases, the government reduces the capital tax rate to extract a smaller fraction of the rents. When the pollution externality is zero, the model is equivalent to the standard model of optimal dynamic taxation. In that case there are no capital rents produced by polluting activities, so the optimal steady-state capital tax rate is zero. Thus, our model without an environmental externality gives the result of a zero optimal capital tax, which is in line with the seminal contributions of Chamley (1985) and Judd (1986). In contrast, in our model with an environmental externality, we obtain a second-order Chamley-Judd result, where the capital tax is always positive. Hence, our result is in line with an important literature showing that the capital tax rate can differ from zero even in the long run (e.g. Economides and Philippopoulos, 2008).

Table 1.1

Parameter values for the numerical example

Parameter	Description	Value
a	Capital share in production	0.33
δ^k	Capital depreciation rate	0.1
σ	Curvature parameter in utility function	2
β	Time discount factor	0.97
μ_1	Consumption weight in utility function	0.3
μ_2	Leisure weight in the utility function	0.3
$\bar{Q}$	Environmental quality without pollution	1
δ^q	Persistence of environmental quality	0.9
A	Long-run total factor productivity	1
ϕ	Long-run pollution externality	0.5
ν	Transformation of spending into units of nature	0.75

Table 1.2

Long-run values when

Variable name	I ($\phi = 0$)	II ($\phi = 0.5$)
c	0.187	0.081
n	0.288	0.312
Q	2.146	0.928
k	1.146	0.241
τ^k	0.000	0.664
τ^l	0.502	0.617
λ	0.507	$0.337*10^{-2}$
ψ	0.160	$0.165*10^{-3}$
ζ	1.636	6.521
ξ	0.878	$0.712*10^{-2}$
χ	0.349	5.328

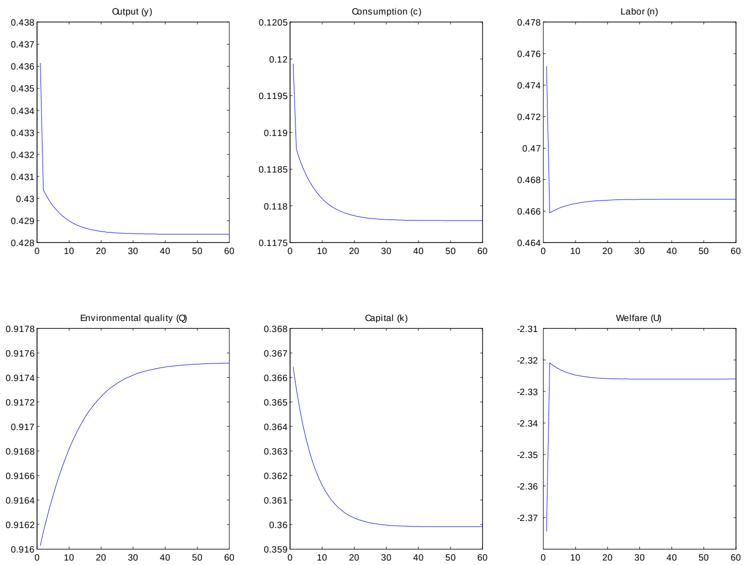

Figure 1: Response of the DCE with endogenous labor to an increase in μ_3, decrease in μ_1, with steady μ_2

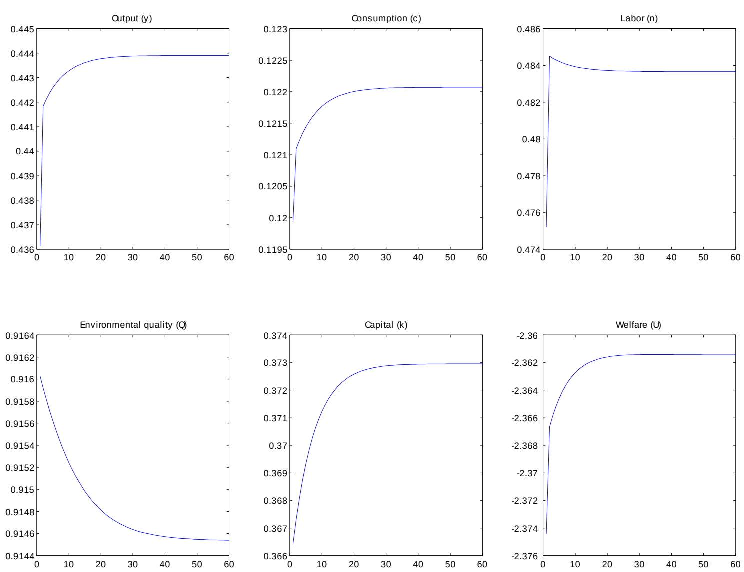

Figure 2: Response of the DCE with endogenous labor to an increase in μ_3, decrease in μ_2, with steady μ_1

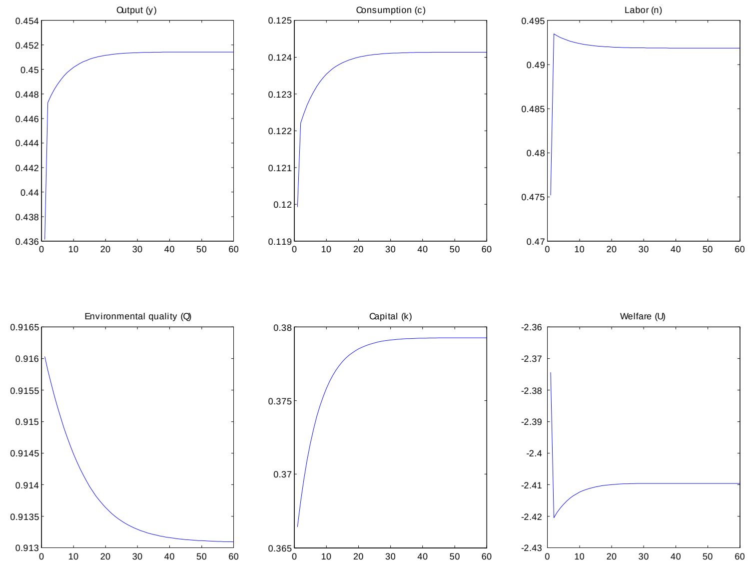

Figure 3: Response of the DCE with endogenous labor to an increase in μ_1, decrease in μ_2, with steady μ_3

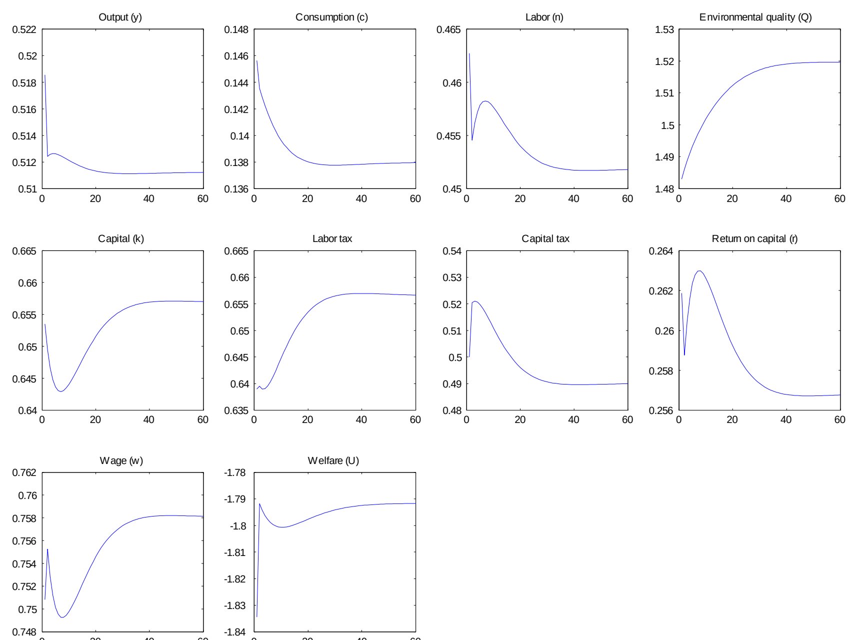

Figure 4: Response of Ramsey economy to an increase in μ_3, decrease in μ_1, with steady μ_2

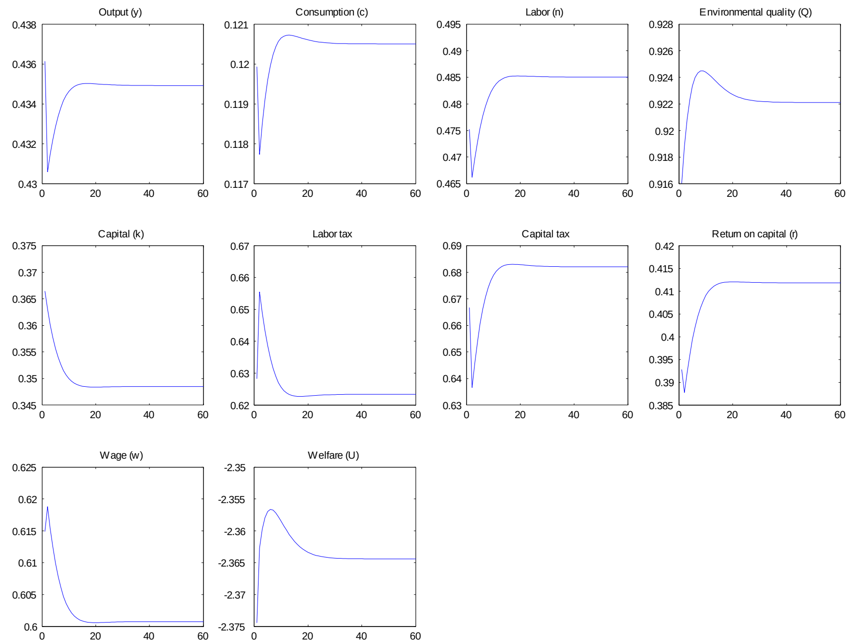

Figure 5: Response of Ramsey economy to an increase in μ_3, decrease in μ_2, with steady μ_1

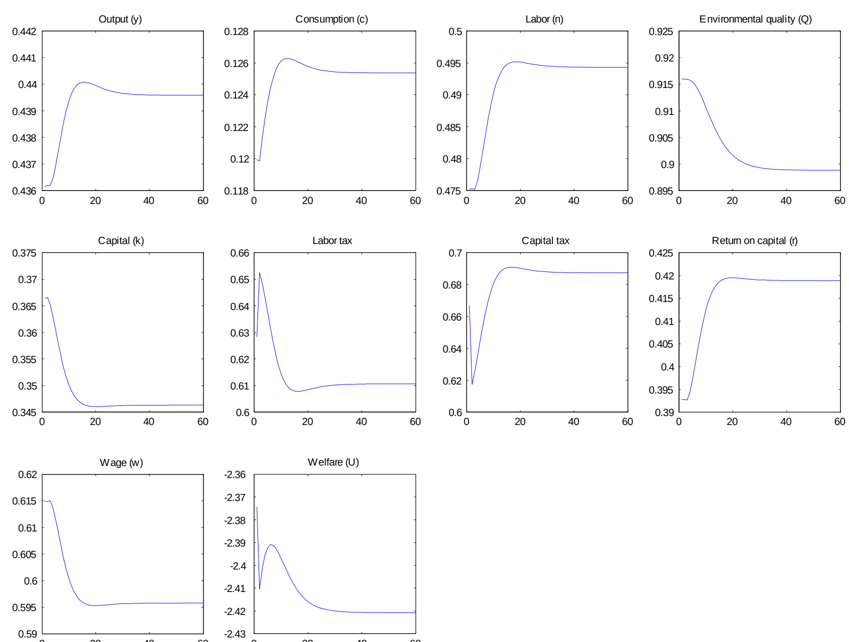

Figure 6: Response of Ramsey economy to an increase in μ_1, decrease in μ_2, with steady μ_3

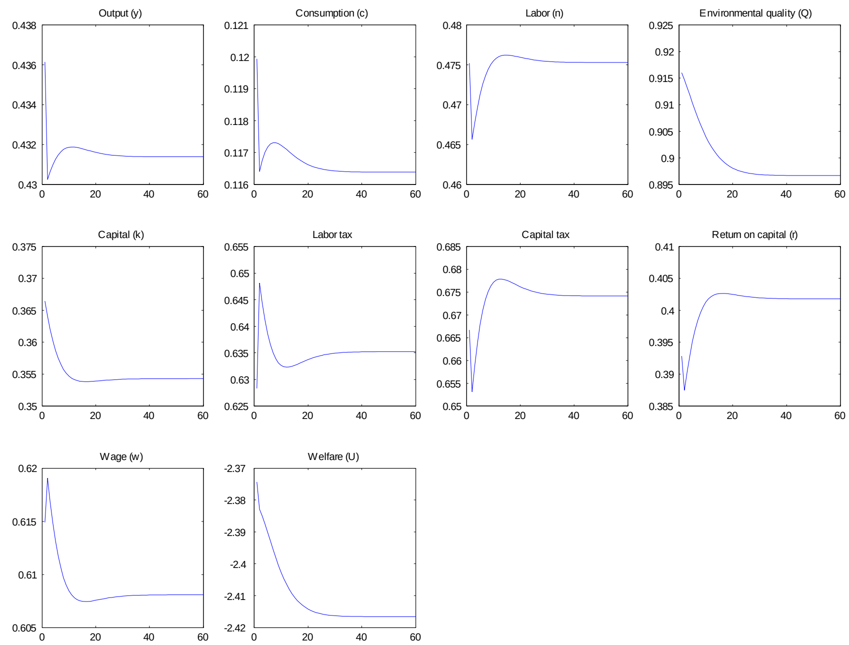

Figure 7: Response of Ramsey economy to 1% increase in the pollution parameter

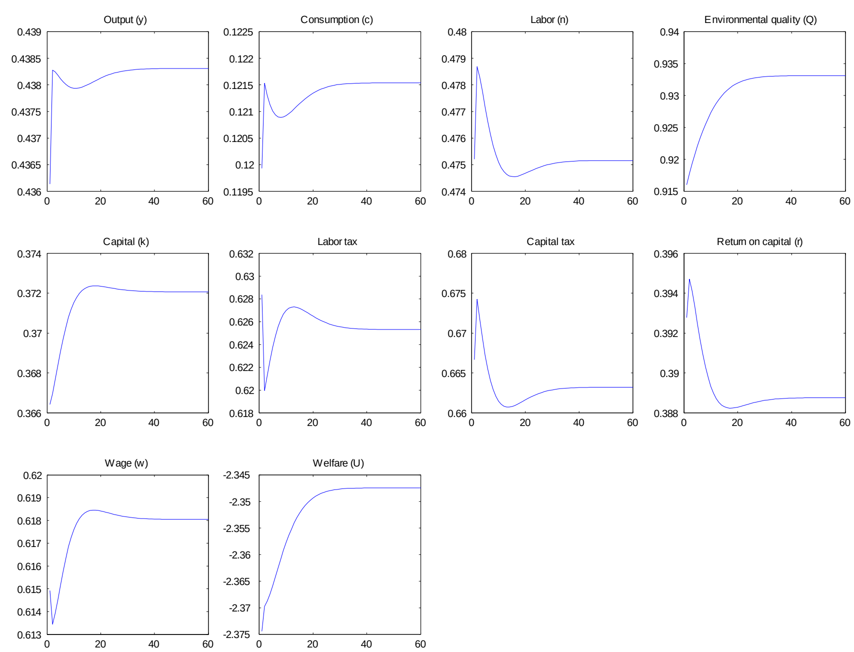

Figure 8: Response of Ramsey economy to 1% increase in the abatement technology

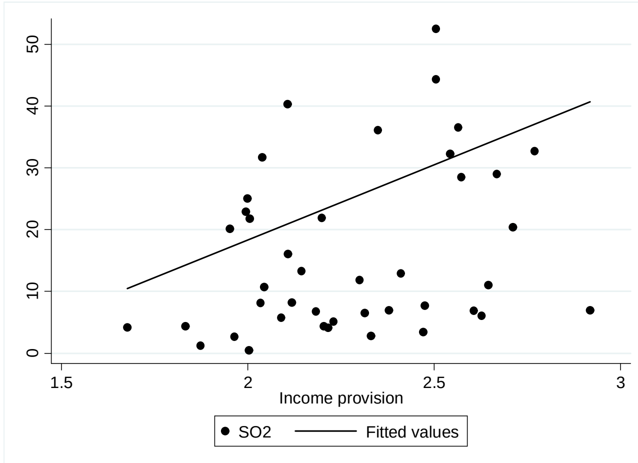

Figure 9: Income provision

Appendix 1.A: Linearization of the DCE

Eq. (26) becomes

$$f(c_t, k_{t+1}, k_t, n_t) = \hat{c}_t + \hat{k}_{t+1} + f_a \hat{n}_t + f_b \hat{k}_t = 0, \quad (1.A1)$$

where for any variable x of the system it holds that $\hat{x}_t = x_t - x^*$, with x^* being the steady state value of the variable and

$$f_a = f_{n_t}(\cdot) = [-A(1-a)(k^*)^a (n^*)^{-a}[1 - a\tau^k - (1-a)\tau^l]], \quad (1.A2)$$

$$f_b = f_{k_t}(\cdot) = [-[aA(k^*)^{a-1}(n^*)^{1-a}[1 - a\tau^k - (1-a)\tau^l] + (1-\delta^k)]]. \quad (1.A3)$$

Eq. (27) becomes

$$g(c_t, k_t, n_t) = \mu_2 \hat{c}_t + g_a \hat{n}_t + g_b \hat{k}_t = 0, \quad (1.A4)$$

where

$$g_a = g_{n_t}(\cdot) = [\mu_1 aA(k^*)^a (n^*)^{-a-1} + \mu_1 (1-a)A(k^*)^a (n^*)^{-a}](1-\tau^l)(1-a), \quad (1.A5)$$

$$g_b = g_{k_t}(\cdot) = [-\mu_1 (1-n^*)(1-a)aA(k^*)^{a-1}(n^*)^{-a}(1-\tau^l)]. \quad (1.A6)$$

Eq. (28) becomes

$$h(c_{t+1}, n_{t+1}, Q_{t+1}, k_{t+1}, c_t, n_t, Q_t) = h_a \hat{c}_{t+1} + h_b \hat{n}_{t+1} + h_c \hat{Q}_{t+1} \tag{1.A7}$$
$$+ h_d \hat{k}_{t+1} + h_e \hat{c}_t + h_f \hat{n}_t + h_g \hat{Q}_t = 0,$$

where

$$h_a = h_{c_{t+1}}(\cdot) = -[\beta[\mu_1(1-\sigma)-1](c^*)^{\mu_1(1-\sigma)-2}[(1-n^*)^{\mu_2}(Q^*)^{1-\mu_1-\mu_2}]^{1-\sigma}] \tag{1.A8}$$
$$[(1-\tau^k)aA(k^*)^{a-1}(n^*)^{1-a} + 1 - \delta^k],$$

$$h_b = h_{n_{t+1}}(\cdot) = [\beta\mu_2(1-\sigma)(c^*)^{\mu_1(1-\sigma)-1}(1-n^*)^{\mu_2(1-\sigma)-1}(Q^*)^{(1-\mu_1-\mu_2)(1-\sigma)} \tag{1.A9}$$
$$[(1-\tau^k)aA(k^*)^{a-1}(n^*)^{1-a} + 1 - \delta^k] - \beta(1-a)(c^*)^{\mu_1(1-\sigma)-1}$$
$$[(1-n^*)^{\mu_2}(Q^*)^{1-\mu_1-\mu_2}]^{1-\sigma}[(1-\tau^k)aA(k^*)^{a-1}(n^*)^{-a}],$$

$$h_c = h_{Q_{t+1}}(\cdot) = -[\beta(1-\mu_1-\mu_2)(1-\sigma)(c^*)^{\mu_1(1-\sigma)-1} \tag{1.A10}$$
$$(1-n^*)^{\mu_2(1-\sigma)}(Q^*)^{(1-\mu_1-\mu_2)(1-\sigma)-1}][(1-\tau^k)aA(k^*)^{a-1}(n^*)^{1-a} + 1 - \delta^k],$$

$$h_d = h_{k_{t+1}}(\cdot) = [-\beta(c^*)^{\mu_1(1-\sigma)-1}(1-n^*)^{\mu_2(1-\sigma)}(Q^*)^{(1-\mu_1-\mu_2)(1-\sigma)} \tag{1.A11}$$
$$(1-\tau^k)a(a-1)A(k^*)^{a-2}(n^*)^{1-a}],$$

$$h_e = h_{c_t}(\cdot) = [[\mu_1(1-\sigma)-1](c^*)^{\mu_1(1-\sigma)-2}[(1-n^*)^{\mu_2}(Q^*)^{1-\mu_1-\mu_2}]^{1-\sigma}, \tag{1.A12}$$

$$h_f = h_{n_t}(\cdot) = -[\mu_2(1-\sigma)(c^*)^{\mu_1(1-\sigma)-1}(1-n^*)^{\mu_2(1-\sigma)-1}(Q^*)^{(1-\mu_1-\mu_2)(1-\sigma)}], \tag{1.A13}$$

$$h_g = h_{Q_t}(\cdot) = [(1-\mu_1-\mu_2)(1-\sigma)(c^*)^{\mu_1(1-\sigma)-1}(1-n^*)^{\mu_2(1-\sigma)}(Q^*)^{(1-\mu_1-\mu_2)(1-\sigma)-1}]. \tag{1.A14}$$

Finally Eq. (29) becomes

$$m(Q_{t+1}, n_t, Q_t, k_t) = \delta^q \hat{Q}_t + m_a \hat{n}_t + m_b \hat{k}_t - \hat{Q}_{t+1} = 0, \tag{1.A15}$$

where

$$m_a = m_{n_t}(\cdot) = -A(1-a)(k^*)^a(n^*)^{-a}[v[a\tau^k + (1-a)\tau^l] - \phi], \tag{1.A16}$$

$$m_b = m_{k_t}(\cdot) = -aA(k^*)^{a-1}(n^*)^{1-a}[v[a\tau^k + (1-a)\tau^l] - \phi]. \tag{1.A17}$$

The 4 by 4 system in matrix notation is

$$\begin{bmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ -h_a & -h_b & -h_d & -h_c \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \hat{c}_{t+1} \\ \hat{n}_{t+1} \\ \hat{k}_{t+1} \\ \hat{Q}_{t+1} \end{bmatrix} = \begin{bmatrix} f_a & 1 & f_b & 0 \\ \mu_2 & g_a & g_b & 0 \\ h_f & h_e & 0 & h_g \\ m_a & 0 & m_b & \delta^q \end{bmatrix} \begin{bmatrix} \hat{c}_t \\ \hat{n}_t \\ \hat{k}_t \\ \hat{Q}_t \end{bmatrix} \Longleftrightarrow A\hat{X}_{t+1} = B\hat{X}_t.$$

One way to check the stability of equilibrium is with the approach of Blanchard and Kahn (1980). We observe that the second equation is a static equation. We substitute this equation into the other three equations of the system and the system becomes

$$\begin{bmatrix} 0 & 1 & 0 \\ h_1 & h_2 & h_c \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \hat{c}_{t+1} \\ \hat{k}_{t+1} \\ \hat{Q}_{t+1} \end{bmatrix} = \begin{bmatrix} f_1 & f_2 & 0 \\ h_3 & h_4 & -h_g \\ m_1 & m_2 & \delta^q \end{bmatrix} \begin{bmatrix} \hat{c}_t \\ \hat{k}_t \\ \hat{Q}_t \end{bmatrix} \Leftrightarrow E\hat{X}_{t+1} = F\hat{X}_t \Leftrightarrow \hat{X}_{t+1} = FE^{-1}\hat{X}_t \Leftrightarrow \hat{X}_{t+1} = C\hat{X}_t.$$

Using the parameter values in the paper of Angelopoulos, Economides, and Philippopoulos (2010), we find that there are two eigenvalues with module smaller than 1 for the backward looking variables $\hat{k}_t$ and $\hat{Q}_t$, and one eigenvalue with module larger than 1 for the forward looking variable $\hat{c}_t$. When we solve the 4 by 4 system using Dynare we find that the eigenvalue of n_t, which is a forward looking variable too, has module larger than 1. The Blanchard-Kahn conditions are satisfied and the model is stable. The steady state of the system is a saddle path, therefore it has a unique equilibrium.

Given that in the initial 4 by 4 system the matrix A is singular, we can also check its stability using the approach of Klein (2000). We first recover the generalized Schur decomposition of (A, B). We get the matrices of complex numbers Q and Z, such that

$S = QAZ$ and $T = QBZ$ are upper triangular, and $QQ' = ZZ' = I$. Then the dynamics equation can be rewritten as

$$AZZ'X_{t+1} = BZZ'X_t. \tag{1.A18}$$

Let us define $\varpi_t = Z'X_t$ to get

$$AZ\varpi_{t+1} = BZ\varpi_t \tag{1.A19}$$

and pre-multiply both sides by Q

$$QAZ\varpi_{t+1} = QBZ\varpi_t, \tag{1.A20}$$

which is equal to

$$S\varpi_{t+1} = T\varpi_t. \tag{1.A21}$$

$\frac{T_{ii}}{S_{ii}}$ are the generalized eigenvalues of the system. We find that we have two stable eigenvalues with modulus below unity, which are associated with the variables k_t and Q_t, and two unstable eigenvalues with modulus greater than unity, which are associated with the variables c_t and n_t. Therefore, the model is stable, the steady state of the system is a saddle path and it has a unique equilibrium.

Appendix 1.B: Linearization of the Ramsey model

For

$$U(c_t, l_t, Q_t) = \mu_1 \ln(c_t) + \mu_2 \ln(l_t) + (1 - \mu_1 - \mu_2) \ln(Q_t), \tag{1.B1}$$

the FOCs of the Ramsey problem become:

$$\mu_1 c_t - \frac{c_t^2 \lambda_t}{1-n_t} + \beta \psi_t \frac{\mu_1}{c_t^2} - c_t^2 \chi_t - \psi_{t-1} \frac{\mu_1}{c_t^2}[(1-\tau_t^k) A k_t^a n_t^{1-a} + 1 - \delta^k] = 0, \tag{1.B2}$$

$$(1-a) A k_t^a n_t^{-a}[\chi_t - \zeta_t \phi + \xi_t [a \tau_t^k + (1-a)\tau_t^l]] \tag{1.B3}$$

$$+\psi_{t-1} \frac{\mu_1}{c_t}(1-\tau_t^l) a(1-a) A k_t^{a-1} n_t^{-a}$$

$$-\frac{c_t \lambda_t}{(1-n_t)^2} - \lambda_t (1-\tau_t^l) \frac{\mu_1}{\mu_2} a(1-a) A k_t^a n_t^{-1-a} = 0,$$

$$\psi_t \frac{\mu_1}{c_{t+1}}(1-\tau_{t+1}^k) a(a-1) A k_{t+1}^{a-2} n_{t+1}^{1-a} - \frac{\chi_t}{\beta} + \lambda_{t+1}(1-\tau_{t+1}^l) \frac{\mu_1}{\mu_2} a(1-a) A k_{t+1}^{a-1} n_{t+1}^{-a} \tag{1.B4}$$

$$+a A k_{t+1}^{a-1} n_{t+1}^{1-a}(\chi_{t+1} - \zeta_{t+1}\phi + \xi_{t+1}[a\tau_{t+1}^k + (1-a)\tau_{t+1}^l]) + \chi_{t+1}(1-\delta^k) = 0,$$

$$-\zeta_t Q_{t+1} + \beta\left(\frac{1-\mu_1-\mu_2}{Q_{t+1}} + \zeta_{t+1}\delta^q\right) = 0, \tag{1.B5}$$

$$\xi_t k_t - \psi_{t-1} \frac{\mu_1}{c_t} = 0, \tag{1.B6}$$

$$\xi_t n_t - \lambda_t \frac{\mu_1}{\mu_2} = 0, \tag{1.B7}$$

$$\frac{\mu_1}{\mu_2}(1-a) A k_t^a n_t^{-a}(1-\tau_t^l) - \frac{c_t}{1-n_t} = 0, \tag{1.B8}$$

$$\beta \frac{\mu_1}{c_{t+1}}[(1-\tau_{t+1}^k) a A k_{t+1}^{a-1} n_{t+1}^{1-a} + 1 - \delta^k] = \frac{\mu_1}{c_t}, \tag{1.B9}$$

$$Q_{t+1} = (1-\delta^q)\bar{Q} + \delta^q Q_t - \phi A k_t^a n_t^{1-a} + \nu g, \tag{1.B10}$$

$$g = A k_t^a n_t^{1-a}[a\tau_t^k + (1-a)\tau_t^l], \tag{1.B11}$$

$$c_t + k_{t+1} = A k_t^a n_t^{1-a} - g + (1-\delta^k) k_t. \tag{1.B12}$$

From the Eqs. $(1.B2)-(1.B12)$ we can eliminate ζ_t, ψ_t and ψ_{t-1} by substituting $(1.B11)$, $(1.B5)$ and $(1.B6)$ at time t and $t+1$, so that Eqs. $(1.B2)-(1.B12)$ be written as

$$\mu_1 c_t - \frac{c_t^2\lambda_t}{1-n_t} + \beta\xi_{t+1}k_{t+1}c_{t+1} - c_t^2\chi_t - \xi_t k_t c_t[(1-\tau_t^k)Ak_t^a n_t^{1-a} + 1 - \delta^k] = 0, \tag{1.B13}$$

$$(1-a)Ak_t^a n_t^{-a}[\chi_t(1-\frac{\varphi}{\nu}) + \xi_t[a\tau_t^k + (1-a)\tau_t^l - \frac{\varphi}{\nu}]] - \frac{\mu_2}{1-n_t} + \xi_t(1-\tau_t^l)a(1-a)Ak_t^a n_t^{-a}$$

$$\tag{1.B14}$$

$$-\frac{c_t\lambda_t}{(1-n_t)^2} - \lambda_t(1-\tau_t^l)\frac{\mu_1}{\mu_2}a(1-a)Ak_t^a n_t^{-1-a} = 0,$$

$$\xi_{t+1}k_{t+1}(1-\tau_{t+1}^k)a(a-1)Ak_{t+1}^{a-2}n_{t+1}^{1-a} - \frac{\chi_t}{\beta} + \lambda_{t+1}(1-\tau_{t+1}^l)\frac{\mu_1}{\mu_2}a(1-a)Ak_{t+1}^{a-1}n_{t+1}^{-a} \tag{1.B15}$$

$$+aAk_{t+1}^{a-1}n_{t+1}^{1-a}[\chi_{t+1}(1-\frac{\varphi}{\nu}) + \xi_{t+1}[a\tau_{t+1}^k + (1-a)\tau_{t+1}^l - \frac{\varphi}{\nu}]] + \chi_{t+1}(1-\delta^k) = 0,$$

$$-(\chi_t+\xi_t)\frac{1}{\nu}Q_{t+1} + \beta\frac{1-\mu_1-\mu_2}{Q_{t+1}} + \frac{\beta\delta^q}{\nu}(\chi_{t+1}+\xi_{t+1}) = 0, \tag{1.B16}$$

$$\xi_t n_t - \lambda_t\frac{\mu_1}{\mu_2} = 0, \tag{1.B17}$$

$$\mu_2 c_t - \mu_1(1-n_t)(1-a)Ak_t^a n_t^{-a}(1-\tau_t^l) = 0, \tag{1.B18}$$

$$\beta\mu_1 c_t[(1-\tau_{t+1}^k)aAk_{t+1}^{a-1}n_{t+1}^{1-a} + 1 - \delta^k] = \mu_1 c_{t+1}, \tag{1.B19}$$

$$(1-\delta^q)\bar{Q} + \delta^q Q_t - \varphi Ak_t^a n_t^{1-a} + \nu Ak_t^a n_t^{1-a}[a\tau_t^k + (1-a)\tau_t^l] - Q_{t+1} = 0, \tag{1.B20}$$

$$c_t + k_{t+1} - Ak_t^a n_t^{1-a}[1 - a\tau_t^k - (1-a)\tau_t^l] - (1-\delta^k)k_t = 0. \tag{1.B21}$$

In this way we have a system with nine equations in $\{c_t, n_t, k_{t+1}, Q_{t+1}, \tau_t^k, \tau_t^l, \lambda_t, \chi_t, \xi_t\}_{t=0}^{\infty}$. We linearize Eqs. $(1.B13)-(1.B21)$ around the steady state to analyze the system's behavior. By using Taylor's theorem we expand the functions of the system around the steady state.

Eq. $(1.B13)$ becomes

$$f_1(c_t, n_t, \lambda_t, \xi_{t+1}, k_{t+1}, c_{t+1}, \chi_t, \xi_t, k_t, \tau_t^k) = f_{1a}\hat{c}_t + f_{1b}\hat{n}_t + f_{1c}\hat{\lambda}_t + f_{1d}\hat{\xi}_{t+1} + f_{1e}\hat{k}_{t+1} \tag{1.B22}$$

$$+f_{1f}\hat{c}_{t+1} + f_{1g}\hat{\chi}_t + f_{1h}\hat{\xi}_t + f_{1i}\hat{k}_t + f_{1j}\hat{\tau}_t^k,$$

where

$$f_{1a} = f_{1c_t}(c^*, n^*, \lambda^*, \xi^*, k^*, c^*, \chi^*, \xi^*, k^*, \tau^{k*}) = [\mu_1 - \frac{2c^*\lambda^*}{1-n^*} - 2c^*\chi^* - \xi^* k^*[(1-\tau^{k*}) \tag{1.B23}$$

$$A(k^*)^a(n^*)^{1-a} + 1 - \delta^k]],$$

$$f_{1b} = f_{1n_t}(c^*, n^*, \lambda^*, \xi^*, k^*, c^*, \chi^*, \xi^*, k^*, \tau^{k*}) = [-[\frac{(c^*)^2\lambda^*}{(1-n^*)^2} \tag{1.B24}$$

$$+\xi^* k^* c^*(1-\tau^{k*})(1-a)A(k^*)^a(n^*)^{-a}]],$$

$$f_{1c} = f_{1\lambda_t}(\cdot) = [-\frac{(c^*)^2}{1-n^*}], \tag{1.B25}$$

$$f_{1d} = f_{1\xi_{t+1}}(\cdot) = \beta k^* c^*, \tag{1.B26}$$

$$f_{1e} = f_{1k_{t+1}}(\cdot) = \beta \xi^* c^*, \tag{1.B27}$$

$$f_{1f} = f_{1c_{t+1}}(\cdot) = \beta \xi^* k^*, \tag{1.B28}$$

$$f_{1g} = f_{1\chi_t}(\cdot) = [-(c^*)^2], \tag{1.B29}$$

$$f_{1h} = f_{1\xi_t}(\cdot) = [-[k^* c^*[(1-\tau^{k*})A(k^*)^a(n^*)^{1-a} + 1 - \delta^k]]], \tag{1.B30}$$

$$f_{1i} = f_{1k_t}(\cdot) = [-\xi^* c^*[(1-\tau^{k*})A(k^*)^a(n^*)^{1-a} + 1 - \delta^k] \tag{1.B31}$$

$$-\xi^* c^*(1-\tau^{k*})Aa(k^*)^a(n^*)^{1-a}],$$

$$f_{1j} = f_{1\tau_t^k}(\cdot) = \xi^* c^*(1-\tau^{k*})A(k^*)^{a+1}(n^*)^{1-a}. \tag{1.B32}$$

Eq. $(1.B14)$ becomes

$$f_2(k_t, n_t, \chi_t, \xi_t, \tau_t^k, \tau_t^l, c_t, \lambda_t) = f_{2a}\hat{k}_t + f_{2b}\hat{n}_t + f_{2c}\hat{\chi}_t + f_{2d}\hat{\xi}_t + f_{2e}\hat{\tau}_t^k + f_{2f}\hat{\tau}_t^l + f_{2g}\hat{c}_t + f_{2h}\hat{\lambda}_t, \tag{1.B33}$$

where

$$f_{2a} = f_{2k_t}(\cdot) = [(1-a)aA(k^*)^{a-1}(n^*)^{-a}[\chi^*(1-\frac{\phi}{\nu}) \tag{1.B34}$$

$$+\xi^*[a\tau^{k*} + (1-a)\tau^{l*} - \frac{\phi}{\nu}]] + \xi^*(1-\tau^{l*})a^2(1-a)A(k^*)^{a-1}(n^*)^{-a}$$

$$-\lambda^*(1-\tau^{l*})\frac{\mu_1}{\mu_2}a^2(1-a)A(k^*)^{a-1}(n^*)^{-1-a}],$$

$$f_{2b} = f_{2n_t}(\cdot) = [-a(1-a)A(k^*)^a(n^*)^{-a-1}[\chi^*(1-\frac{\phi}{\nu}) \tag{1.B35}$$

$$+\xi^*[a\tau^{k*} + (1-a)\tau^{l*} - \frac{\phi}{\nu}]] - \frac{\mu_2}{(1-n^*)^2} - \xi^*(1-\tau^{l*})a^2(1-a)A(k^*)^a(n^*)^{-a-1}$$

$$-\frac{2c^*\lambda^*(1-n^*)}{(1-n^*)^4} + \lambda^*(1-\tau^{l*})\frac{\mu_1}{\mu_2}a(1-a)(a+1)A(k^*)^a(n^*)^{-a-2}],$$

$$f_{2c} = f_{2\chi_t}(\cdot) = (1-a)A(k^*)^a(n^*)^{-a}(1-\frac{\phi}{\nu}), \tag{1.B36}$$

$$f_{2d} = f_{2\xi_t}(\cdot) = [(1-a)A(k^*)^a(n^*)^{-a}, \tag{1.B37}$$

$$[a\tau^{k*} + (1-a)\tau^{l*} - \frac{\phi}{\nu}]] + (1-\tau^{l*})a(1-a)A(k^*)^a(n^*)^{-a}], \tag{1.B38}$$

$$f_{2e} = f_{2\tau_t^k}(\cdot) = (1-a)A(k^*)^a(n^*)^{-a}\xi^*a, \tag{1.B39}$$

$$f_{2f} = f_{2\tau_t^l}(\cdot) = [(1-a)^2A(k^*)^a(n^*)^{-a}\xi^* - \xi^*a(1-a)A(k^*)^a(n^*)^{-a} \tag{1.B40}$$

$$+\lambda^*\frac{\mu_1}{\mu_2}a(1-a)A(k^*)^a(n^*)^{-a-1}],$$

$$f_{2g} = f_{2c_t}(\cdot) = [-\frac{\lambda^*}{(1-n^*)^2}], \tag{1.B41}$$

$$f_{2h} = f_{2\lambda_t}(\cdot) = [-\frac{c^*}{(1-n^*)^2} - (1-\tau^{l*})\frac{\mu_1}{\mu_2}a(1-a)A(k^*)^a(n^*)^{-a-1}]. \tag{1.B42}$$

Eq. $(1.B15)$ becomes

$$f_3(\xi_{t+1}, k_{t+1}, \tau_{t+1}^k, n_{t+1}, \chi_t, \lambda_{t+1}, \tau_{t+1}^l, \chi_{t+1}) = f_{3a}\hat{\xi}_{t+1} + f_{3b}\hat{k}_{t+1} + f_{3c}\tau_{t+1}^k + f_{3d}\hat{n}_{t+1} \tag{1.B43}$$

$$+f_{3e}\hat{\chi}_t + f_{3f}\hat{\lambda}_{t+1} + f_{3g}\hat{\tau}_{t+1}^l + f_{3h}\hat{\chi}_{t+1},$$

where

$$f_{3a} = f_{3\xi_{t+1}}(\cdot) = [(1-\tau^{k*})a(a-1)A(k^*)^{a-1}(n^*)^{1-a} \tag{1.B44}$$
$$+aA(k^*)^{a-1}(n^*)^{1-a}[a\tau^{k*} + (1-a)\tau^{l*} - \frac{\phi}{\nu}]],$$

$$f_{3b} = f_{3k_{t+1}}(\cdot) = [\xi^*(1-\tau^{k*})a(a-1)^2A(k^*)^{a-2}(n^*)^{1-a} \tag{1.B45}$$
$$+\lambda^*(1-\tau^{l*})\frac{\mu_1}{\mu_2}a(1-a)^2A(k^*)^{a-2}(n^*)^{-a}$$
$$+a(a-1)A(k^*)^{a-2}(n^*)^{1-a}[\chi^*(1-\frac{\phi}{\nu}) + \xi^*[a\tau^{k*} + (1-a)\tau^{l*} - \frac{\phi}{\nu}]]],$$

$$f_{3c} = f_{3\tau^k_{t+1}}(\cdot) = [a^2A(k^*)^{a-1}(n^*)^{1-a}\xi^* - \xi^*a(a-1)A(k^*)^{a-1}(n^*)^{1-a}], \tag{1.B46}$$

$$f_{3d} = f_{3n_{t+1}}(\cdot) = [-\xi^*(1-\tau^{k*})a(a-1)^2A(k^*)^{a-1}(n^*)^{-a} \tag{1.B47}$$
$$-\lambda^*(1-\tau^{l*})\frac{\mu_1}{\mu_2}a^2(1-a)A(k^*)^{a-1}(n^*)^{-1-a}$$
$$+a(1-a)A(k^*)^{a-1}(n^*)^{-a}[\chi^*(1-\frac{\phi}{\nu}) + \xi^*[a\tau^{k*} + (1-a)\tau^{l*} - \frac{\phi}{\nu}]]],$$

$$f_{3e} = f_{3\chi_t}(\cdot) = [-\frac{1}{\beta}], \tag{1.B48}$$

$$f_{3f} = f_{3\lambda_{t+1}}(\cdot) = (1-\tau^{l*})\frac{\mu_1}{\mu_2}a(1-a)A(k^*)^{a-1}(n^*)^{-a}, \tag{1.B49}$$

$$f_{3g} = f_{3\tau^l_{t+1}}(\cdot) = [a(1-a)A(k^*)^{a-1}(n^*)^{1-a}\xi^* - \lambda^*\frac{\mu_1}{\mu_2}aA(k^*)^{a-1}(n^*)^{-a}], \tag{1.B50}$$

$$f_{3h} = f_{3\chi_{t+1}}(\cdot) = [aA(k^*)^{a-1}(n^*)^{1-a}(1-\frac{\phi}{\nu}) + 1 - \delta^k]. \tag{1.B51}$$

Eq. $(1.B16)$ becomes

$$f_4(\chi_t, \xi_t, Q_{t+1}, \chi_{t+1}, \xi_{t+1}) = f_{4a}\hat{\chi}_t + f_{4b}\hat{\xi}_t + f_{4c}\hat{Q}_{t+1} + f_{4d}\hat{\chi}_{t+1} + f_{4e}\hat{\xi}_{t+1}, \tag{1.B52}$$

where

$$f_{4a} = f_{4\chi_t}(\cdot) = -\frac{Q^*}{\nu}, \tag{1.B53}$$

$$f_{4b} = f_{4\xi_t}(\cdot) = -\frac{Q^*}{\nu}, \tag{1.B54}$$

$$f_{4c} = f_{4Q_{t+1}}(\cdot) = [(\chi^* + \xi^*)\frac{1}{\nu} - \frac{\beta(1-\mu_1-\mu_2)}{(Q^*)^2}], \tag{1.B55}$$

$$f_{4d} = f_{4\chi_{t+1}}(\cdot) = \frac{\beta\delta^q}{\nu}, \tag{1.B56}$$

$$f_{4e} = f_{4\xi_{t+1}}(\cdot) = \frac{\beta\delta^q}{\nu}. \tag{1.B57}$$

Eq. $(1.B17)$ becomes

$$f_5(\xi_t, n_t, \lambda_t) = f_{5a}\hat{\xi}_t + f_{5b}\hat{n}_t + f_{5c}\hat{\lambda}_t, \tag{1.B58}$$

where

$$f_{5a} = f_{5\xi_t}(\cdot) = n^*, \tag{1.B59}$$

$$f_{5b} = f_{5n_t}(\cdot) = \xi^*, \tag{1.B60}$$

$$f_{5c} = f_{5\lambda_t}(\cdot) = [-\frac{\mu_1}{\mu_2}]. \tag{1.B61}$$

Eq. $(1.B18)$ becomes

$$f_6(c_t, n_t, k_t, \tau^l_t) = \mu_2\hat{c}_t + f_{6a}\hat{n}_t + f_{6b}\hat{k}_t + f_{6c}\hat{\tau}^l_t, \tag{1.B62}$$

where

$$f_{6a} = f_{6n_t}(\cdot) = [\mu_1(1-a)A(k^*)^a(n^*)^{-a}(1-\tau^{l*}) \tag{1.B63}$$

$$+a\mu_1(1-n^*)(1-a)A(k^*)^a(n^*)^{-a-1}(1-\tau^{l*})],$$

$$f_{6b} = f_{6k_t}(\cdot) = [-\mu_1(1-n^*)(1-a)aA(k^*)^{a-1}(n^*)^{-a}(1-\tau^{l*})], \tag{1.B64}$$

$$f_{6c} = f_{6\tau_t^l}(\cdot) = \mu_1(1-n^*)(1-a)A(k^*)^a(n^*)^{-a}. \tag{1.B65}$$

Eq. $(1.B19)$ becomes

$$f_7(c_t, \tau_{t+1}^k, k_{t+1}, n_{t+1}, c_{t+1}) = f_{7a}\hat{c}_t + f_{7b}\tau_{t+1}^k + f_{7c}\hat{k}_{t+1} + f_{7d}\hat{n}_{t+1} + [-\mu_1]\hat{c}_{t+1}, \tag{1.B66}$$

where

$$f_{7a} = f_{7c_t}(\cdot) = \beta\mu_1[(1-\tau^{k*})aA(k^*)^{a-1}(n^*)^{1-a} + 1 - \delta^k], \tag{1.B67}$$

$$f_{7b} = f_{7\tau_{t+1}^k}(\cdot) = [-\beta\mu_1 c^* aA(k^*)^{a-1}(n^*)^{1-a}], \tag{1.B68}$$

$$f_{7c} = f_{7k_{t+1}}(\cdot) = \beta\mu_1 c^*(1-\tau^{k*})a(a-1)A(k^*)^{a-2}(n^*)^{1-a}, \tag{1.B69}$$

$$f_{7d} = f_{7n_{t+1}}(\cdot) = \beta\mu_1 c^*(1-\tau^{k*})a(1-a)A(k^*)^{a-1}(n^*)^{-a}. \tag{1.B70}$$

Eq. $(1.B20)$ becomes

$$f_8(Q_t, k_t, n_t, \tau_t^k, \tau_t^l, Q_{t+1}) = \delta^q\hat{Q}_t + f_{8a}\hat{k}_t + f_{8b}\hat{n}_t + f_{8c}\hat{\tau}_t^k + f_{8d}\hat{\tau}_t^l - \hat{Q}_{t+1}, \tag{1.B71}$$

where

$$f_{8a} = f_{8k_t}(\cdot) = [-\phi a A(k^*)^{a-1}(n^*)^{1-a} + \nu A a(k^*)^{a-1}(n^*)^{1-a}[a\tau^{k*} + (1-a)\tau^{l*}]], \tag{1.B72}$$

$$f_{8b} = f_{8n_t}(\cdot) = [-\phi(1-a)A(k^*)^a(n^*)^{-a} + \nu(1-a)A(k^*)^a(n^*)^{-a} \tag{1.B73}$$

$$[a\tau^{k*} + (1-a)\tau^{l*}]],$$

$$f_{8c} = f_{8\tau_t^k}(\cdot) = \nu A(k^*)^a(n^*)^{1-a}a, \tag{1.B74}$$

$$f_{8d} = f_{8\tau_t^l}(\cdot) = \nu A(k^*)^a(n^*)^{1-a}(1-a). \tag{1.B75}$$

Eq. $(1.B21)$ becomes

$$f_9(c_t, k_{t+1}, k_t, n_t, \tau_t^k, \tau_t^l) = \hat{c}_t + \hat{k}_{t+1} + f_{9a}\hat{k}_t + f_{9b}\hat{n}_t + f_{9c}\hat{\tau}_t^k + f_{9d}\hat{\tau}_t^l, \tag{1.B76}$$

where

$$f_{9a} = f_{9k_t}(\cdot) = [-[aA(k^*)^{a-1}(n^*)^{1-a}[1 - a\tau^{k*} - (1-a)\tau^{l*}] + (1-\delta^k)]], \tag{1.B77}$$

$$f_{9b} = f_{9n_t}(\cdot) = [-A(1-a)(k^*)^a(n^*)^{-a}[1 - a\tau^{k*} - (1-a)\tau^{l*}]], \tag{1.B78}$$

$$f_{9c} = f_{9\tau_t^k}(\cdot) = A(k^*)^a(n^*)^{1-a}a, \tag{1.B79}$$

$$f_{9d} = f_{9\tau_t^l}(\cdot) = A(k^*)^a(n^*)^{1-a}(1-a). \tag{1.B80}$$

We observe that the three of the equations in the system are static. We substitute these equations into the other six equations of the system. More specifically, we solve f_2, f_5 and, f_6 with respect to $\hat{\tau}_t^k$, $\hat{n}_t$, and $\hat{\tau}_t^l$ respectively:

$$\begin{bmatrix} f_2(k_t, n_t, \chi_t, \xi_t, \tau_t^k, \tau_t^l, c_t, \lambda_t) = 0 \\ f_5(\xi_t, n_t, \lambda_t) = 0 \\ f_6(c_t, n_t, k_t, \tau_t^l) = 0 \end{bmatrix}$$

$$
\Leftrightarrow \begin{bmatrix} \hat{\tau}^k_t = \hat{k}_t(\frac{f_{2f}}{f_{2a}} - \frac{f_{2a}}{f2e}) + \hat{\xi}_t(\frac{f_{2b}}{f_{2a}}\frac{n^*}{\xi^*} - \frac{f_{2d}}{f_{2a}} - \frac{f_{2f}}{f2e}f_{6a}\frac{n^*}{\xi^*}) + \hat{\lambda}_t(\frac{f_{2b}}{f_{2a}}\frac{f_{5a}}{\xi^*} - \frac{f_{2f}}{f_{2a}}f_{6a}\frac{f_{5a}}{\xi^*} - \frac{f_{2h}}{f_{2a}}) \\ +\hat{\chi}_t(-\frac{f_{2c}}{f_{2a}}) + \hat{c}_t(\frac{f_{2f}}{f_{2a}}\mu_2 - \frac{f_{2g}}{f_{2a}}) \\ \hat{n}_t = [-\frac{n^*}{\xi^*}]\hat{\xi}_t + [-\frac{f_{5a}}{\xi^*}]\hat{\lambda}_t \\ \hat{\tau}^l_t = -\mu_2\hat{c}_t - f_{6b}\hat{k}_t + f_{6a}\frac{n^*}{\xi^*}\hat{\xi}_t + f_{6a}\frac{f_{5a}}{\xi^*}\hat{\lambda}_t \end{bmatrix}.
$$

Therefore, the system becomes

$$
\begin{bmatrix} f_{1f} & f_{1e} & 0 & 0 & 0 & f_{1d} \\ f_{35} & f_{32} & 0 & f_{33} & f_{34} & f_{31} \\ 0 & 0 & f_{4c} & 0 & f_{4d} & f_{4e} \\ f_{75} & f_{71} & 0 & f_{73} & f_{74} & f_{72} \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{c}_{t+1} \\ \hat{k}_{t+1} \\ \hat{Q}_{t+1} \\ \hat{\lambda}_{t+1} \\ \hat{\chi}_{t+1} \\ \hat{\xi}_{t+1} \end{bmatrix} = \begin{bmatrix} f_{11} & -f_{15} & 0 & -f_{13} & -f_{14} & -f_{12} \\ 0 & 0 & 0 & 0 & -f_{3e} & 0 \\ 0 & 0 & 0 & 0 & -f_{4e} & -f_{4b} \\ -f_{7a} & 0 & 0 & 0 & 0 & 0 \\ f_{85} & f_{83} & \delta^q & f_{82} & f_{84} & f_{81} \\ f_{91} & f_{92} & 0 & f_{94} & f_{95} & f_{93} \end{bmatrix} \begin{bmatrix} \hat{c}_t \\ \hat{k}_t \\ \hat{Q}_t \\ \hat{\lambda}_t \\ \hat{\chi}_t \\ \hat{\xi}_t \end{bmatrix}
$$

$$
\Leftrightarrow D\hat{X}_{t+1} = E\hat{X}_t \Leftrightarrow \hat{X}_{t+1} = ED^{-1}\hat{X}_t \Leftrightarrow \hat{X}_{t+1} = F\hat{X}_t.
$$

By using the parameter values in the paper of Angelopoulos et al. (2010), we find that the three eigenvalues of F have absolute value smaller than one, while the other three have absolute value larger than one. The Blanchard-Kahn conditions are satisfied and the model is stable. The steady state of the system is a saddle path, therefore it has a unique equilibrium.

Appendix 1.C: Program codes

DCE solved as a system using Maple

```
>
> assign ('alpha'=0.33);
> assign ('Alpha'=1);
> assign ('deltak'=0.1);
> assign ('sigma'=2);
> assign ('beta'=0.97);
> assign ('mu1'=0.3);
> assign ('Qbar'=1);
> assign ('deltaq'=0.9);
> assign ('phi'=0.5);
> assign ('nu'=0.75);
> assign ('mu2'=0.3);
> assign ('tauk' = 0.6666666664);
> assign ('taul' = 0.6283516770);
> assign ('g' = 0.2795640845);
>
>
> eq1:= c/(1-n)-mu1/mu2*(1-taul)*(1-alpha)*Alpha*k^alpha*n^(-alpha) = 0;
```

$$eq1 := \frac{c}{1-n} - \frac{0.2490043764\, k^{0.33}}{n^{0.33}} = 0 \quad (1)$$

```
> eq2:= 1-beta*((1-tauk)*alpha*Alpha*k^(alpha-1)*n^(1-alpha)+1-deltak) = 0;
```

$$eq2 := 0.127 - \frac{0.1067000001\, n^{0.67}}{k^{0.67}} = 0 \quad (2)$$

```
> eq3:= (1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*g-Q = 0;
```

$$eq3 := 0.3096730634 - 0.1\, Q - 0.5\, k^{0.33}\, n^{0.67} = 0 \quad (3)$$

```
> eq4:= Alpha*k^alpha*n^(1-alpha)*(alpha*tauk+(1-alpha)*taul) - g = 0;
```

$$eq4 := 0.6409956235\, k^{0.33}\, n^{0.67} - 0.2795640845 = 0 \quad (4)$$

```
> eq5:= Alpha*k^alpha*n^(1-alpha)-g+(1-deltak)*k-c-k = 0;
```

$$eq5 := k^{0.33}\, n^{0.67} - 0.2795640845 - 0.1\, k - c = 0 \quad (5)$$

```
> fsolve({eq1,eq2,eq3,eq5},{c, n, Q, k});
```

$$\{Q = 0.9160286584, c = 0.1199336490, k = 0.3664266158, n = 0.4752055354\} \quad (6)$$

```
>
```

Response of the DCE with endogenous labor to an increase in μ_3, decrease in μ_1, with steady μ_2 using Dynare

```
var c, k, Q, U, n, y;
varexo mu1;
predetermined_variables k, Q;


parameters alpha, beta, Alpha, deltak, deltaq, Qbar, nu, phi, sigma, taul, tauk,
mu2, g;


alpha = 0.33;
beta   = 0.97;
deltak   = 0.1;
sigma = 2;
deltaq = 0.9;
Alpha = 1;
Qbar = 1;
phi = 0.5;
nu = 0.75;
g = .2795640845;
tauk = .6666666664;
taul =.6283516770;
mu2 = 0.3;
model;

mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;

c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
beta*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma))*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak) =0;

(1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*Alpha*k^alpha*n^(1-
alpha)*(alpha*tauk+(1-alpha)*taul)-Q(+1) =0;

Alpha*k^alpha*n^(1-alpha)-(Alpha*k^alpha*n^(1-alpha)*(alpha*tauk+(1-
alpha)*taul))+(1-deltak)*k-c-k(+1) =0;

U=(((c^mu1)*((1-n)^mu2)*(Q^(1-mu1-mu2)))^(1-sigma))/(1-sigma);

y=Alpha*k^alpha*n^(1-alpha);

end;
```

```
initval;

Q = 0.9160286585;
U = -81.53955920;
c = 0.1199336490;
k = 0.3664266157;
n = 0.4752055354;
y = 0.4361403951;
mu1 = 0.3;
end;

steady;

endval;
Q = 0.9160286585;
U = -81.53955920;
c = 0.1199336490;
k = 0.3664266157;
n = 0.4752055354;
y = 0.4361403951;
mu1 = 0.29;
end;

steady;

resid(1);

simul(periods=200);

figure(1); clf; title('Response to a temporary 1% increase in mu3');

subplot(2,3,1); plot(y(1:60)); title('Output (y)');
subplot(2,3,2); plot(c(1:60)); title('Consumption (c)');
subplot(2,3,3); plot(n(1:60)); title('Labor (n)');
subplot(2,3,4); plot(Q(1:60)); title('Environmental quality (Q)');
subplot(2,3,5); plot(k(1:60)); title('Capital (k)');
subplot(2,3,6); plot(U(1:60)); title('Welfare (U)');
```

Response of the DCE with endogenous labor to an increase in μ_3, decrease in μ_2, with steady μ_1 using Dynare

```
var c, k, Q, U, n, y;
varexo mu2;
predetermined_variables k, Q;


parameters alpha, beta, Alpha, deltak, deltaq, Qbar, nu, phi, sigma, mu1, taul,
tauk, g;


alpha = 0.33;
beta   = 0.97;
deltak   = 0.1;
sigma = 2;
deltaq = 0.9;
Alpha = 1;
Qbar = 1;
phi = 0.5;
nu = 0.75;
g = .2795640845;
tauk = .6666666664;
taul =.6283516770;
mu1 = 0.3;
model;

mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;

c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
beta*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma))*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak) =0;

(1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*Alpha*k^alpha*n^(1-
alpha)*(alpha*tauk+(1-alpha)*taul)-Q(+1) =0;

Alpha*k^alpha*n^(1-alpha)-(Alpha*k^alpha*n^(1-alpha)*(alpha*tauk+(1-
alpha)*taul))+(1-deltak)*k-c-k(+1) =0;

U=(((c^mu1)*((1-n)^mu2)*(Q^(1-mu1-mu2)))^(1-sigma))/(1-sigma);

y=Alpha*k^alpha*n^(1-alpha);

end;
```

```
initval;
Q = 0.9160286585;
U = -81.53955920;
c = 0.1199336490;
k = 0.3664266157;
n = 0.4752055354;
y = 0.4361403951;
mu2 = 0.3;
end;

steady;



endval;
Q = 0.9160286585;
U = -81.53955920;
c = 0.1199336490;
k = 0.3664266157;
n = 0.4752055354;
y = 0.4361403951;
mu2 = 0.29;
end;

steady;

resid(1);

simul(periods=200);

figure(2); clf; title('Response to a temporary 1% increase in mu3');

subplot(2,3,1); plot(y(1:60)); title('Output (y)');
subplot(2,3,2); plot(c(1:60)); title('Consumption (c)');
subplot(2,3,3); plot(n(1:60)); title('Labor (n)');
subplot(2,3,4); plot(Q(1:60)); title('Environmental quality (Q)');
subplot(2,3,5); plot(k(1:60)); title('Capital (k)');
subplot(2,3,6); plot(U(1:60)); title('Welfare (U)');
```

Response of the DCE with endogenous labor to an increase in μ_1, decrease in μ_2, with steady μ_3 using Dynare

```
var c, k, Q, U, n, y;
varexo mu1,mu2;
predetermined_variables k, Q;


parameters alpha, beta, Alpha, deltak, deltaq, Qbar, nu, phi, sigma, taul, tauk, g;


alpha = 0.33;
beta   = 0.97;
deltak   = 0.1;
sigma = 2;
deltaq = 0.9;
Alpha = 1;
Qbar = 1;
phi = 0.5;
nu = 0.75;
g = .2795640845;
tauk = .6666666664;
taul =.6283516770;

model;

mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;

c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
beta*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma))*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak) =0;

(1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*Alpha*k^alpha*n^(1-
alpha)*(alpha*tauk+(1-alpha)*taul)-Q(+1) =0;

Alpha*k^alpha*n^(1-alpha)-(Alpha*k^alpha*n^(1-alpha)*(alpha*tauk+(1-
alpha)*taul))+(1-deltak)*k-c-k(+1) =0;

U=(((c^mu1)*((1-n)^mu2)*(Q^(1-mu1-mu2)))^(1-sigma))/(1-sigma);

y=Alpha*k^alpha*n^(1-alpha);

end;
```

```
initval;
Q = 0.9160286585;
U = -81.53955920;
c = 0.1199336490;
k = 0.3664266157;
n = 0.4752055354;
y = 0.4361403951;
mu1 = 0.3;
mu2 = 0.3;
end;

steady;




endval;
Q = 0.9160286585;
U = -81.53955920;
c = 0.1199336490;
k = 0.3664266157;
n = 0.4752055354;
y = 0.4361403951;
mu1 = 0.31;
mu2 = 0.29;
end;

steady;

resid(1);

simul(periods=200);

figure(2); clf; title('Response to a temporary 1% increase in mu3');

subplot(2,3,1); plot(y(1:60)); title('Output (y)');
subplot(2,3,2); plot(c(1:60)); title('Consumption (c)');
subplot(2,3,3); plot(n(1:60)); title('Labor (n)');
subplot(2,3,4); plot(Q(1:60)); title('Environmental quality (Q)');
subplot(2,3,5); plot(k(1:60)); title('Capital (k)');
subplot(2,3,6); plot(U(1:60)); title('Welfare (U)');
```

Ramsey model solved as a system using Maple

```
> eq1:= mu1*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-lambda/(1-n)-chi+(mu1*(1-sigma)-1)*c^(mu1*(1-sigma)-2)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))*psi*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-tauk)-deltak) =0;
```

$$eq1 := \frac{0.3}{c^{1.3}(1-n)^{0.3}Q^{0.4}} - \frac{\lambda}{1-n} - \chi - \frac{1.3\,\psi\left(\frac{0.33\,n^{0.67}(1-tauk)}{k^{0.67}} - 0.1\right)}{c^{2.3}(1-n)^{0.3}Q^{0.4}} = 0 \qquad (1)$$

```
> eq2:= -mu2*c^(mu1*(1-sigma))*(1-n)^(mu2*(1-sigma)-1)*Q^((1-mu1-mu2)*(1-sigma))-lambda*(alpha*mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-1-alpha)*(1-taul)+c/(1-n)^2)+(1-alpha)*Alpha*k^alpha*n^(-alpha)*(xi*(alpha*tauk+(1-alpha)*taul)-zeta*phi+chi)-mu2*(1-sigma)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma)-1)*Q^((1-mu1-mu2)*(1-sigma))*psi*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-tauk)-deltak)+psi*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))*(1-alpha)*(1-tauk)*alpha*Alpha*k^(alpha-1)*n^(-alpha) =0;
```

$$eq2 := -\frac{0.3}{c^{0.3}(1-n)^{1.3}Q^{0.4}} - \lambda\left(\frac{0.2211000000\,k^{0.33}(1-taul)}{n^{1.33}} + \frac{c}{(1-n)^2}\right) + \frac{0.67\,k^{0.33}\left(\xi\,(0.33\,tauk + 0.67\,taul) - 0.5\,\zeta + \chi\right)}{n^{0.33}} + \frac{0.3\,\psi\left(\frac{0.33\,n^{0.67}(1-tauk)}{k^{0.67}} - 0.1\right)}{c^{1.3}(1-n)^{1.3}Q^{0.4}} + \frac{0.2211\,\psi\,(1-tauk)}{c^{1.3}(1-n)^{0.3}Q^{0.4}k^{0.67}n^{0.33}} = 0 \qquad (2)$$

```
> eq3:= -chi/beta+alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(xi*(alpha*tauk+(1-alpha)*taul)-zeta*phi+chi)+chi*(1-deltak)+psi*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))*(alpha-1)*alpha*Alpha*k^(alpha-2)*n^(1-alpha)*(1-tauk)+lambda*mu1/mu2*alpha*(1-alpha)*Alpha*k^(alpha-1)*n^(-alpha)*(1-taul) =0;
```

$$eq3 := -0.130927835\,\chi + \frac{0.33\,n^{0.67}\left(\xi\,(0.33\,tauk + 0.67\,taul) - 0.5\,\zeta + \chi\right)}{k^{0.67}} - \frac{0.2211\,\psi\,n^{0.67}(1-tauk)}{c^{1.3}(1-n)^{0.3}Q^{0.4}k^{1.67}} + \frac{0.2211000000\,\lambda\,(1-taul)}{k^{0.67}n^{0.33}} = 0 \qquad (3)$$

```
> eq4:= (1-mu1-mu2)*(1-sigma)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma)-1)*psi*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-tauk)-deltak)-zeta/beta+(1-mu1-mu2)*c^(mu1*(1-sigma))*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma)-1)+zeta*deltaq =0;
```

$$eq4 := -\frac{0.4\,\psi\left(\frac{0.33\,n^{0.67}(1-tauk)}{k^{0.67}} - 0.1\right)}{c^{1.3}(1-n)^{0.3}Q^{1.4}} - 0.130927835\,\zeta + \frac{0.4}{c^{0.3}(1-n)^{0.3}Q^{1.4}} = 0 \qquad (4)$$

```
> eq5:= xi*k-psi*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma)) =0;
```

$$eq5 := \xi\,k - \frac{\psi}{c^{1.3}(1-n)^{0.3}Q^{0.4}} = 0 \qquad (5)$$

```
> eq6:= xi*n-lambda*mu1/mu2 =0;
```

$$eq6 := \xi\, n - 1.000000000\,\lambda = 0 \quad (6)$$

```
>
> eq7:= mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;
```

$$eq7 := \frac{0.6700000000\, k^{0.33}\,(1 - taul)}{n^{0.33}} - \frac{c}{1 - n} = 0 \quad (7)$$

```
> eq8:= 1-beta*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-tauk)+1-deltak) =0;
```

$$eq8 := 0.127 - \frac{0.3201\, n^{0.67}\,(1 - tauk)}{k^{0.67}} = 0 \quad (8)$$

```
> eq9:= (1-deltaq)*Qbar-(1-deltaq)*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*g =0;
```

$$eq9 := 0.3096730634 - 0.1\,Q - 0.5\,k^{0.33}\,n^{0.67} = 0 \quad (9)$$

```
> eq10:= Alpha*k^alpha*n^(1-alpha)*(alpha*tauk+(1-alpha)*taul)-g =0;
```

$$eq10 := k^{0.33}\,n^{0.67}\,(0.33\,tauk + 0.67\,taul) - 0.2795640845 = 0 \quad (10)$$

```
> eq11:= c+k*deltak-Alpha*k^alpha*n^(1-alpha)+g =0;
```

$$eq11 := c + 0.1\,k - k^{0.33}\,n^{0.67} + 0.2795640845 = 0 \quad (11)$$

```
> eq12:= y-Alpha*k^alpha*n^(1-alpha) =0;
```

$$eq12 := y - k^{0.33}\,n^{0.67} = 0 \quad (12)$$

```
> eq13:= U-(((1-beta^100))/(1-beta))*(c^mu1*n^mu2*Q^(1-mu1-mu2))^(1-sigma)/(1-sigma) =0;
```

$$eq13 := U + \frac{31.74824974}{c^{0.3}\,n^{0.3}\,Q^{0.4}} = 0 \quad (13)$$

```
>
>
>
> assign ('alpha'=0.33);
> assign ('Alpha'=1);
> assign ('deltak'=0.1);
> assign ('sigma'=2);
> assign ('beta'=0.97);
> assign ('mu1'=0.3);
> assign ('Qbar'=1);
> assign ('deltaq'=0.9);
> assign ('phi'=0.5);
> assign ('nu'=0.75);
> assign ('mu2'=0.3);
> assign ('g'=0.2795640845);
>
```

```
> fsolve({eq1,eq2,eq3,eq4,eq5,eq6, eq7, eq8,eq9,eq10,eq11,eq12,eq13}, {c, n, Q, k, lambda, psi, zeta, xi, chi,
  tauk, taul, y, U});
```

$\{Q = 0.9160286585, U = -77.66214868, c = 0.1199336490, \chi = 6.270286194, k = 0.3664266157, n = 0.4752055354, \psi = 0.0001650687340, \xi = 0.007121685887, y = 0.4361403951, \lambda = 0.003364625004, tauk = 0.6666666664, taul = 0.6283516770, \zeta = 7.931271623\}$ (14)

Response of Ramsey economy to an increase in μ_3, decrease in μ_1, with steady μ_2 using Dynare

```
var n, c, k, Q, taul, tauk, chi, lambda, zeta, psi, xi, r, w, y, U;

varexo mu1;
predetermined_variables k, Q;

parameters alpha, beta, Alpha, deltak, deltaq, Qbar, phi, nu, mu2, sigma, g;
alpha = 0.33;
beta   = 0.97;
deltak   = 0.1;
sigma  = 2;
deltaq = 0.9;
Alpha = 1;
Qbar = 1;
mu2 = 0.3;
phi = 0.5;
nu = 0.75;
g = .2795640845;

model;

mu1*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-lambda/(1-
n)-chi+(mu1*(1-sigma)-1)*c^(mu1*(1-sigma)-2)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-
mu2)*(1-sigma))*(psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-tauk)+1-deltak)-
psi) = 0;

-mu2*c^(mu1*(1-sigma))*(1-n)^(mu2*(1-sigma)-1)*Q^((1-mu1-mu2)*(1-sigma))-
lambda*(alpha*mu1/mu2*(1-alpha)*k^alpha*n^(-alpha-1)*(1-taul)+c/(1-n)^2)+(1-
alpha)*Alpha*k^alpha*n^(-alpha)*(xi*(alpha*tauk+(1-alpha)*taul)-
zeta*phi+chi)+mu2*(1-sigma)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma)-1)*Q^((1-mu1-
mu2)*(1-sigma))*(psi-psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-tauk)+1-
deltak))+psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-
sigma))*(1-alpha)*alpha*Alpha*k^(alpha-1)*n^(-alpha)*(1-tauk) =0;

-chi/beta+alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(xi(+1)*(alpha*tauk(+1)+(1-
alpha)*taul(+1))-zeta(+1)*phi+chi(+1))+chi(+1)*(1-deltak)+psi*c(+1)^(mu1*(1-sigma)-
1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma))*(alpha-
1)*alpha*Alpha*k(+1)^(alpha-2)*n(+1)^(1-alpha)*(1-
tauk(+1))+lambda*mu1/mu2*alpha*(1-alpha)*Alpha*k(+1)^(alpha-1)*n(+1)^(-alpha)*(1-
taul(+1)) =0;

(1-mu1-mu2)*(1-sigma)*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-
mu1-mu2)*(1-sigma)-1)*(psi*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-
tauk(+1))+1-deltak)-psi(+1))-zeta/beta+(1-mu1-mu2)*c(+1)^(mu1*(1-sigma))*(1-
n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma)-1)+zeta(+1)*deltaq =0;

xi*alpha*Alpha*k^alpha*n^(1-alpha)-psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*alpha*Alpha*k^(alpha-1)*n^(1-alpha) =0;
```

```
xi*n-lambda*mu1/mu2 =0;

mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;

c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
beta*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma))*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak) =0;

(1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*g-Q(+1) =0;

Alpha*k^alpha*n^(1-alpha)*(1-alpha*(1-tauk)-(1-alpha)*(1-taul))-g =0;

Alpha*k^alpha*n^(1-alpha)-g+(1-deltak)*k-c-k(+1) =0;

r = alpha*Alpha*k^(alpha-1)*n^(1-alpha);

w= (1-alpha)*Alpha*k^alpha*n^(-alpha);

y=Alpha*k^alpha*n^(1-alpha);

U=(((c^mu1)*((1-n)^mu2)*(Q^(1-mu1-mu2)))^(1-sigma))/(1-sigma);

end;



initval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
mu1 = 0.3;
end;


steady;

resid(1);
```

```
endval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
mu1 = 0.29;
end;

steady;

resid(1);

check;

simul(periods=200);

figure(3); clf; title('Response to a temporary 1% increase in mu1');
subplot(3,4,1); plot(y(1:60)); title('Output (y)');
subplot(3,4,2); plot(c(1:60)); title('Consumption (c)');
subplot(3,4,3); plot(n(1:60)); title('Labor (n)');
subplot(3,4,5); plot(k(1:60)); title('Capital (k)');
subplot(3,4,4); plot(Q(1:60)); title('Environmental quality (Q)');
subplot(3,4,6); plot(taul(1:60)); title('Labor tax');
subplot(3,4,7); plot(tauk(1:60)); title('Capital tax');
subplot(3,4,8); plot(r(1:60)); title('Return on capital (r)');
subplot(3,4,9); plot(w(1:60)); title('Wage (w)');
subplot(3,4,10); plot(U(1:60)); title('Welfare (U)');
```

Response of Ramsey economy to an increase in μ_3, decrease in μ_2, with steady μ_1 using Dynare

```
var n, c, k, Q, taul, tauk, chi, lambda, zeta, psi, xi, r, w, y, U;
varexo mu2;
predetermined_variables k, Q;

parameters alpha, beta, Alpha, deltak, deltaq, Qbar, phi, nu, mu1, sigma, g;

alpha = 0.33;
beta   = 0.97;
deltak   = 0.1;
sigma  = 2;
deltaq = 0.9;
Alpha = 1;
Qbar = 1;
mu1 = 0.3;
phi = 0.5;
nu = 0.75;
g = .2795640845;

model;

mu1*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
lambda/(1-n)-chi+(mu1*(1-sigma)-1)*c^(mu1*(1-sigma)-2)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*(psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-
alpha)*(1-tauk)+1-deltak)-psi) = 0;

-mu2*c^(mu1*(1-sigma))*(1-n)^(mu2*(1-sigma)-1)*Q^((1-mu1-mu2)*(1-sigma))-
lambda*(alpha*mu1/mu2*(1-alpha)*k^alpha*n^(-alpha-1)*(1-taul)+c/(1-n)^2)+(1-
alpha)*Alpha*k^alpha*n^(-alpha)*(xi*(alpha*tauk+(1-alpha)*taul)-
zeta*phi+chi)+mu2*(1-sigma)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma)-1)*Q^((1-
mu1-mu2)*(1-sigma))*(psi-psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-
tauk)+1-deltak))+psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-
mu2)*(1-sigma))*(1-alpha)*alpha*Alpha*k^(alpha-1)*n^(-alpha)*(1-tauk) =0;

-chi/beta+alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-
alpha)*(xi(+1)*(alpha*tauk(+1)+(1-alpha)*taul(+1))-
zeta(+1)*phi+chi(+1))+chi(+1)*(1-deltak)+psi*c(+1)^(mu1*(1-sigma)-1)*(1-
n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma))*(alpha-
1)*alpha*Alpha*k(+1)^(alpha-2)*n(+1)^(1-alpha)*(1-
tauk(+1))+lambda*mu1/mu2*alpha*(1-alpha)*Alpha*k(+1)^(alpha-1)*n(+1)^(-
alpha)*(1-taul(+1)) =0;

(1-mu1-mu2)*(1-sigma)*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-
sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma)-1)*(psi*(alpha*Alpha*k(+1)^(alpha-
1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak)-psi(+1))-zeta/beta+(1-mu1-
mu2)*c(+1)^(mu1*(1-sigma))*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma)-1)+zeta(+1)*deltaq =0;

xi*alpha*Alpha*k^alpha*n^(1-alpha)-psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*alpha*Alpha*k^(alpha-1)*n^(1-alpha) =0;

xi*n-lambda*mu1/mu2 =0;
mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;
```

```
c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
beta*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma))*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak) =0;

(1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*g-Q(+1) =0;

Alpha*k^alpha*n^(1-alpha)*(1-alpha*(1-tauk)-(1-alpha)*(1-taul))-g =0;

Alpha*k^alpha*n^(1-alpha)-g+(1-deltak)*k-c-k(+1) =0;

r = alpha*Alpha*k^(alpha-1)*n^(1-alpha);

w= (1-alpha)*Alpha*k^alpha*n^(-alpha);

y=Alpha*k^alpha*n^(1-alpha);

U=(((c^mu1)*((1-n)^mu2)*(Q^(1-mu1-mu2)))^(1-sigma))/(1-sigma);

end;


initval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
mu2 = 0.3;
end;


steady;


endval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
mu2 = 0.29;
end;
```

```
steady;

resid(1);

simul(periods=100);

figure(3); clf; title('Response to a temporary 1% increase in mu1');
subplot(3,4,1); plot(y(1:60)); title('Output (y)');
subplot(3,4,2); plot(c(1:60)); title('Consumption (c)');
subplot(3,4,3); plot(n(1:60)); title('Labor (n)');
subplot(3,4,5); plot(k(1:60)); title('Capital (k)');
subplot(3,4,4); plot(Q(1:60)); title('Environmental quality (Q)');
subplot(3,4,6); plot(taul(1:60)); title('Labor tax');
subplot(3,4,7); plot(tauk(1:60)); title('Capital tax');
subplot(3,4,8); plot(r(1:60)); title('Return on capital (r)');
subplot(3,4,9); plot(w(1:60)); title('Wage (w)');
subplot(3,4,10); plot(U(1:60)); title('Welfare (U)');
```

Response of Ramsey economy to an increase in μ_1, decrease in μ_2, with steady μ_3 using Dynare

```
var n, c, k, Q, taul, tauk, chi, lambda, zeta, psi, xi, r, w, y, U;


varexo mu1, mu2;
predetermined_variables k, Q;


parameters alpha, beta, Alpha, deltak, deltaq, Qbar, phi, nu, sigma, g;
alpha = 0.33;
beta   = 0.97;
deltak   = 0.1;
sigma  = 2;
deltaq = 0.9;
Alpha = 1;
Qbar = 1;
phi = 0.5;
nu = 0.75;
g = .2795640845;


model;

mu1*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
lambda/(1-n)-chi+(mu1*(1-sigma)-1)*c^(mu1*(1-sigma)-2)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*(psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-
alpha)*(1-tauk)+1-deltak)-psi) = 0;

-mu2*c^(mu1*(1-sigma))*(1-n)^(mu2*(1-sigma)-1)*Q^((1-mu1-mu2)*(1-sigma))-
lambda*(alpha*mu1/mu2*(1-alpha)*k^alpha*n^(-alpha-1)*(1-taul)+c/(1-n)^2)+(1-
alpha)*Alpha*k^alpha*n^(-alpha)*(xi*(alpha*tauk+(1-alpha)*taul)-
zeta*phi+chi)+mu2*(1-sigma)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma)-1)*Q^((1-
mu1-mu2)*(1-sigma))*(psi-psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-
tauk)+1-deltak))+psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-
mu2)*(1-sigma))*(1-alpha)*alpha*Alpha*k^(alpha-1)*n^(-alpha)*(1-tauk) =0;

-chi/beta+alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-
alpha)*(xi(+1)*(alpha*tauk(+1)+(1-alpha)*taul(+1))-
zeta(+1)*phi+chi(+1))+chi(+1)*(1-deltak)+psi*c(+1)^(mu1*(1-sigma)-1)*(1-
n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma))*(alpha-
1)*alpha*Alpha*k(+1)^(alpha-2)*n(+1)^(1-alpha)*(1-
tauk(+1))+lambda*mu1/mu2*alpha*(1-alpha)*Alpha*k(+1)^(alpha-1)*n(+1)^(-
alpha)*(1-taul(+1)) =0;

(1-mu1-mu2)*(1-sigma)*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-
sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma)-1)*(psi*(alpha*Alpha*k(+1)^(alpha-
1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak)-psi(+1))-zeta/beta+(1-mu1-
mu2)*c(+1)^(mu1*(1-sigma))*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma)-1)+zeta(+1)*deltaq =0;

xi*alpha*Alpha*k^alpha*n^(1-alpha)-psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*alpha*Alpha*k^(alpha-1)*n^(1-alpha) =0;

xi*n-lambda*mu1/mu2 =0;
```

```
mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;
c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
beta*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma))*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak) =0;

(1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*g-Q(+1) =0;

Alpha*k^alpha*n^(1-alpha)*(1-alpha*(1-tauk)-(1-alpha)*(1-taul))-g =0;

Alpha*k^alpha*n^(1-alpha)-g+(1-deltak)*k-c-k(+1) =0;

r = alpha*Alpha*k^(alpha-1)*n^(1-alpha);

w= (1-alpha)*Alpha*k^alpha*n^(-alpha);

y=Alpha*k^alpha*n^(1-alpha);

U=(((c^mu1)*((1-n)^mu2)*(Q^(1-mu1-mu2)))^(1-sigma))/(1-sigma);

end;


initval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
mu1 = 0.3;
mu2 = 0.3;
end;


steady;


resid(1);
```

```
endval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
mu1 = 0.31;
mu2 = 0.29;
end;

steady;

resid(1);

check;



simul(periods=100);

figure(3); clf; title('Response to a temporary 1% increase in mu1');
subplot(3,4,1); plot(y(1:60)); title('Output (y)');
subplot(3,4,2); plot(c(1:60)); title('Consumption (c)');
subplot(3,4,3); plot(n(1:60)); title('Labor (n)');
subplot(3,4,5); plot(k(1:60)); title('Capital (k)');
subplot(3,4,4); plot(Q(1:60)); title('Environmental quality (Q)');
subplot(3,4,6); plot(taul(1:60)); title('Labor tax');
subplot(3,4,7); plot(tauk(1:60)); title('Capital tax');
subplot(3,4,8); plot(r(1:60)); title('Return on capital (r)');
subplot(3,4,9); plot(w(1:60)); title('Wage (w)');
subplot(3,4,10); plot(U(1:60)); title('Welfare (U)');
```

Response of Ramsey economy to 1% increase in the pollution parameter using Dynare

```
var n, c, k, Q, taul, tauk, chi, lambda, zeta, psi, xi, r, w, y, U;
varexo phi;
predetermined_variables k, Q;

parameters alpha, beta, Alpha, deltak, deltaq, Qbar, nu, mu2, mu1, sigma, g;

alpha = 0.33;
beta   = 0.97;
deltak   = 0.1;
sigma  = 2;
deltaq = 0.9;
Alpha = 1;
Qbar = 1;
mu1 = 0.3;
nu = 0.75;
mu2 = 0.3;
g = .2795640845;

model;

mu1*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
lambda/(1-n)-chi+(mu1*(1-sigma)-1)*c^(mu1*(1-sigma)-2)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*(psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-
alpha)*(1-tauk)+1-deltak)-psi) = 0;

-mu2*c^(mu1*(1-sigma))*(1-n)^(mu2*(1-sigma)-1)*Q^((1-mu1-mu2)*(1-sigma))-
lambda*(alpha*mu1/mu2*(1-alpha)*k^alpha*n^(-alpha-1)*(1-taul)+c/(1-n)^2)+(1-
alpha)*Alpha*k^alpha*n^(-alpha)*(xi*(alpha*tauk+(1-alpha)*taul)-
zeta*phi+chi)+mu2*(1-sigma)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma)-1)*Q^((1-
mu1-mu2)*(1-sigma))*(psi-psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-
tauk)+1-deltak))+psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-
mu2)*(1-sigma))*(1-alpha)*alpha*Alpha*k^(alpha-1)*n^(-alpha)*(1-tauk) =0;

-chi/beta+alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-
alpha)*(xi(+1)*(alpha*tauk(+1)+(1-alpha)*taul(+1))-
zeta(+1)*phi+chi(+1))+chi(+1)*(1-deltak)+psi*c(+1)^(mu1*(1-sigma)-1)*(1-
n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma))*(alpha-
1)*alpha*Alpha*k(+1)^(alpha-2)*n(+1)^(1-alpha)*(1-
tauk(+1))+lambda*mu1/mu2*alpha*(1-alpha)*Alpha*k(+1)^(alpha-1)*n(+1)^(-
alpha)*(1-taul(+1)) =0;

(1-mu1-mu2)*(1-sigma)*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-
sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma)-1)*(psi*(alpha*Alpha*k(+1)^(alpha-
1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak)-psi(+1))-zeta/beta+(1-mu1-
mu2)*c(+1)^(mu1*(1-sigma))*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma)-1)+zeta(+1)*deltaq =0;

xi*alpha*Alpha*k^alpha*n^(1-alpha)-psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*alpha*Alpha*k^(alpha-1)*n^(1-alpha) =0;

xi*n-lambda*mu1/mu2 =0;
```

```
mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;

c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
beta*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma))*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak) =0;

(1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*g-Q(+1) =0;

Alpha*k^alpha*n^(1-alpha)*(1-alpha*(1-tauk)-(1-alpha)*(1-taul))-g =0;

Alpha*k^alpha*n^(1-alpha)-g+(1-deltak)*k-c-k(+1) =0;

r = alpha*Alpha*k^(alpha-1)*n^(1-alpha);

w= (1-alpha)*Alpha*k^alpha*n^(-alpha);

y=Alpha*k^alpha*n^(1-alpha);

U=(((c^mu1)*((1-n)^mu2)*(Q^(1-mu1-mu2)))^(1-sigma))/(1-sigma);

end;


initval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
phi = 0.5;
end;


steady;

endval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
phi = 0.51;
end;
```

```
steady;

resid(1);

simul(periods=100);

figure(3); clf; title('Response to a temporary 1% increase in mu1');
subplot(3,4,1); plot(y(1:60)); title('Output (y)');
subplot(3,4,2); plot(c(1:60)); title('Consumption (c)');
subplot(3,4,3); plot(n(1:60)); title('Labor (n)');
subplot(3,4,5); plot(k(1:60)); title('Capital (k)');
subplot(3,4,4); plot(Q(1:60)); title('Environmental quality (Q)');
subplot(3,4,6); plot(taul(1:60)); title('Labor tax');
subplot(3,4,7); plot(tauk(1:60)); title('Capital tax');
subplot(3,4,8); plot(r(1:60)); title('Return on capital (r)');
subplot(3,4,9); plot(w(1:60)); title('Wage (w)');
subplot(3,4,10); plot(U(1:60)); title('Welfare (U)');
```

Response of Ramsey economy to 1% increase in the abatement technology using Dynare

```
var n, c, k, Q, taul, tauk, chi, lambda, zeta, psi, xi, r, w, y, U;
varexo nu;
predetermined_variables k, Q;

parameters alpha, beta, Alpha, deltak, deltaq, Qbar, phi, mu2, mu1, sigma, g;

alpha = 0.33;
beta   = 0.97;
deltak   = 0.1;
sigma  = 2;
deltaq = 0.9;
Alpha = 1;
Qbar = 1;
mu1 = 0.3;
phi = 0.5;
mu2 = 0.3;
g = .2795640845;

model;

mu1*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
lambda/(1-n)-chi+(mu1*(1-sigma)-1)*c^(mu1*(1-sigma)-2)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*(psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-
alpha)*(1-tauk)+1-deltak)-psi) = 0;

-mu2*c^(mu1*(1-sigma))*(1-n)^(mu2*(1-sigma)-1)*Q^((1-mu1-mu2)*(1-sigma))-
lambda*(alpha*mu1/mu2*(1-alpha)*k^alpha*n^(-alpha-1)*(1-taul)+c/(1-n)^2)+(1-
alpha)*Alpha*k^alpha*n^(-alpha)*(xi*(alpha*tauk+(1-alpha)*taul)-
zeta*phi+chi)+mu2*(1-sigma)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma)-1)*Q^((1-
mu1-mu2)*(1-sigma))*(psi-psi(-1)*(alpha*Alpha*k^(alpha-1)*n^(1-alpha)*(1-
tauk)+1-deltak))+psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-
mu2)*(1-sigma))*(1-alpha)*alpha*Alpha*k^(alpha-1)*n^(-alpha)*(1-tauk) =0;

-chi/beta+alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-
alpha)*(xi(+1)*(alpha*tauk(+1)+(1-alpha)*taul(+1))-
zeta(+1)*phi+chi(+1))+chi(+1)*(1-deltak)+psi*c(+1)^(mu1*(1-sigma)-1)*(1-
n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma))*(alpha-
1)*alpha*Alpha*k(+1)^(alpha-2)*n(+1)^(1-alpha)*(1-
tauk(+1))+lambda*mu1/mu2*alpha*(1-alpha)*Alpha*k(+1)^(alpha-1)*n(+1)^(-
alpha)*(1-taul(+1)) =0;

(1-mu1-mu2)*(1-sigma)*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-
sigma))*Q(+1)^((1-mu1-mu2)*(1-sigma)-1)*(psi*(alpha*Alpha*k(+1)^(alpha-
1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak)-psi(+1))-zeta/beta+(1-mu1-
mu2)*c(+1)^(mu1*(1-sigma))*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma)-1)+zeta(+1)*deltaq =0;

xi*alpha*Alpha*k^alpha*n^(1-alpha)-psi(-1)*c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-
sigma))*Q^((1-mu1-mu2)*(1-sigma))*alpha*Alpha*k^(alpha-1)*n^(1-alpha) =0;

xi*n-lambda*mu1/mu2 =0;
mu1/mu2*(1-alpha)*Alpha*k^alpha*n^(-alpha)*(1-taul)-c/(1-n) =0;
```

```
c^(mu1*(1-sigma)-1)*(1-n)^(mu2*(1-sigma))*Q^((1-mu1-mu2)*(1-sigma))-
beta*c(+1)^(mu1*(1-sigma)-1)*(1-n(+1))^(mu2*(1-sigma))*Q(+1)^((1-mu1-mu2)*(1-
sigma))*(alpha*Alpha*k(+1)^(alpha-1)*n(+1)^(1-alpha)*(1-tauk(+1))+1-deltak) =0;

(1-deltaq)*Qbar+deltaq*Q-phi*Alpha*k^alpha*n^(1-alpha)+nu*g-Q(+1) =0;

Alpha*k^alpha*n^(1-alpha)*(1-alpha*(1-tauk)-(1-alpha)*(1-taul))-g =0;

Alpha*k^alpha*n^(1-alpha)-g+(1-deltak)*k-c-k(+1) =0;

r = alpha*Alpha*k^(alpha-1)*n^(1-alpha);

w= (1-alpha)*Alpha*k^alpha*n^(-alpha);

y=Alpha*k^alpha*n^(1-alpha);

U=(((c^mu1)*((1-n)^mu2)*(Q^(1-mu1-mu2)))^(1-sigma))/(1-sigma);

end;


initval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
nu = 0.75;
end;


steady;


endval;
Q = 0.9160286585;
U = -77.66214868;
c = 0.1199336490;
chi = 6.270286194;
k = 0.3664266157;
n = 0.4752055354;
psi = 0.1650687340e-3;
xi =0.7121685887e-2;
y = 0.4361403951;
lambda = 0.3364625004e-2;
tauk = 0.6666666664;
taul = 0.6283516770;
zeta = 7.931271623;
nu = 0.76;
end;
```

```
steady;

resid(1);

simul(periods=200);

figure(3); clf; title('Response to a temporary 1% increase in mu1');
subplot(3,4,1); plot(y(1:60)); title('Output (y)');
subplot(3,4,2); plot(c(1:60)); title('Consumption (c)');
subplot(3,4,3); plot(n(1:60)); title('Labor (n)');
subplot(3,4,5); plot(k(1:60)); title('Capital (k)');
subplot(3,4,4); plot(Q(1:60)); title('Environmental quality (Q)');
subplot(3,4,6); plot(taul(1:60)); title('Labor tax');
subplot(3,4,7); plot(tauk(1:60)); title('Capital tax');
subplot(3,4,8); plot(r(1:60)); title('Return on capital (r)');
subplot(3,4,9); plot(w(1:60)); title('Wage (w)');
subplot(3,4,10); plot(U(1:60)); title('Welfare (U)');
```

Chapter 2
Environmental awareness, labor supply, and consumption: Empirical evidence from micro data

2.1 Introduction

How does environmental awareness affect the households' decision making? The increasing environmental concerns of individuals, especially in high-income economies, place the answer to this question in the center of the agenda of researchers and policy makers alike. Our premise is that higher environmental awareness should change the relevant labor/leisure decisions, as well as the consumption patterns of individuals, especially against polluting goods. In this chapter we aim to analyze empirically these potential effects of the increasing environmental awareness, using representative household-level survey data.

Our study is primarily motivated by the policy-relevant debate on the rising environmental awareness of individuals and households. Only in the two-year period between 2009 and 2011 the European citizens raised their perception about climate being a very serious problem (as opposed to a fairly serious one) by 4% points, which is already quite higher compared to other independent studies in the previous decades (Eurobarometer, 2011). Also, in 2011 84% of European citizens suggest that the decision to buy a specific product is influenced by the product's impact on the environment. This is again up by 6% points compared to 2009. Evidently, the decision to consume is strongly guided by the consumers' environmental awareness.

The role of environmental awareness in the labor/leisure decision of individuals and households is much more under-researched even at the level of anecdotal evidence. The first chapter of this thesis is, to our knowledge, the first theoretical attempt to relate the household's environmental awareness with the labor/leisure decisions. This relation can intuitively be attributed to at least two reasons. First, environmentally aware households might decide to decrease their labor supply if they relate their work to the worsening of environmental conditions. Examples can be found in the workings of labor unions in the United States, Europe, and Japan, even from the 1960s. Second, the theory of social status posits that the nature of one's job is one of the most important identifiers of social status. As environmental awareness rises, the job-related social status might be increasingly linked to greener types of employment.

To this end, this chapter provides an empirical test of one of the predictions of the theoretical model of the first chapter of this thesis, where a benevolent Ramsey social planner uses the available policy instruments to correct for an environmental externality. Specifically, we empirically test the response of consumption and labor supply to an increase in households' environmental awareness. Using survey data from the Panel Study of Income Dynamics (PSID) for the year 2011, we examine precisely these potential causal relations. We use information on the decision to donate for environmental purposes as a proxy for environmental awareness, as well as the annual work hours of the household's head to measure labor supply. For consumption we consider both total consumption and the consumption of polluting goods. To identify the labor supply and consumption equations we control for a rich set of economic, demographic, cultural, and intellectual characteristics of the households.

We believe that our data set is appropriate for this purpose, since they are collected from households that belong to a society where an elected government tries to maximize the welfare of the citizens using policy instruments. Moreover, the consumption and labor decisions are made given that the households are aware of their disposable income.

Identification of a causal effect of environmental awareness on the households' labor supply and consumption can be problematic if we do not account for potential reverse causality and omitted variables issues. Thus, we complement the OLS method with instrumental variables (IV) and simultaneous equations techniques. For the former we exploit the information on whether the households' heads have a medical condition associated with the quality of the environment that, by their own statement, does not affect their everyday activities. We assume that this condition enhances their environmental awareness, but not directly affects their leisure/labor or their consumption decisions precisely because it never affected their activities.

The results from all methods show that increased environmental awareness mainly reduces the supply of labor and this effect is economically significant. Specifically, our preferred specification shows that the environmentally aware households decrease their labor supply by 6.7%, while the effect on polluting consumption is negative but not always statistically significant. These findings verify the theoretical considerations of the first chapter, especially with respect to the labor/ leisure decisions of households. Environmentally aware households choose to work less because they internalize the harmful effects of these activities to the environment and are willing to tradeoff work hours with environmental quality. Moreover, we find that whether the agent is occupied in a polluting industry or not does not change the effect of environmental awareness on both work hours and polluting consumption.

The rest of this chapter is structured along the following lines. Section 2.2 provides a review of the related literature. Section 2.3 discusses the empirical model and the data set. Section 2.4 analyzes the identification issues and discusses the empirical results. Section 2.5 concludes.

2.2 Related literature

Our study on the effect of environmental awareness on the level of consumption and the labor supply of households is broadly related to two very large, but independent literatures. The first, which is empirical in nature, concerns the consumption and labor-supply habits of households and the second, which is mostly theoretical, considers the role of environmental quality or awareness in formal micro or macro models.

The empirical labor supply literature usually concentrates on the estimation of an equation of the number of hours worked on wages and other control variables (Blundell and MaCurdy, 1998; Meghir and Phillips, 2008). Most of this literature focuses on the elasticity of wages or on the effect of various incentives (e.g., taxation or transfers) on the labor supply of individuals (male or female) and households (families). With the emergence of household-level survey data, solutions to many of the empirical identification problems, such as the endogeneity of wages or other individuals' incentives, have become more effective. These solutions include the use of better instrumental variables, better econometric techniques (e.g., fixed effects models) and larger availability of related variables.

For the U.S. there now exist a number of large surveys on household decision-making that allow estimating labor supply equations at the family or individual level. For example, Hausman (1981), MaCurdy, Green and Paarsch (1990), Triest (1990), French (2004), Domeij and Floden (2006) all use the Panel Study of Income Dynamics (PSID) to estimate the response of labor supply to a number of economic forces that affect individuals' or households' incentives.

The equivalent empirical research on the determinants of the level of individuals' or households' consumption is also quite voluminous and covers several determinants of consumption. Most of these studies analyze the life-cycle patterns in consumption (Fernandez-Villaverde and Krueger, 2007), the effect of family size and structure (Attanasio and Browning, 1995), the role of habits (Carrasco, Labeaga and López-Salido, 2005), etc. A common feature of these studies is that they estimate empirical models, where the level of household consumption is a function of family income and a number of other determinants, chosen on the basis of the objectives of each study. A common feature of the consumption literature with the labor-supply literature is that they both favor obtaining data from PSID (Andreski, Li, Samancioglou, and Schoeni, 2014).

A rather separate strand of literature, originating mostly outside the field of economics, considers the role of environmental awareness in shaping the public opinion and actions. Within the economics literature, the modelling of environmental awareness is a recent endeavor. Conrad (2005), using a micro model of consumer preferences, suggests that increasing environmental awareness may affect the utility of consuming a product for which a greener substitute is available. In the model of Arora and Gangopadhyay (1995) all consumers value environmental quality equally, but their differential income generates a different ability to afford a cleaner environment. In turn, Bansal and Gangopadhyay (2003) study the welfare responses to environmental taxation policies and show that consumers are willing to pay more for greener products. Doni and Ricchiuti (2013) analyze how the interaction between green consumers and responsible firms affects the market equilibrium. The main result of the latter study is that when the abatement costs are fixed, the efficiency of the clean-up effort is always increasing in their degree of responsibility. On the other hand, when the abatement costs are variable, a higher level of responsibility may reduce social welfare.

Aside from this theoretical micro literature on consumers' environmental awareness, there is a growing theoretical macro literature that models the role of the environment in determining economic outcomes. The theoretical prediction of the relation between consumption and environmental quality or awareness has been highlighted in a number of recent theoretical general equilibrium macro models, in which the environmental quality enters the household's objective function along with consumption. A seminal contribution to this literature is the study by Bovenberg and Smulders (1995), which incorporates pollution-augmenting technological change. As reviewed in the first chapter of this thesis, a similar setup is used in the study by Vella, Dioikitopoulos, and Kalyvitis (2014), as well as by Angelopoulos, Economides, and Philippopoulos (2010) and Xepapadeas (2005).

Concerning the effect of environmental awareness on the labor/leisure decisions of households, the only existing theoretical framework comes from the first chapter of this thesis. There, we present a general equilibrium micro-founded model, which considers the role of environmental quality as a key element in the household decision-making process. One of the predictions of the Ramsey economy is that an increase in environmental awareness, with an associated decline in the weight of households on consumption, decreases the supply of labor, *ceteris paribus*. The effect on consumption of the same shock in environmental awareness is also negative. To our knowledge, this is the only study linking environmental awareness to the labor supply decisions of households.

So far we have reviewed two strands of literature, one on the empirical studies explaining labor-supply and consumption patterns of individuals and households and another, mostly theoretical in nature, that considers the role of environmental awareness in the spending, consumption and the overall macroeconomic dynamics. Clearly, the above studies point to a gap in the empirical literature linking environmental awareness with the labor-supply and consumption decisions of households. To our knowledge, there is no formal empirical analysis on this nexus, and this chapter aims to fill this gap in the literature. However, we do heavily rely on both literatures, as they provide an explicit guide and theoretical motivation to the empirical analysis below.

Based on these theoretical considerations we formulate our testable hypothesis as follows:

H1. Environmental awareness has a negative effect on the labor supply of households, *ceteris paribus*.

H2. Environmental awareness has a negative effect on the consumption of households, especially on the consumption of polluting goods, *ceteris paribus*.

2.3 Empirical model and data

The theoretical framework points to the estimation of labor supply and consumption equations with environmental awareness as the main explanatory variable. The relevant equations are of the following form:

$$L_i^s = a_0 + a_1 EA_i + a_2 X_i^1 + u_i^1, \tag{2.1}$$

$$C_i = b_0 + b_1 EA_i + b_2 X_i^2 + u_i^2. \tag{2.2}$$

In equation (2.1) L is the labor supply of household (or individual) i, EA is environmental awareness, X^1 is a vector of control variables affecting labor supply, and u^1 is the stochastic disturbance. In equation (2.2) C is the consumption of the polluting goods, X^2 is a vector of control variables affecting this consumption, and u^2 are the unobserved components. These two equations can be estimated either as a system of equations or separately. We use both approaches.

To estimate equations (2.1) and (2.2) we use cross-sectional household-level data for the United States in the year 2011. Our data source is the Panel Study of Income Dynamics (PSID) and, more specifically, the 2011 public release family file, which consists of 8,907 records and 5,136 variables for 51 states. This file contains one record for each family interviewed and includes all family-level variables collected in 2011, with information on a very wide range of economic, financial, demographic, behavioral, and numerous other variables. We define the main variables used in the empirical analysis in Table 2.1 and provide summary statistics in Table 2.A1.

[Insert Table 2.1 here]

The variable used to measure labor supply is the household's head annual total hours of work. This is the measure usually employed in the bulk of the empirical literature of labor supply equations (e.g., Heckman, 1993). Concerning *polluting consumption*, we use the dollar value of annual expenses for gas or electricity plus expenses for vehicle fuel. We also use a proxy for total consumption, which includes all basic consumption expenditures by households on an annual basis.[10] We prefer using polluting consumption because environmentally aware people are more likely to reduce the consumption of the polluting goods, and this is in line with the theoretical considerations of our theoretical framework and other studies (e.g., Angelopoulos,

[10] These include the polluting expenses plus total other utilities, expenses for house repairs, car-related expenses, transportation and parking expenses, school-related expenses, medical expenses, clothing, and recreational expenses. We exclude food expenses as we consider food to be a more basic good that is irrelevant to environmental awareness.

Economides, and Philippopoulos, 2010; Dioikitopoulos, Vella, and Kalyvtis, 2014; Clemens and Pittel, 2011).

Our explanatory variable characterizing environmental awareness is a dummy variable, which takes a value equal to one if the household has donated money for environmental purposes and zero otherwise. These environmental purposes include organizations that preserve the environment, such as conservation efforts, animal and park protection, etc.

Following the literature on the estimation of labor-supply and consumption equations (e.g., Friedberg, 2001), we also control for a number of other basic variables. Given the rich information in the PSID, we experiment with a very large number of potential control variables, but resort to the ones described below. The reason for our choice is that these variables seem to be directly related with some underlying theory, they are usually statistically significant in our regressions, and they do not present high pairwise correlation coefficients (Table 2.A2 is the correlation matrix).

In general, the control variables can be categorized in three groups. First, we control for economic variables. One of the most basic factors that determine household decisions is the level of income (Blundell and Macurdy, 1999), which in our case also serves as a proxy for the wage rate. Our measure is the household's total income, which was collected in 2011 for the tax year 2010, and is calculated using the taxable, transfer, and social security income of all the family members. We favor this approach instead of also including a direct measure of the wage rate because we are not focusing on the labor supply elasticity. However, we also consider a more direct proxy of the wage rate, calculated as the labor income or the labor income per hour. These two measures are highly correlated with *household income* and, thus, we only include the total household income in the estimated equations.

Also, the total wealth of households probably has an independent, relative to income, effect on labor supply because a very wealthy household may decide to lower its working hours. Thus, we use the total household wealth (assets minus debts) plus the value of home equity. Further, the decision to work and consume can be influenced by whether the household owns its own house. To this end, we use *own house,* which is a dummy variable equal to one if the household owns their house and zero otherwise, and *house rooms*, which represents the actual number of rooms in the household's home excluding bathrooms. Finally, *mortgage* is a dummy variable equal to one if the property has a mortgage or loan and zero otherwise.

The second group of determinants consists of the demographic characteristics of the households. We control for the age and the age-squared of each household's head because of the relevant non-linearities of age in relevant empirical models suggested by the life-cycle hypothesis (Modigliani, 1966). Moreover, we control for the head's gender and marital status, as well as the number of children in each household.

Third, the labor supply and consumption of households are usually affected by a number of variables characterizing their quality of life. An obvious such characteristic is the health status of individuals, with more healthy individuals being associated with higher workload and consumption (Parsons, 1977). As a proxy for the health status we use a variable that takes values from one (excellent health) to five (poor health). Another important determinant of the labor supply and consumption patterns of individuals is their educational background (Browning and Crossley, 2001). Educated individuals usually work more hours because their expertise knowledge increases their employment chances. Consequently, more educated family members are wealthier and this can lead to higher levels of consumption. To measure education we use the head's completed education level. Finally, certain social and emotional characteristics of individuals can affect labor supply and consumption. Two of these are the respondents' reported life satisfaction and their religiosity. For the latter, we find that the significance in some of the estimated equations comes mainly from the wives' religiosity (how often the wife attends religious services within one year).

2.4 Empirical identification and results

2.4.1 Environmental awareness and labor supply

An important identification problem in estimating reduced-form equations such as (2.1) is distinguishing labor supply from labor demand. In our setting the richness of the data set allows to observe the labor supply at the very micro level (households' heads) and this is a first safeguard against this identification problem. However, it could still be the case that the local labor demand affects the households' decisions because of economic fluctuations, specific local characteristics of the labor market, local regulatory policies etc. We control for these effects by introducing interaction terms between state dummy variables and 10 dummy variables constructed from the respective categories of the Beale-Ross Rural-Urban residence code (state*Beale dummies). This residence code groups the residential areas in 10 categories, with the most urban one being the central counties of metropolitan areas of one million population or more, and the completely rural one at the other end. Another merit of this approach is that these dummy variables capture the effect of other local economic and qualitative characteristics, most notably the effect of environmental quality for which we do not include an explicit control variable and the relevant taxes that are included in the Ramsey-type model.[11]

Table 2.2 reports the OLS results on the effect of environmental awareness on labor supply when the head of the family is employed.[12] The Table has three columns. In column I we use as explanatory variables the households' economic characteristics (*household income*, *household wealth*, *own house*, *house rooms*, and *mortgage*). In column II we add the variables related to the households' demographics (*age of head*,

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[11] Instead, we also experiment with explicit controls for environmental quality using data from the United States Environmental Protection Agency. We do not observe any significant changes in the coefficient on environmental awareness.

[12] In Table 2.A3 in the Appendix we also consider the case for all household heads (both employed and unemployed). Even though the results are similar, this case is somewhat meaningless for the labor supply equations simply because some of the individuals do not work.

gender of head, *No. of children* and *married head*). In column III we add the rest of the variables that describe the quality of life of the households (*health of head*, *education of head*, *life satisfaction* and *religiosity of wife*).

[Insert Table 2.2 about here]

In all three columns the coefficients on environmental awareness are negative and statistically significant at the 1% level of statistical significance. These effects are also economically important, as they indicate that environmentally aware households are associated with a decline in the annual working hours of their head by 121.4 hours for the mean household in our sample when we use all three categories of explanatory variables in column III (the respective values for columns I and II are 134.564 and 105.068, respectively).

These findings are in line with our theoretical underpinnings of the first chapter of the thesis. Specifically, environmentally aware households choose to work less because they internalize the effects of the polluting output and are willing to tradeoff work hours with environmental quality. This can hold because of at least two main reasons. First, households simply decide to work less if they relate their work with environmental degradation. These individual choices create general social trends that can shift the labor supply to a lower equilibrium. Examples for this mechanism can be found in the behavior of labor unions concerning environmental issues in a number of countries. In the U.S. one of the greatest supporters of pollution control in the mass environmental movements as early as in the late 1960s were the labor unions, which more recently formed many alliances with environmental groups (Kojola, 2009). Similar examples can be given for other countries (e.g., Inoue, 1999).

The second reason relates to employee social status. An environmentally aware household decides on its labor supply based, inter alia, on the job satisfaction as a very important element of its well-being. But apart from this satisfaction, the nature of jobs positions the households within a societal group. This idea is central in theories of social stratification and class at least since the times of Marx and Weber. In other words, as environmental awareness increases, the labor supply linked to environmentally harmful activities is lower because of the lower social status given to such production activities.

As regards the control variables, we observe that *household income* and *house rooms* are positively and significantly correlated with the labor supply. Living in a larger house creates higher expenses and requires more labor supply as a source of income.[13] The coefficient of *own house* is also positive and statistically significant in columns II – III. This result is also intuitive: families that own their house and live together are the typical ones that supply more labor. In turn, *wealth* bears a negative and significant coefficient, which is in line with the proposition that a lower level of wealth prompts household members to increase their labor supply. This can be especially true for younger individuals that have not accumulated wealth and perhaps have to repay tuition-related loans. Yet, even older workers with low levels of wealth can delay their retirement if pension schemes are unfavorable (Daly, Hobijn, and Kwok, 2009). In contrast, a high level of wealth works as a disincentive to increase the supply of labor.

The coefficient on *age of head* is positive and statistically significant, while the respective on *age of head squared* is negative and significant. This finding is in line with the life-cycle hypothesis and suggests that the impact of age on work hours is positive up to a certain age and becomes negative as individuals grow older and retire. *Gender of head* carries a positive and significant coefficient, implying that men work more hours than women. Further, the larger the number of children, the lower is the labor supply. *Married head* and *education of head* both bear a positive and significant coefficient. These findings are intuitive given respective selection mechanisms: the head needs to work more to financially sustain the household, while educated individuals can find jobs more easily.

[13] Causality can also run in the opposite direction: more hours worked earn higher incomes and this allows living in a larger house. However, identifying causality in this relation is beyond the scope of the present analysis.

For the variables characterizing the quality of life of households, *life satisfaction* has a negative and statistically significant coefficient, which implies that the more the head of the family is satisfied with his/ her life, the higher is his/ her *labor supply.* This finding is in line with Alesina, Glaeser, and Sacerdote (2006), who show that people who are more balanced in their approach to life are happier. Finally, *health of head* and *religiosity of wife* are insignificant determinants of *labor supply* in our sample. These variables are, instead, statistically significant when we consider all individuals, both employed and unemployed (see Table 2.A3 in the Appendix).

2.4.2 Endogeneity issues in the labor supply equation

So far we have essentially assumed that environmental awareness is an exogenous determinant of the labor supply decisions of households if we control for certain household characteristics and state*Beale fixed effects. However, causality may run in the opposite direction owing to a potential effect of labor supply on environmental awareness. For example, individuals with jobs in polluting industries can be more environmentally aware. Also, irrespective of the state*Beale dummies there could be other household or individual characteristics (omitted variables) affecting the relation between environmental awareness and labor supply.

To rule out any other source of endogeneity, we use a number of IV models. The first is the two-stage least squares (2SLS) model introduced by Lewbel (2012). This approach may be applied when no external instruments are available or, as in our case, to supplement external instruments so as to improve the efficiency of the 2SLS estimator. Lewbel's method exploits the relationship between heteroskedastic error variances and exogenous regressors to achieve identification. Thus, it relies on two conditions. First, the error term from the first stage regression, say ε_i^j, should be heteroskedastic, with $j = 1, 2$, where 1 is for *labor supply* and 2 for *polluting consumption*. Second, there exists a vector of variables $Z_i \subseteq X_i$ satisfying the following condition:

$$\text{Cov}\,(Z_i, u_i\varepsilon_i) = 0. \tag{2.3}$$

We test these conditions and we find that both are satisfied.

Given the above, in the first stage regression, the endogenous variable *environmental awareness* is regressed on *X* and we obtain the estimated residuals $\hat{\varepsilon}_i$. The reduced form residuals are then multiplied with each of the included exogenous variables in mean-centered form:

$$(Z_i - \bar{Z})\hat{\varepsilon}_i, \tag{2.4}$$

where $\bar{Z}$ is the mean of Z_i. Then, in the second stage, these constructed instruments are used in equations (2.1) and (2.2), respectively.

We begin with the application of Lewbel's method without any external instruments. Comparing the coefficients derived using the method of Lewbel (Table 2.3) with those from the OLS model (Table 2.2) we observe that the estimation results are almost the same. More specifically, in all three columns the coefficients of environmental awareness are negative and statistically significant at the 1% level. The negative effect is still economically significant as, based on the more restrictive specification of column III, it indicates that the heads of environmentally aware households provide 96.935 (or 6.5%) less hours per year.

[Insert Table 2.3 about here]

The second IV model complements the instrumental variables from the method of Lewbel with an explicit instrumental variable, which we name *environmental disease*. This is a dummy variable equal to one if the head of the household has or ever had a chronic lung disease or cancer, while these diseases never affected his/ her everyday life, and zero otherwise. We only use lung diseases and cancer from a variety of other health problems because these are more directly related to environmental quality. Thus, we assume that individuals that have ever suffered from these diseases place a higher weight on environmental quality (e.g., air and water quality). We assign a variable equal to one only for the individuals that their everyday life was never affected because otherwise it would be very likely that the labor supply of the affected individuals would be lower and the exclusion restriction would not be satisfied. Our data set has this explicit information because individuals are specifically asked about whether the disease affected the respondents' everyday life. Given that working is one of the most important elements of everyday life, we feel that the instrumental variable in its restricted form does not have a direct effect on the household head's labor supply. The empirical results, reported in Table 2.4, are almost the same as before, both qualitatively and quantitatively.[14]

[Insert Table 2.4 about here]

Moreover, because our endogenous variable is binary, we can theoretically improve on the efficiency of the estimates by using the treatment effects IV model. The results, presented in Table 2.A4 remain almost the same in terms of statistical significance. However, in terms of economic significance, the impact of environmental awareness is five to six times larger compared to the results of Table 2.4. Thus, we feel that the IV method of Lewbel (2012), combining our external instrument with the constructed instruments, indeed improves on our inference and it is the one favored in our study.

In Table 2.5 we examine the potential heterogeneous effect of the heads' level of polluting occupation on the relation between environmental awareness and labor supply for the employed. The intuition behind this test is to explore the possibility that our main result so far is not homogeneous across all employees, but is mainly affected by those who are occupied in the more heavily polluting jobs. To test this conjecture we use the following equation:

$$L_i^s = a_0 + a_1 EA_i + a_2 X_i + a_3 EA_i * PO_i + u_i^1, \tag{2.5}$$

[14] We also use a standard 2SLS procedure with only *environmental disease* as an instrument. The coefficients derived using this method are the same in terms of statistical significance, but the standard errors are larger. This implies that using the Lewbel's method reduces bias at least in our sample.

where PO is a dummy variable that takes the value one if the head is employed in one of the following sectors: agriculture, forestry, fishing, hunting, mining, utilities, construction, and manufacturing; and zero otherwise. We find that the interaction term is statistically insignificant, which implies that whether the occupation of the household's head is more heavily polluting or not does not affect the relation of environmental awareness and labor supply.

[Insert Table 2.5 about here]

2.4.3 Environmental awareness and polluting consumption

In this section we consider the effect of environmental awareness on polluting consumption. Given that all households consume, we report in Table 2.6 the OLS results for all available observations (both employed and unemployed heads). Just as before, in column I we use as explanatory variables the households' economic characteristics, in column II we add the variables related to the households' demographics, and in column III we add the rest of the variables that describe the quality of life for the households. All specifications include state*Beale fixed effects.

[Insert Table 2.6 around here]

In all columns the coefficients on environmental awareness are negative and statistically significant at conventional levels. These effects are also economically significant. Based on the results of column III, environmentally aware households consume $209.6 less of the polluting goods, which is an effect equivalent to a 7.5% reduction. Similar to the labor supply equation, the effect of all the control variables is in line with our prior expectations.

In Table 2.7 we examine the effect of environmental awareness on polluting consumption only for the employed heads. We provide this sensitivity analysis for two reasons. First, the families with unemployed heads will consume less because of their lower income. Second, we carry out his analysis for the shake o symmetry with the labor supply equations, which will also allow regressing the labor supply and consumption equations as a system (this is further discussed in sub-section 2.4.5). Evidently, the estimation results are almost the same as in Table 2.6 with the difference that the variables describing the quality of life for the households are statistically insignificant. Thus, it now remains to be examined whether this effect prevails in the IV regressions.

[Insert Table 2.7 around here]

2.4.4 Endogeneity issues in the consumption equation

There are a number of endogeneity concerns associated with analyzing the effect of environmental awareness on polluting consumption decisions of the households. The first one is the existence of reverse causality. For example, individuals who consume more polluting goods are exposed to hazardous chemicals and, thus, become more environmentally aware. The second, and similar to the case of labor supply, is that there could be other variables that affect the relation between environmental awareness and polluting consumption and are not included in the regression.

To deal with these issues we follow a similar strategy with the labor-supply regressions. First, we employ the two-stage least squares (2SLS) of Lewbel (2012) without any external instrumental variables and report the results in Table 2.8. In all three columns the coefficients on environmental awareness are negative, but only in column I the coefficient is statistically significant. In Table 2.9 we repeat this exercise by augmenting Lewbel's method with *environmental disease* as an instrumental variable and we obtain almost the same results. These findings show that when we control for the demographic characteristics of the household, consumption does not significantly respond to environmental awareness. Thus, in this case, the OLS results are not confirmed as the effect of environmental awareness on polluting consumption is less robust compared to the case of labor supply.

[Insert Tables 2.8 and 2.9 around here]

In a similar fashion with the regressions of Table 2.5, and to verify that our results are not driven by the employees in the more heavily polluting jobs, we estimate the equation:

$$C_i = b_0 + b_1 EA_i + b_2 Z_i + b_3 EA_i * PO_i + u_i^2. \quad (2.6)$$

Just as in the case of the labor supply equations, we find that the interaction term is statistically insignificant. Therefore, the occupation of the household's head does not affect the relation between environmental awareness and polluting consumption.

2.4.5 Other sensitivity analyses

In this section we examine the case of simultaneity between labor supply and consumption. This simultaneity comes almost naturally from the equilibrium solution of our theoretical model. We approach this issue in two ways. First, we control for polluting consumption in the specifications of Table 2.5 (results are in Table 2.A5) and, respectively, for labor supply in the specifications of Table 2.10 (results are in Table 2.A6). In Table 2.A5 *polluting consumption* bears in all three columns a positive and statistical significant coefficient at the 1% significance level, and the same holds in Table 2.A6 for *labor supply*. Evidently, the coefficient estimates and the statistical significance of *environmental awareness* are essentially the same with those of Tables 2.5 and 2.10.

The second approach to examine the simultaneity between labor supply and consumption is to estimate the simultaneous equation model for equations (2.1) and (2.2). We do this using the Full Information Maximum Likelihood (FIML) method. We report the estimation results in Table 2.A7. To identify the model we need to place some restrictions in terms of differentiating the explanatory variables of the two equations. As we observe in the previous specifications that the variables characterizing the quality of life of households' heads are statistically insignificant in all the polluting consumption equations, we exclude these from equation (2.2). Again, in the labor supply equation, the environmental awareness is negative and statistically significant at the 1% level. Environmentally aware households offer 121.07 less work hours, which is equivalent to an 8.1% decrease. In the polluting-consumption equation the effect of environmental quality is statistically significant, but only at the 10% level. Environmentally aware households spend $193.206 less in polluting goods, which is equivalent to a 5% decrease.

2.5 Conclusions

This chapter analyses the effect of environmental awareness on the labor supply and consumption decisions of the households. We use a large sample with household survey data and we estimate labor supply and polluting consumption equations using OLS, instrumental variables, and simultaneous-equations regressions. To eliminate endogeneity we use as an instrumental variable for environmental awareness the medical conditions that are related with environmental quality and do not affect the everyday life of the person afflicted. Moreover, we increase the efficiency of our IV procedure using the method of Lewbel (2012).

Our evidence suggests that environmentally aware households decrease labor supply and this is a statistically and economically significant finding in all the estimated specifications. More specifically, according to our preferred specification, environmentally aware households decrease their labor supply by 6.7%. We also find a negative effect of environmental awareness on consumption, but this effect is not as robust in terms of statistical significance.

In our Ramsey-type model of the first chapter of this thesis, the households internalize the effect of their consumption and labor/ leisure choices, while a benevolent social planner tries to correct for the environmental externality with appropriate policy instruments. The findings there show that the higher the environmental awareness *vis-à-vis* a lower weight on consumption and a constant weight on labor/ leisure, the lower is the labor supply and consumption. Thus, our empirical findings are in line with the theoretical predictions of our model, but show that the most potent effect is that for the labor supply.

Our results highlight the importance of understanding the microeconomic foundations of household behavior related to environmental awareness and open up a path for further empirical analysis on this issue. Specifically, the interrelationship between environmental awareness and Ramsey-type taxation has not been given a thorough examination by the relevant empirical literature. Also, from an even more macroeconomic perspective, examining the effects of environmental awareness on real economic outcomes, like growth, unemployment and welfare seems to be a fruitful exercise. We leave these ideas for future research.

Table 2.1
Variable definitions

Variable	Definition
Labor supply	Household's head annual total hours of work.
Polluting consumption	Expenses ($ value) for gas/ electricity plus expenses for vehicle fuel.
Environmental awareness	Dummy variable equal to one if the household has donated money for environmental purposes and zero otherwise.
Household income	Total household income in 2010.
Household wealth	Total household wealth (assets minus debts) plus the value of home equity.
Own house	Dummy variable equal to one if the household owns their house and zero otherwise.
House rooms	Actual number of rooms in household's home excluding bathrooms.
Mortgage	Dummy variable equal to one if the property has a mortgage or loan and zero otherwise.
Age of head	The age of the household's head.
Gender of head	The gender of the household's head.
No. of children	Number of children in the household.
Married head	Dummy variable equal to one if the head is married and zero otherwise.
Health of head	The health status of head, taking values from one (excellent) to five (poor).
Education of head	Head's completed education level. Values in the range 1-16 represent the actual grade of school completed, with values 13-16 representing college education. A code value of 17 indicates that the head completed at least some postgraduate work.
Life satisfaction	The level of life satisfaction of the head, taking values from one (completely satisfied) to five (not at all satisfied).
Religiosity of wife	How often the wife attends religious services within one year.
Polluting job	Dummy variable equal to one if the head is employed in one of the following sectors: agriculture, forestry, fishing, hunting, mining, utilities, construction, manufacturing; and zero otherwise.
Environmental disease	Dummy variable equal to one (and zero otherwise) if the head has or ever had a chronic lung disease or cancer but declares that this does not affect his everyday activities.

Table 2.2
Environmental awareness and labor supply for the employed

	I	II	III
Environmental awareness	-134.564***	-105.068***	-121.417***
	(-3.695)	(-2.976)	(-3.301)
Household income	0.001***	0.001***	0.001***
	(5.363)	(4.609)	(4.080)
Household wealth	-0.000***	-0.000**	-0.000**
	(-3.753)	(-2.142)	(-2.209)
Own house	69.602	82.411**	71.226*
	(1.627)	(2.133)	(1.798)
House rooms	26.588***	20.386***	19.145***
	(4.822)	(3.695)	(3.372)
Mortgage	46.459	-2.219	-7.344
	(0.994)	(-0.058)	(-0.190)
Age of head		55.497***	57.302***
		(10.083)	(10.038)
Age of head squared		-0.685***	-0.695***
		(-10.976)	(-10.745)
Gender of head		147.966***	152.728***
		(4.506)	(4.571)
No. of children		-31.283***	-30.915***
		(-3.410)	(-3.200)
Married head		67.868**	60.375*
		(2.088)	(1.772)
Health of head			-19.624
			(-1.624)
Education of head			10.188**
			(2.139)
Life satisfaction			-27.062**
			(-2.112)
Religiosity of wife			-0.090
			(-0.351)
Observations	5,860	5,859	5,530
R-squared	0.068	0.105	0.108

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the labor supply equation only for the household heads that are employed. Dependent variable is the hours of labor provided by the head of the household. All variables are defined in Table 2.1. All three specifications include state dummies. Estimation method is OLS with robust standard errors. The ***, **, and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.3
Environmental awareness and labor supply for the employed: IV regressions

	I	II	III
Environmental awareness	-126.800***	-106.343**	-96.935**
	(-2.810)	(-2.573)	(-2.432)
Household income	0.001***	0.001***	0.001***
	(5.375)	(4.632)	(4.083)
Household wealth	-0.000***	-0.000**	-0.000**
	(-3.784)	(-2.153)	(-2.241)
Own house	69.366	82.426**	70.936*
	(1.628)	(2.144)	(1.802)
House rooms	26.561***	20.391***	19.076***
	(4.843)	(3.717)	(3.379)
Mortgage	46.515	-2.217	-7.275
	(1.000)	(-0.059)	(-0.189)
Age of head		55.492***	57.367***
		(10.134)	(10.111)
Age of head squared		-0.685***	-0.697***
		(-11.030)	(-10.829)
Gender of head		147.941***	153.082***
		(4.530)	(4.611)
No. of children		-31.299***	-30.729***
		(-3.430)	(-3.199)
Married head		67.893**	59.689*
		(2.100)	(1.762)
Health of head			-19.469
			(-1.620)
Education of head			9.935**
			(2.095)
Life satisfaction			-27.139**
			(-2.130)
Religiosity of wife			-0.086
			(-0.337)
Observations	5,860	5,859	5,530
UIT	0.000	0.000	0.000
WIT with critical value	29.868 (11.07)	43.208 (11.04)	69.678 (11.02)
OIT	0.433	0.328	0.284

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the labor supply equation. Dependent variable is the hours of labor provided by the head of the household. All variables are defined in Table 2.1. Estimation method is two-stage least squares with robust standard errors, where the first stage includes instruments constructed using the method of Lewbel (2012). UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a values lower than 0.05 to reject the null hypothesis at the 5% level. WIT is the Wald *F*-statistic of the weak identification test by Kleibergen and Paap, which must be higher than its critical value to reject the null. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to reject the null hypothesis at the 5% level. The ***, ** and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.4
Environmental awareness and labor supply for the employed: IV regressions with two instrumental variables

	I	II	III
Environmental awareness	-131.386***	-108.429***	-98.141**
	(-2.907)	(-2.622)	(-2.463)
Household income	0.001***	0.001***	0.001***
	(5.380)	(4.635)	(4.084)
Household wealth	-0.000***	-0.000**	-0.000**
	(-3.780)	(-2.152)	(-2.241)
Own house	69.506	82.449**	70.950*
	(1.632)	(2.145)	(1.802)
House rooms	26.577***	20.400***	19.080***
	(4.846)	(3.719)	(3.380)
Mortgage	46.482	-2.213	-7.279
	(0.999)	(-0.058)	(-0.190)
Age of head		55.484***	57.364***
		(10.133)	(10.111)
Age of head squared		-0.685***	-0.697***
		(-11.028)	(-10.828)
Gender of head		147.900***	153.064***
		(4.529)	(4.611)
No. of children		-31.324***	-30.738***
		(-3.433)	(-3.201)
Married head		67.934**	59.723*
		(2.101)	(1.763)
Health of head			-19.476
			(-1.620)
Education of head			9.948**
			(2.098)
Life satisfaction			-27.135**
			(-2.130)
Religiosity of wife			-0.086
			(-0.337)
First stage			
Environmental disease	0.024***	0.019**	0.018**
	(2.63)	(2.11)	(2.07)
Observations	5,860	5,859	5,530
UIT	0.000	0.000	0.000
WIT with critical value	30.251 (11.07)	44.690 (11.03)	69.913 (11.01)
OIT	0.434	0.287	0.250

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the labor supply equation. Dependent variable is the hours of labor provided by the head of the household. All variables are defined in Table 2.1. Estimation method is two-stage least squares with robust standard errors, where the first stage includes instruments constructed using the method of Lewbel (2012) and environmental disease. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a values lower than 0.05 to reject the null hypothesis at the 5% level. WIT is the Wald *F*-statistic of the weak identification test by Kleibergen and Paap, which must be higher than its critical value to reject the null. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to reject the null hypothesis at the 5% level. The ***, ** and * denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.5
Heterogeneous effect for households with polluting jobs

	I	II	III
Environmental awareness	-127.340***	-88.541**	-115.778**
	(-2.791)	(-1.974)	(-2.467)
Household income	0.001***	0.001***	0.001***
	(5.381)	(4.619)	(4.103)
Household wealth	-0.000***	-0.000**	-0.000**
	(-3.789)	(-2.199)	(-2.259)
Own house	56.765	78.651**	67.486*
	(1.325)	(2.036)	(1.709)
House rooms	26.358***	20.509***	19.092***
	(4.811)	(3.739)	(3.384)
Mortgage	50.691	-0.267	-5.765
	(1.083)	(-0.007)	(-0.149)
Polluting job	86.475***	32.699	35.525
	(2.544)	(1.687)	(1.902)
Environmental awareness*	8.062	-5.412	6.191
Polluting job	(0.099)	(-0.071)	(0.079)
Age of head		55.106***	56.955***
		(10.058)	(10.041)
Age of head squared		-0.681***	-0.691***
		(-10.958)	(-10.748)
Gender of head		142.597***	146.863***
		(4.346)	(4.403)
No. of children		-31.179***	-30.694***
		(-3.416)	(-3.193)
Married head		65.727**	58.501*
		(2.028)	(1.726)
Health of head			-19.486
			(-1.621)
Education of head			11.241**
			(2.321)
Life satisfaction			-27.108**
			(-2.130)
Religiosity of wife			-0.089
			(-0.352)
Observations	5,860	5,859	5,530
UIT	0.000	0.000	0.000
WIT with critical value	477.40 (11.06)	348.61 (11.03)	275.80 (11.00)
OIT	0.479	0.247	0.141

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the labor supply equation. Dependent variable is the hours of labor provided by the head of the household. All variables are defined in Table 2.1. Estimation method is two-stage least squares with robust standard errors, where the first stage includes instruments constructed using the method of Lewbel (2012) and environmental disease. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a values lower than 0.05 to reject the null hypothesis at the 5% level. WIT is the Wald *F*-statistic of the weak identification test by Kleibergen and Paap, which must be higher than its critical value to reject the null. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to reject the null hypothesis at the 5% level. The ***, ** and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.6
Environmental awareness and polluting consumption: OLS regressions

	I	II	III
Environmental awareness	-350.505***	-181.963*	-209.604**
	(-3.356)	(-1.805)	(-2.022)
Household income	0.006***	0.005***	0.005***
	(5.964)	(4.975)	(5.120)
Household wealth	-0.000***	-0.000**	-0.000***
	(-4.011)	(-2.459)	(-2.815)
Own house	94.690	319.919***	318.218***
	(0.828)	(2.724)	(2.629)
House rooms	205.548***	130.569***	127.388***
	(10.091)	(6.541)	(6.124)
Mortgage	508.065***	230.533*	256.935*
	(3.775)	(1.733)	(1.801)
Age of head		38.116***	41.249***
		(4.588)	(4.710)
Age of head squared		-0.581***	-0.588***
		(-7.350)	(-7.168)
Gender of head		208.210***	235.215***
		(2.805)	(3.108)
No. of children		147.530***	169.067***
		(4.450)	(4.958)
Married head		859.341***	804.896***
		(10.094)	(9.342)
Health of head			-68.716**
			(-2.375)
Education of head			-3.663
			(-0.296)
Life satisfaction			-0.663
			(-0.023)
Religiosity of wife			0.415***
			(3.373)
Observations	8,506	8,502	8,055
R-squared	0.135	0.188	0.197
State dummies	Yes	Yes	Yes

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the consumption equation. Dependent variable is the dollar expense of the polluting consumption of the household. All variables are defined in Table 2.1. Estimation method is OLS with robust standard errors. The ***, **, and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.7
Environmental awareness and polluting consumption for the employed

	I	II	III
Environmental awareness	-324.563**	-220.201*	-218.509*
	(-2.551)	(-1.760)	(-1.707)
Household income	0.004***	0.003***	0.004***
	(4.428)	(3.698)	(4.106)
Household wealth	-0.000***	-0.000	-0.000
	(-2.682)	(-1.313)	(-1.587)
Own house	421.907***	365.661***	426.421***
	(3.276)	(2.817)	(3.256)
House rooms	206.488***	129.627***	134.910***
	(8.228)	(5.053)	(5.010)
Mortgage	128.720	-17.571	-33.873
	(1.097)	(-0.161)	(-0.303)
Age of head		71.158***	69.934***
		(4.540)	(4.368)
Age of head squared		-0.870***	-0.861***
		(-4.871)	(-4.738)
Gender of head		212.709**	252.396***
		(2.256)	(2.618)
No. of children		161.563***	186.003***
		(4.008)	(4.483)
Married head		857.579***	758.253***
		(8.178)	(7.161)
Health of head			10.582
			(0.250)
Education of head			-16.200
			(-1.010)
Life satisfaction			11.562
			(0.269)
Religiosity of wife			1.084
			(1.441)
Observations	5,759	5,758	5,440
R-squared	0.110	0.144	0.155

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the consumption equation. Dependent variable is the dollar expense of the polluting consumption of the household. All variables are defined in Table 2.1. All three specifications include state dummies. Estimation method is OLS with robust standard errors. The ***, **, and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.8
Environmental awareness and consumption for the employed: IV regressions

	I	II	III
Environmental awareness	-297.053**	-211.049	-185.729
	(-1.973)	(-1.396)	(-1.265)
Household income	0.004***	0.003***	0.004***
	(4.451)	(3.721)	(4.123)
Household wealth	-0.000***	-0.000	-0.000
	(-2.701)	(-1.322)	(-1.601)
Own house	421.063***	365.571***	426.050***
	(3.284)	(2.832)	(3.273)
House rooms	206.392***	129.587***	134.817***
	(8.249)	(5.069)	(5.035)
Mortgage	128.921	-17.600	-33.801
	(1.104)	(-0.162)	(-0.304)
Age of head		71.193***	70.024***
		(4.568)	(4.403)
Age of head squared		-0.871***	-0.862***
		(-4.901)	(-4.780)
Gender of head		212.901**	252.911***
		(2.270)	(2.639)
No. of children		161.674***	186.258***
		(4.021)	(4.511)
Married head		857.388***	757.292***
		(8.219)	(7.190)
Health of head			10.790
			(0.257)
Education of head			-16.534
			(-1.036)
Life satisfaction			11.454
			(0.268)
Religiosity of wife			1.090
			(1.456)
Observations	5,759	5,758	5,440
UIT	0.000	0.000	0.000
WIT with critical value	34.451 (11.07)	43.193 (11.04)	70.426 (11.02)
OIT	0.466	0.272	0.245

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the consumption equation. Dependent variable is the dollar expense of the polluting consumption of the household. All variables are defined in Table 2.1. Estimation method is two-stage least squares with robust standard errors, where the first stage includes instruments constructed using the method of Lewbel (2012). UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a values lower than 0.05 to reject the null hypothesis at the 5% level. WIT is the Wald *F*-statistic of the weak identification test by Kleibergen and Paap, which must be higher than its critical value to reject the null. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to reject the null hypothesis at the 5% level. The ***, ** and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.9
Environmental awareness and consumption for the employed: IV regressions with two instrumental variables

	I	II	III
Environmental awareness	-296.968**	-206.836	-183.064
	(-1.978)	(-1.368)	(-1.247)
Household income	0.004***	0.003***	0.004***
	(4.451)	(3.720)	(4.123)
Household wealth	-0.000***	-0.000	-0.000
	(-2.701)	(-1.322)	(-1.601)
Own house	421.060***	365.530***	426.020***
	(3.283)	(2.831)	(3.273)
House rooms	206.392***	129.569***	134.809***
	(8.251)	(5.070)	(5.035)
Mortgage	128.922	-17.614	-33.795
	(1.104)	(-0.163)	(-0.304)
Age of head		71.209***	70.031***
		(4.569)	(4.404)
Age of head squared		-0.871***	-0.863***
		(-4.902)	(-4.780)
Gender of head		212.990**	252.953***
		(2.271)	(2.640)
No. of children		161.726***	186.278***
		(4.022)	(4.511)
Married head		857.301***	757.214***
		(8.218)	(7.189)
Health of head			10.807
			(0.257)
Education of head			-16.561
			(-1.038)
Life satisfaction			11.446
			(0.268)
Religiosity of wife			1.090
			(1.457)
First stage			
Environmental disease	0.023***	0.020***	0.017***
	(2.66)	(2.17)	(1.98)
Observations	5,759	5,758	5,440
UIT	0.000	0.000	0.000
WIT with critical value	34.790 (11.07)	44.663 (11.03)	70.733 (11.01)
OIT	0.502	0.293	0.273

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the consumption equation. Dependent variable is the dollar expense of the polluting consumption of the household. All variables are defined in Table 2.1. Estimation method is two-stage least squares with robust standard errors, where the first stage includes instruments constructed using the method of Lewbel (2012) and environmental disease. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a values lower than 0.05 to reject the null hypothesis at the 5% level. WIT is the Wald *F*-statistic of the weak identification test by Kleibergen and Paap, which must be higher than its critical value to reject the null. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to reject the null hypothesis at the 5% level. The ***, ** and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.10
Heterogeneous effect for households with polluting jobs

	I	II	III
Environmental awareness	-183.204	-92.906	-70.606
	(-1.231)	(-0.628)	(-0.474)
Household income	0.004***	0.003***	0.004***
	(4.445)	(3.743)	(4.134)
Household wealth	-0.000***	-0.000	-0.000*
	(-2.816)	(-1.454)	(-1.707)
Own house	347.798***	332.895**	395.917***
	(2.655)	(2.541)	(2.995)
House rooms	204.627***	130.565***	134.091***
	(8.329)	(5.125)	(5.051)
Mortgage	154.141	0.354	-19.739
	(1.317)	(0.003)	(-0.177)
Polluting job	489.909***	284.459***	284.667***
	(4.832)	(2.751)	(2.698)
Environmental awareness*	-66.927	-45.901	-130.339
Polluting job	(-0.195)	(-0.138)	(-0.380)
Age of head		67.601***	67.353***
		(4.328)	(4.234)
Age of head squared		-0.832***	-0.832***
		(-4.675)	(-4.610)
Gender of head		165.259*	207.309**
		(1.764)	(2.161)
No. of children		162.601***	188.490***
		(4.069)	(4.586)
Married head		840.484***	742.885***
		(8.016)	(7.046)
Health of head			12.782
			(0.305)
Education of head			-8.753
			(-0.550)
Life satisfaction			10.898
			(0.255)
Religiosity of wife			1.099
			(1.475)
Observations	5,759	5,758	5,440
UIT	0.000	0.000	0.000
WIT with critical value	468.69 (11.06)	336.86 (11.03)	267.43 (11.00)
OIT	0.509	0.816	0.837

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the consumption equation. Dependent variable is the dollar expense of the polluting consumption of the household. All variables are defined in Table 2.1. Estimation method is two-stage least squares with robust standard errors, where the first stage includes instruments constructed using the method of Lewbel (2012) and environmental disease. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a values lower than 0.05 to reject the null hypothesis at the 5% level. WIT is the Wald *F*-statistic of the weak identification test by Kleibergen and Paap, which must be higher than its critical value to reject the null. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to reject the null hypothesis at the 5% level. The ***, ** and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Appendix 2.A

Table 2.A1
Summary statistics

Variable	Obs.	Mean	Std. dev.	Min.	Max.
Labor supply	8,907	1,490.6	1,066.6	0	5,824
Polluting consumption	8,713	2,791.1	2,804.4	0	60,000
Environmental awareness	8,898	0.065	0.246	0	1
Household income	8,907	64,873.5	83,647.7	-70,000	2,420,000
Household wealth	8,907	206,076.7	885,400.1	-990,023	4.25e+07
Own house	8,907	0.529	0.499	0	1
House rooms	8,700	5.293	2.418	0	19
Mortgage	8,898	0.391	0.600	0	9
Age of head	8,907	45.21	16.61	17	98
Gender of head	8,907	0.679	0.467	0	1
No. of children	8,907	0.801	1.175	0	11
Married head	8,903	0.522	0.500	0	1
Health of head	8,876	2.516	1.067	1	5
Education of head	8,525	13.06	2.534	0	17
Life satisfaction	8,907	2.176	0.979	0	9
Religiosity of wife	8,809	18.20	116.1	0	9,490
Polluting job	8,907	0.237	0.426	0	1
Environmental disease	8,907	0.056	0.230	0	1

Notes: The table reports the number of observations and summary statistics (mean, standard deviation, minimum, and maximum) for the variables used in the empirical analysis.

Table 2.A2
Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Environmental awareness	1.00															
2. Household income	0.18	1.00														
3. Household wealth	0.12	0.43	1.00													
4. Own house	0.13	0.31	0.19	1.00												
5. House rooms	0.13	0.41	0.24	0.54	1.00											
6. Mortgage	0.07	0.25	0.04	0.62	0.38	1.00										
7. Age of head	0.12	0.08	0.18	0.37	0.22	0.09	1.00									
8. Gender of head	0.05	0.25	0.09	0.25	0.22	0.20	-0.02	1.00								
9. No. of children	-0.07	0.01	-0.07	-0.04	0.17	0.05	-0.32	0.00	1.00							
10. Married head	0.08	0.33	0.12	0.39	0.41	0.29	0.08	0.71	0.17	1.00						
11. Health of head	-0.05	-0.18	-0.07	-0.06	-0.12	-0.09	0.28	-0.13	-0.08	-0.12	1.00					
12. Education of head	0.17	0.30	0.15	0.17	0.24	0.15	-0.06	0.06	-0.08	0.08	-0.26	1.00				
13. Life satisfaction	-0.02	-0.12	-0.07	-0.15	-0.12	-0.08	-0.09	-0.10	-0.04	-0.17	0.21	-0.05	1.00			
14. Religiosity of wife	-0.01	0.04	0.02	0.08	0.07	0.06	0.05	0.11	0.01	0.15	-0.02	0.01	-0.03	1.00		
15. Polluting job	-0.01	0.03	0.06	0.14	0.06	0.04	0.17	0.18	-0.04	0.16	0.05	-0.14	-0.04	0.02	1.00	
16. Environmental disease	0.06	0.02	0.06	0.06	0.04	-0.01	0.17	-0.03	-0.08	-0.01	0.05	0.03	0.01	0.01	0.03	1.00

Table 2.A3
Environmental awareness and labor supply: OLS regressions

	I	II	III
Environmental awareness	-188.670***	-70.383*	-113.188***
	(-4.237)	(-1.860)	(-2.924)
Household income	0.004***	0.003***	0.002***
	(6.884)	(6.133)	(5.551)
Household wealth	-0.000***	-0.000***	-0.000***
	(-3.514)	(-3.312)	(-3.382)
Own house	-231.872***	112.088***	60.028*
	(-4.985)	(3.321)	(1.758)
House rooms	38.696***	33.538***	24.936***
	(5.352)	(5.352)	(4.036)
Mortgage	268.785***	80.105***	98.104***
	(4.649)	(2.596)	(3.073)
Age of head		33.426***	40.600***
		(9.964)	(11.832)
Age of head squared		-0.599***	-0.633***
		(-18.891)	(-19.676)
Gender of head		96.011***	82.940***
		(3.003)	(2.590)
No. of children		-53.995***	-48.912***
		(-5.585)	(-4.919)
Married head		116.256***	113.183***
		(3.430)	(3.299)
Health of head			-134.592***
			(-12.479)
Education of head			15.231***
			(3.125)
Life satisfaction			-22.244**
			(-1.978)
Religiosity of wife			-0.122***
			(-2.962)
Observations	8,683	8,679	8,215
R-squared	0.122	0.295	0.314
State dummies	Yes	Yes	Yes

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the labor supply equation. Dependent variable is the hours of labor provided by the head of the household. All variables are defined in Table 2.1. Estimation method is OLS with robust standard errors. The ***, **, and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.A4
Treatment effects model: Labor supply equation

	I	II	III
Environmental awareness	-665.351***	-587.699***	-611.788***
	(-6.039)	(-5.074)	(-5.209)
Household income	0.001***	0.001***	0.001***
	(5.219)	(4.497)	(3.966)
Household wealth	-0.000***	-0.000**	-0.000**
	(-3.638)	(-2.090)	(-2.141)
Own house	69.458	81.883**	70.706*
	(1.636)	(2.131)	(1.796)
House rooms	26.475***	20.349***	19.051***
	(4.801)	(3.702)	(3.371)
Mortgage	47.094	-1.819	-6.969
	(1.017)	(-0.048)	(-0.181)
Age of head		55.215***	57.003***
		(10.091)	(10.047)
Age of head squared		-0.681***	-0.691***
		(-10.970)	(-10.740)
Gender of head		148.741***	153.499***
		(4.554)	(4.622)
No. of children		-31.529***	-31.228***
		(-3.450)	(-3.247)
Married head		67.275**	59.927*
		(2.080)	(1.769)
Health of head			-19.340
			(-1.609)
Education of head			10.258**
			(2.161)
Life satisfaction			-27.056**
			(-2.124)
Religiosity of wife			-0.087
			(-0.341)
First stage			
Environmental disease	0.480***	0.443***	0.454***
	(4.74)	(4.45)	(4.47)
Observations	5,860	5,859	5,530
Lambda	258.9***	234.9***	238.7***

Table 2.A5
Control for polluting consumption in Table 2.5

	I	II	III
Environmental awareness	-113.732**	-111.789**	-93.649**
	(-2.566)	(-2.513)	(-2.234)
Household income	0.001***	0.001***	0.001***
	(5.197)	(4.527)	(3.947)
Household wealth	-0.000***	-0.000**	-0.000**
	(-3.625)	(-1.988)	(-2.072)
Own house	35.230	62.539	48.203
	(0.822)	(1.596)	(1.204)
House rooms	21.481***	18.025***	16.048***
	(3.965)	(3.284)	(2.848)
Mortgage	81.257*	26.322	21.974
	(1.748)	(0.685)	(0.565)
Polluting consumption	0.019***	0.013***	0.015***
	(4.473)	(3.056)	(4.067)
Age of head		54.988***	57.309***
		(10.305)	(10.408)
Age of head squared		-0.683***	-0.699***
		(-11.343)	(-11.261)
Gender of head		143.446***	146.008***
		(4.394)	(4.397)
No. of children		-33.811***	-33.806***
		(-3.666)	(-3.492)
Married head		53.969*	47.029
		(1.660)	(1.383)
Health of head			-21.963*
			(-1.808)
Education of head			10.091**
			(2.115)
Life satisfaction			-27.624**
			(-2.192)
Religiosity of wife			-0.095
			(-0.383)
Observations	5,759	5,758	5,440
UIT	0.000	0.000	0.000
WIT with critical value	42.097 (11.06)	37.167 (11.03)	53.860 (11.00)
OIT	0.326	0.476	0.243

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the labor supply equation. Dependent variable is the hours of labor provided by the head of the household. All variables are defined in Table 2.1. Estimation method is two-stage least squares with robust standard errors, where the first stage includes instruments constructed using the method of Lewbel (2012) and environmental disease. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a values lower than 0.05 to reject the null hypothesis at the 5% level. WIT is the Wald *F*-statistic of the weak identification test by Kleibergen and Paap, which must be higher than its critical value to reject the null. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to reject the null hypothesis at the 5% level. The ***, ** and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.A6
Control for labor supply in Table 2.10

	I	II	III
Environmental awareness	-230.622*	-135.833	-194.293
	(-1.663)	(-0.866)	(-1.522)
Household income	0.004***	0.003***	0.003***
	(4.103)	(3.492)	(4.003)
Household wealth	-0.000**	-0.000	-0.000
	(-2.471)	(-1.239)	(-1.491)
Own house	408.401***	353.127***	415.393***
	(3.243)	(2.744)	(3.195)
House rooms	199.453***	125.868***	131.264***
	(8.116)	(4.982)	(4.943)
Mortgage	106.708	-22.403	-38.178
	(0.943)	(-0.207)	(-0.344)
Labor supply	0.268***	0.177***	0.201***
	(5.063)	(3.294)	(4.046)
Age of head		61.493***	58.217***
		(3.845)	(3.617)
Age of head squared		-0.751***	-0.718***
		(-4.094)	(-3.912)
Gender of head		188.140**	222.361**
		(2.021)	(2.336)
No. of children		167.980***	192.274***
		(4.180)	(4.684)
Married head		844.771***	746.375***
		(8.070)	(7.115)
Health of head			14.995
			(0.358)
Education of head			-18.228
			(-1.150)
Life satisfaction			17.064
			(0.400)
Religiosity of wife			1.101
			(1.541)
Observations	5,759	5,758	5,440
UIT	0.000	0.000	0.000
WIT with critical value	81.550 (11.06)	35.171 (11.03)	5,208.84 (11.00)
OIT	0.581	0.413	0.368

Notes: The table reports coefficients and t-statistics (in parentheses) from the estimation of the consumption equation. Dependent variable is the dollar expense of the polluting consumption of the household. All variables are defined in Table 2.1. Estimation method is two-stage least squares with robust standard errors, where the first stage includes instruments constructed using the method of Lewbel (2012) and environmental disease. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a values lower than 0.05 to reject the null hypothesis at the 5% level. WIT is the Wald *F*-statistic of the weak identification test by Kleibergen and Paap, which must be higher than its critical value to reject the null. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to reject the null hypothesis at the 5% level. The ***, ** and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Table 2.A7
Simultaneous equation model for equations (2.1) and (2.2)

Dependent variable:	Labor supply	Consumption
Consumption	-0.006	
	(-0.23)	
Labor supply		0.350*
		(1.88)
Environmental awareness	-121.070***	-193.206*
	(-2.93)	(-1.68)
Household income	0.002***	0.004***
	(12.92)	(5.84)
Household wealth	0.000***	0.000**
	(-5.25)	(-2.18)
Own house	48.083**	330.318***
	(1.47)	(3.67)
House rooms	22.933***	113.917***
	(3.65)	(6.91)
Mortgage	135.676***	210.577***
	(5.22)	(2.80)
Age of head	39.857***	31.598***
	(11.03)	(2.79)
Age of head squared	-0.627***	-0.412***
	(-17.13)	(-2.87)
Gender of head	81.528***	201.705**
	(2.59)	(2.27)
No. of children	-47.550***	196.736***
	(-4.50)	(6.78)
Married head	127.065***	753.818***
	(3.43)	(8.19)
Health of head	-136.636***	
	(-12.86)	
Education of head	15.934***	
	(3.66)	
Life satisfaction	-22.755**	
	(-2.10)	
Religiosity of wife	-0.112	
	(-1.35)	
Observations	8,055	

Notes: The table reports coefficients and t-statistics (in parentheses) from the simultaneous estimation of the labor supply and the consumption equations. Dependent variables are the hours of labor provided by the head of the household and the dollar expense of the polluting consumption of the household, respectively. All variables are defined in Table 2.1. Estimation method is full information maximum likelihood with robust standard errors. As life satisfaction was found to be an insignificant determinant of polluting consumption, it is not included in the consumption equation to satisfy the identification restriction. The ***, ** and * marks denote statistical significance at the 1, 5 and 10% level, respectively.

Chapter 3
Relative effective taxation and income inequality: Evidence from OECD countries

3.1 Introduction

The impact of redistributive taxation on economic outcomes in general and income inequality in particular, has attracted the interest of a large body of research in public policy at least since the time of Pigou (1920). However, the vast majority of the existing studies examine the impact of taxes in isolation from one another, while they are severely restrained by the measurement of effective taxation. This chapter examines how changes in the mix of different tax rates, i.e., labor, consumption and capital tax rates, affect income inequality. To the best of our knowledge, this is the first study to examine the impact of *relative tax rates* on inequality using a cross-country panel data set and tax rates that are directly comparable across countries and over time.

Clearly, understanding the effects of the labor, consumption, and capital tax rates relative to each other on income inequality is important from both a theoretical and policy perspective. From a policy perspective, the history of public policy demonstrates that policy makers do not use the various fiscal instruments in isolation of the rest, but combine them in an attempt to influence the economic activity, redistribute income, and allocate the resources (Easterly and Rebelo, 1993; Persson and Tabellini, 1996; Kemmerling, 2005). Thus, it is common practice for the social planner to combine changes in various forms of taxation in an effort to increase public sector efficiency or to promote better economic outcomes. For example, if governments reduce capital tax rates to attract foreign and domestic investments, the current tax revenues may decline in the short run (i.e., until foreign investments are established). To compensate for this fiscal gap, policy makers may decide to simultaneously increase consumption and/or labor taxes. Thus, the total effect on inequality should be one that considers the impact of relative taxes.

Indeed, the literature that examines the impact of relative taxes on inequality is scant and confounded only to theoretical papers (e.g., Cremer, Helmuth, Pestieau, and Rochet, 2001; Freitas, 2012). This class of models further motivates our analysis as it is suggestive of an important channeling of the effect of relative taxation on the real economy and the distribution of income. The main conjecture of this literature is that higher consumption taxes, especially in relation to other forms of taxation, are regressive and lead to a rise in income inequality.

Our study provides the first effort to empirically investigate the effect of relative tax rates on income inequality. We use a cross-country panel data set of OECD countries over the period 1970-2001. This is an ideal setting because of the availability of effective tax rates, which are directly comparable across countries. Specifically, the effective tax rate is defined as the ratio between the tax revenues from particular taxes and the corresponding tax base. This rate incorporates the different socioeconomic characteristics, tax policy and legislation, creating a level playing field between the countries considered.

In turn, our income inequality measure is the fitted values from a regression between the Gini index and the Theil index. This measure of income inequality has three distinct advantages over the other income inequality measures used in the related literature (Galbraith and Kum, 2005). First, the richness of the Theil index allows us to obtain annual estimates of household income inequality for OECD countries that are missing from database of the Gini index. Second, it is more accurate than the Gini coefficient, since the incorporation of the Theil index in the underlying regressions enhances the strength of our measure and accounts for within-country pay dispersion. Third, our measure offers standardized values by using the gross household income as a reference, while the unexplained variations of the Gini index are treated as residuals.

An important issue, however, is the potential reverse causation between economic inequality and taxation that may generate an endogeneity problem in the relationship under consideration (Benabou, 2000; Adam, Kammas, and Lapatinas, 2013). We tackle this issue mainly by constructing a series of variables that measure the extent to which countries are affected by tax competition. We assume that if there is an impact of tax competition on inequality, this impact must be distributed only through the level of the different tax rates, thus satisfying the exclusion restriction. In other words, we assume that tax competition per se does not have an independent effect on income inequality, but can only influence inequality if the endogenous tax rates are adjusted because of elements related to tax competition.

Our preliminary results, based on the *levels* of the various effective tax rates, indicate that only the labor tax rate has a negative and significant effect on income inequality. However, we obtain the exact opposite effect when we exclude from the labor tax rate the social contributions. This finding verifies the strong redistributive effect of social security contributions. In contrast, the relative tax rates exert an important role in determining income inequality. More specifically, an increase of the labor to capital (consumption) tax ratio leads to a higher (lower) level of income inequality. Based on our preferred specification, the impact of a 0.1 absolute increase in the labor to consumption tax ratio with social contributions is equivalent to a 3.4% reduction in inequality. Respectively, a 0.1 absolute increase in the labor to capital tax ratio yields an increase of 1.07% in inequality for the average country. Moreover, the same impact of an increase in the labor to capital tax ratio without social contributions increases income inequality by 1.4%. Finally, we find that as countries become more economically developed the impact of relative tax rates on income inequality diminishes.

The rest of the chapter is structured as follows. Section 3.2 analyzes the theoretical mechanisms through which taxation affects the within-country distribution of income. Section 3.3 describes the data set. Section 3.4 presents and discusses the identification issues, as well as the empirical methodology and the results. Section 3.5 concludes the chapter.

3.2 Theoretical considerations and related literature

Over the last decades almost all OECD countries have substantially redesigned their tax systems. These tax reforms have followed the so-called *tax cut cum base broadening* strategy in the case of top statutory personal and corporate income tax, whereas in the case of consumption taxes the trend has been towards an increased averaged standard VAT rate (OECD, 2011). Meanwhile, in many OECD countries, income inequality has drifted up over the same period (Joumard, Pisu, and Bloch, 2012).

There are multiple mechanisms through which tax rates can exert an impact on income inequality and this discussion is non-exhaustive. The most direct mechanism is through the redistribution of income, which works in a similar fashion for all tax rates (see Gottschalk and Smeeding, 1997). For example, the progressive income taxes have a positive effect on the distribution of income and this is especially true when a state can efficiently raise tax revenue and spend it in social transfers for redistribution (Brandolini and Smeeding, 2007; World of Work Report, 2008). The same holds for corporate taxes, but with the wrinkle that a high corporate taxation can yield a capital flight from the country, which then makes this type of taxation regressive.

Another mechanism through which taxation affects inequality involves the price level. As the literature identifies a positive relationship between inflation and income inequality (Albanesi, 2007), the increase in the consumption tax rate, which raises the prices of end products, will likely increase inequality. Further, when institutions are weak, prices may increase by even more, and this is especially harmful for the low-income households (Warren, 2008). Similarly, an increase in capital tax rates induces an increase in the unit cost of production, which is usually reflected in the end products, thereby raising inequality *via* inflation. In contrast, an increase in the labor tax rate lowers the disposable income of households, leading to a decrease in the aggregate demand and a decline in the price level, thereby decreasing inequality (Ljungqvist and Uhlig, 2000).

A similar strand of arguments comes from the labor economics literature. In particular, when capital tax rates increase, real output decreases as firms might be inclined to flee to other countries with more favorable taxation or even cease operating. Under both scenarios, the unemployment of domestic unskilled workers increases, thus leading to higher inequality (Bettendorf, Van der Horst and De Mooij, 2009).

Clearly, the levels of the three tax rates considered in our study are interrelated in actual economies through their mix, which varies widely among countries. For example, the mix of direct (labor) and indirect (consumption) tax rates varies considerably between European and North American OECD countries, with the former generally having significantly higher consumption tax rates. Indeed, during the period 1970 to 2001, the ratio of the effective labor to consumption tax rate is as high as 1.89 in the U.S. and as low as 0.77 in Ireland and 0.78 in Portugal. A similar picture can be drawn for capital taxation. Even within European countries the ratio of the effective labor tax rate over the capital tax rate has been historically quite different, ranging from 2.31 in Germany to 0.78 in the UK. The same holds for the ratio of the effective consumption to capital tax rate, which ranges from 2.04 in Finland to 0.52 in the U.S. These tax policy differences are quite important and can be perceived as affecting the levels of inequality in ways that the existing empirical literature has not yet considered.

Indeed, the political economy debate on the optimal mix of taxes as a determinant of economic welfare is mainly theoretical and dates back at least to Harberger (1962). This study suggests that, even in a closed economy, imposing a tax on one sector will cause capital to flee to another sector, which might also cause a reallocation of labor taxation. In a similar fashion, we can argue that governments, also based on their specific ideologies and electoral cycles, can compensate e.g. income tax decreases with capital tax increases and *vice versa*.

In turn, Cremer, Helmuth, Pestieau, and Rochet (2001) examine a model of a tax mix between consumption and income taxes and show that the benefits of commodity taxes are of redistributive nature, which contradicts the traditional view of Atkinson and Stiglitz (1976) that commodity taxes tend to be regressive and can be justified (if at all) only by efficiency considerations. Freitas (2012) attributes differences in the optimal tax mix to the extent of the informal sector, noting that high consumption taxes is a notable characteristic of developing countries with high tax evasion. Further, shifting the tax mix to less-distorting taxes, in particular from labor income and corporate taxes to consumption taxes would improve incentives to work, save and invest, but could undermine equity (OECD, 2012).

Our study is broadly related to a number of other single country studies on tax policy and income inequality. For example Engel, Galetovic, and Raddatz (1999) quantify the direct impact of taxes on the household income distribution in Chile and estimate the distributional effect of several changes in the tax structure. They find that a high-yield proportional tax can have a far bigger redistributive impact than a low-yield progressive tax. The studies by Martínez-Vázquez, Vulovic, and Dodson (2012) and Weller (2007) are, to the best of our knowledge, the only ones that use cross-country panel data to examine the separate impact of tax rates on inequality. These studies conclude that progressive personal income taxes and corporate income taxes reduce income inequality as well as higher shares of GDP spent on social welfare, education, health and housing public expenditures.

Our study is also related with two large but separate literatures on the effective tax rates and income inequality, respectively. Concerning the former Mendoza, Razin, and Tesar (1994) are among the first to compute effective tax rates for large industrial countries, as a means to highlight the important international differences in tax policy. Importantly, Martinez-Mongay (2000) refines these tax rates for a larger panel of OECD countries, creating a unique data set and leveling the playing field between these countries. These studies spurred a large literature on the effects and the determinants of effective taxation. For example, Devereux, Lockwood, and Redoano (2008) study whether countries compete over corporate tax rates, while Backus, Henriksen, and Storesletten (2008) study the effect of these taxes on the global allocation of capital.

The literature on the distribution of income is also quite large and it generally concludes that there is a global rising trend in income inequality (Alvaredo, Atkinson, Piketty, and Saez, 2013). This increasing trend has been attributed to a number of factors, such as financial liberalization and globalization, the rising skill gap between white and blue collar labor, increasing bargaining power of top-income people (Hoeller, Joumard, and Koske, 2014; Milanovic, 2012), etc.

Fiscal policy is the main government tool to affect income inequality through the redistribution of income. A number of empirical studies provide evidence that direct taxation is more redistributive than the indirect taxation, and that social transfers lead to a more narrow distribution of income.[15] However, the results on the effect of specific types of taxation on inequality are mixed. For example, these studies find that increasing spending on social benefits does not always lead to a reduction in inequality. Evidently, even though there is a significant body of empirical literature on the separate effect of the various tax rates on inequality, there is to our knowledge no empirical work on the relative effect of these tax rates on inequality. Further, the channels in this literature point to the redistributive nature of the direct and indirect taxation as the main driving force of income distribution and its tightening. Yet, as we discuss above, there could be other channels working beyond the redistributive nature of taxation.

The two common characteristics of most of the above studies is that (i) they use statutory tax rates, thereby failing to fully capture the complexity of the tax system as they ignore the tax base, and (ii) they do not examine empirically the mix of different taxes in explaining income inequality differences across countries. It is precisely these gaps in the literature that we aim to fill in the empirical analysis.

[15] This is the essence of the work by Chu, Davoodi, and Gupta (2004); Niehues (2010); Ospina (2010); Martínez-Vázquez, Vulovic, and Moreno-Dodson (2012); Muinelo-Gallo and Roca-Sagles (2013); and Woo, Bova, Kinda, and Zhang (2013).

3.3 Data and variables

We examine the relationship between effective taxation and income inequality using country-level data. The estimated equation is of the following general form:

$$y_{i,t} = a_0 + a_1 tax_{i,t} + a_2 x_{i,t} + u_{i,t}, \tag{3.1}$$

where y is a measure of income inequality observed in country i at time t, tax is the variable characterizing the various tax rates, x is the vector of control variables, and u is the stochastic term.

We use a panel of 17 OECD countries spanning the period 1970-2001, for which we have information on both effective taxation and income inequality. In particular, the data on the effective tax rates for all labor, consumption, and capital tax rates are only available for this period, and they represent a unique effort to level the playing field in terms of having direct comparability of these tax rates between countries. Although the time dimension of our sample is dictated by data availability on effective tax rates, it still constitutes an interesting period of examination as most OECD countries implemented fundamental tax reforms during the 1980s and 1990s (OECD, 2011). These tax reforms were driven by the need to provide a more competitive fiscal environment in the sense of fostering greater investment, risk-taking, and entrepreneurship. However, the income distributional consequences of these tax changes remain an open question.

As in most empirical studies of income inequality, our panel is unbalanced in the sense that some observations are missing for some years and specific countries. Table 3.1 reports how the variables employed in the empirical analysis are measured and their data sources. Our main data sources are the effective tax rates from the Economic and Financial Affairs (ECFIN) provided by Carlos Martinez-Mongay (2000), the World Development Indicators (WDI) database, the Economic Freedom of the World database by the Frazer Institute, the Polity IV (2004) database and the KOF Index of Globalization. Table 3.2 provides basic descriptive statistics, while

Table 3.3 reports the correlation coefficients between the explanatory variables of income inequality.

[Insert Tables 3.1, 3.2 and 3.3 about here]

3.3.1 Income inequality

As a measure of income inequality we use the Estimated Household Income Inequality (EHII) data set. This is a global data set that combines the information in the databases by Deininger and Squire (1996) (D&S), the University of Texas Inequality Project, and the United Nations Industrial Development Organization database (UTIP-UNIDO). More specifically, the estimates of gross household income inequality are the fitted values from a regression between the D&S inequality measures (Gini index) and the UTIP-UNIDO pay inequality measures (Theil index), while controlling for the source characteristics in the D&S data and for the share of manufacturing in total employment (for more details, see Galbraith and Kum, 2004).

The EHII data set has three distinct advantages over that of D&S and other income inequality databases. First, the incorporation of the UTIP-UNIDO data set provides annual estimates of household income inequality for countries that are missing in the D&S data set. Second, the EHII data set borrows accuracy from the UTIP-UNIDO pay dispersion measures. Simple Gini coefficients do not account for within-country pay dispersion, whereas the incorporation of the Theil index in the underlying regressions enhances the strength of the EHII. Third, it is well-known that the D&S Gini coefficients are, in some cases, either implausibly low or implausibly high (e.g., Galbraith and Kum, 2004), and this likely stems from the differences in the means through which the Gini coefficients are constructed (e.g., income-based vs. expenditure-based). EHII offers standardized measures by using household gross income as a reference, while the unexplained variations in the D&S data set are treated as residuals.

3.3.2 Tax rates

The main explanatory variables are the ECFIN effective tax rates. We use both the effective and implicit labor, consumption, and capital tax rates. The effective labor tax is defined as the ratio of the non-wage labor cost and labor income tax revenues to gross wages. The implicit labor tax rate is the effective tax on employed labor after excluding the taxation of the self-employed labor income. Labor taxes include total social security contributions, taxes on payroll and workforce, social security contributions paid by the employers, as well as taxes on wages and salaries. The consumption tax rate is the ratio of tax revenues from consumption taxes to the pre-tax value of consumption or the difference between the consumer price (post-tax price) and the producer price (pre-tax price). The effective consumption tax rate is expressed as a percentage of the producer price and the implicit tax is expressed in terms of consumer prices. Finally, the capital tax rate includes personal capital income taxes, corporate income taxes, and property taxes, where the depreciation is included in the capital tax base. The effective capital tax excludes the imputed wage income of the self-employed, whereas the implicit capital tax incorporates this item as capital income.

For our analysis, and given that we consider the more general measure of inequality possible, the effective labor tax is perhaps a more appropriate variable compared to the implicit labor tax. This is because the latter is the effective tax rate on the income of employed labor only. In a similar vein, we prefer the effective capital tax because the wage of self-employed income is not considered as capital income but as labor income. Finally, the explicit and implicit consumption taxes refer to the same tax expressed in terms of producer and consumer prices, respectively, and yield similar outcomes. Thus, for the most part of the empirical analysis, we place more emphasis on effective tax rates.

We focus on labor, consumption, and corporate taxes both in terms of their direct effect on income inequality, as well as in terms of their relative tax burden. To this end, we construct six new variables, namely the ratio of effective labor to capital tax burden, the ratio of effective labor to consumption tax burden and the ratio of effective consumption to capital tax burden, as well as the corresponding ratios using the implicit tax rates.

As already mentioned the effective labor taxes from the ECFIN database include social contributions. Social contributions are paid on a compulsory or voluntary basis by employers or employees or the self- or non-employed to insure against social risks (sickness, family disability, etc.). The pure effect of the tax structure on income inequality may be blurred by these contributions (Adam and Kammas, 2007). To account for this possibility, we also use the decomposed effective labor taxes (i.e. labor taxes excluding social contributions) and compute the corresponding ratios of relative tax burdens.

3.3.3 Control variables

Following the related literature, we use an array of explanatory variables to control for population, education, growth, development, and price stability (e.g., Delis, Hasan, and Kazakis, 2013). These variables are observed at the country-year level and data are collected from the WDI. *Population* is the natural logarithm of total population, which counts all residents regardless of their legal status or citizenship. We control for the population of a country, since changes in the dynamics of population can influence income inequality. *Education* is the ratio of secondary total enrollment to the population of the specific age group. A higher school enrollment rate is widely considered as a factor lowering income inequality (e.g., Barro, 1999). *Growth* is the annual percentage growth rate of GDP at constant 2005 $U.S prices.[16] GDP per capita (the proxy for economic development) is the natural logarithm of gross domestic product divided by the midyear population. The latter two variables capture the effect of macroeconomic conditions and overall economic development on income

[16] Using 2005 as the base year is not an issue, even though our sample ends in 2001. This is essentially because there are no changes in the growth variable when we use a different base year. Naturally, using 1995, 1985, or any other year to produce constant prices has no effect on our results.

inequality.[17] Finally, *price stability* is the standard deviation of inflation, which controls for price fluctuations that have been shown in the literature to primarily affect the poor (Albanesi, 2007).

In addition, we control for the governmental involvement in the production process (Ashby and Sobel, 2008). We use government size as a proxy for the extent to which countries rely on the policies of the central government to allocate resources, goods, and services. This variable is measured by the summation of government spending, tax revenues, and investment as a share of GDP. We also use a measure of the overall level of tariffs, which generally constrain international trade and tend to widen inequality (Baier and Bergstrand, 2001). We obtain these variables from the Economic Freedom of the World annual report.

Although *tariffs* represents institutional obstacles to international economic transactions, it does not fully capture crucial elements of economic integration, such as the actual level of cross-border direct or portfolio investment. To this end, we use a more general measure of economic globalization, which includes these aspects as potential determinants of inequality. This measure additionally controls for the fact that capital taxes are less progressive in open economies because capital can flee and the tax burden can be shifted to the less mobile labor (Martínez-Vázquez, Vulovic, and Dodson, 2012).

We additionally use a political globalization index that encompasses information on the number of embassies in one country, membership in international organizations, and international treaties. The effect of political globalization on inequality is ambiguous. On the one hand, the opponents of political globalization argue that the elements comprising our variable tend to increase lobbying and the favoritism of political and economic elites. In turn, this increases the gap between the rich and the poor, e.g. *via* the buildup of institutions that do not favor redistribution policies. On the other hand, the proponents of political globalization suggest that it enhances interaction and cooperation with other countries, strengthens the institutions

[17] Instead of *growth* we also use the unemployment rate as a control variable. The two variables are highly correlated and provide similar results.

especially of poor countries, increases economic activity, and reinforces competition. All these create more equal opportunities. Information on these two variables is from the KOF Index of Globalization.

As a proxy for the level of democracy we use the Polity index taken from the Polity IV (2004) database. The Polity index focuses on the institutional structure of the political regimes. The variable Polity is computed by subtracting the Autocracy score from the Democracy score given in Polity IV. The Polity index obtains values from -10 to 10, with a score equal to -10 (+10) indicating a strongly autocratic (democratic) regime. The theoretical prior of the effect of democracy on income inequality is also unclear. According to Lenski (1966), this increased political equality observed in more democratic regimes leads to more economic equality, because the equal distribution of goods and services is one of the most common demands of the voters. In contrast, others (e.g., Gradstein and Milanovic, 2000; Beitz, 1982) find a positive link between democracy and inequality. They argue that authoritarian regimes are more likely to pursue egalitarian policies because they are better at protecting the interests of the poor. For example, even though democracies are more receptive to demands by voters, they tend to place an unequal weight on those demands favoring the elites.

We further experiment with over 100 other variables from various data sources, including institutional and demographic characteristics of countries. The former include variables such as corruption and the rule of law that have been shown to affect income inequality especially in developing countries (e.g., Freitas, 2012). The latter characteristics include variables such as ethnolinguistic fractionalization and polarization, population density, and urbanization rates. We find that in our sample these effects are statistically insignificant, with the results probably driven by the relative homogeneity of our sample of OECD countries across these dimensions and the use of country fixed effects.

3.4 Empirical methodology and results

3.4.1 Identification issues

In this study we consider the causal effect of taxes and tax structure on income inequality. However, causality may run in the opposite direction owing to a potential effect of inequality on labor and capital taxes. Adam, Kammas, and Lapatinas (2013) develop a theoretical model in the fashion of Persson and Tabellini (2000) and show that higher inequality increases capital taxation and reduces labor income taxation. This study attributes this finding to the fact that policy makers cater, at least to some extent, for the wishes of the median voter.

To rule out reverse causality and omitted variable bias, we use an instrumental variables (IV) approach. Specifically, we construct measures of tax competition faced by individual countries. Tax competition is present when governments lower their tax rates, especially capital tax rates, to encourage the inflow of productive resources or discourage the exodus of those resources, e.g. attract foreign direct investment (Devereux, Griffith, and Klemm, 2002). The same holds for specific types of labor and/or consumption taxes (e.g., lower consumption taxes in tourism-related services in specific regions). Tax competition can cause inequality either within a specific country or across different countries. The former can emerge because some tax payers, either firms or consumers, face favorable taxes. For example, firms that reside in tourist areas that are favorably taxed have an advantage over other types of firms. The cross-country inequality arises because of the very nature of the existence of tax competition that is the desire to attract foreign direct investment.[18] However, and most notably, a necessary condition for the potency of these mechanisms is for tax competition to alter either the absolute level of capital, labor and consumption taxes or their relative levels. Indeed, it is unlikely that the mere existence of tax competition would have an independent direct effect on inequality, i.e., not through changes in

[18] The desire to attract FDI is also relevant to the within-country income inequality. For example, capital taxes are lower and compensated by higher consumption taxes.

taxation and this implies that the exclusion restriction for tax competition measures to be used as instrumental variables are satisfied.[19]

We can construct three tax competition measures for labor, consumption, and capital, respectively. Following the related literature (Redoano, 2007; Devereux, Lockwood, and Redoano, 2008; Overesch and Rincke, 2011), the tax competition variable, *tc,* is defined as a linear combination of other countries' tax rates at time $t-1$, with weights $w_{ij} \geq 0$ if $i = j$ and $w_{ij} = 0$ if $i = j$:

$$tc_{-i,t-1} = \sum_{j=1}^{N} w_{ij} tc_{j,t-1} \,. \tag{3.2}$$

We consider three possible weights. The first is the uniform weight. The literature cited above extensively employs this weight, which is equal to $1/N$, where N is the number of countries in our dataset. By using this weight we assume that country neighborliness does not play any role in tax competition. Also, given that our N is relatively low and smaller than the time dimension, the uniform weight is a viable choice (Overesch and Rincke, 2011).

The second type of weight considers the geographical distance between the capitals of two countries (in km) and is given by:

$$w_{ij} = \frac{1/d^2_{ij}}{\sum_{k \neq j} 1/d^2_{ik}}, \tag{3.3}$$

where d_{ij} is the geographical distance between the capitals of the countries i and j and $i \neq j$ (if $i = j$ then $w_{ij} = 0$). Following the related literature (e.g., Carr, Markusen, and Maskus, 2001), we assume that as the geographical distance increases, information and transaction costs increase and profits from economic transactions decline. Therefore,

[19] One wrinkle in the validity of this statement can be that tax competition affects inequality through economic openness. However, by including a measure for trade openness (i.e., *tariffs*) we control for this channel in the first stage of the IV method. We also experiment by controlling for the ratio of imports plus exports over GDP as another formal measure of economic openness and the results are very similar.

this weight internalizes the fact that governments care more about the tax policy of their neighboring countries than the tax policy of the more distant countries.

The third weight is determined by the distance (in km) among countries, as well as by the population (in millions) of each country:

$$w_{ij} = \frac{\ln(pop_j + 1) \big/ d^2_{ij}}{\sum_{k \neq j} \ln(pop_k + 1) \big/ d^2_{ik}}, \tag{3.4}$$

where pop_j is the population of country *j* (again, if $i = j$, then $w_{ij} = 0$). In this way we can ensure that small countries have a smaller effect in other countries' tax policies, compared to larger countries. Given that this weight imposes the largest restrictions (i.e., it includes both distance and population in the weight function), it is the one favored in our empirical analysis that follows.

The final choice of the specific instruments to be used, among the various tax competition indices, in each regression depends on the results of the over- and under-identification tests. We expect that the most important determinant of taxation will be the capital-based tax competition since this policy tool is more frequently used by governments to attract foreign direct investments. In general, we try to use more than one instrument on each endogenous variable, so as to be able to test for over-identifying restrictions.

To this end, and when we cannot identify a good second instrument from the tax competition measures, we sometimes also use the land area of countries (in squared kilometers). There are at least three channels through which land area can affect tax rates. The first is through institutional quality. Hansson and Olsson (2011) find that there is a significant negative relationship between the size of a country and the strength of the rule of law. In turn, a poor rule of law implies lower tax effort and revenues, thus leading to higher tax rates to compensate for the revenue losses. The second channel is through the impact on relative taxes. Larger countries have more space to accommodate enterprises, therefore land is cheaper and this can yield a lower capital tax rate. To compensate for the revenue losses, these countries might be inclined to increase labor and consumption tax rates. Third, large countries can face diseconomies of scale in the production of public goods (e.g., more costly electricity and transportation network) and this could require higher tax rates. Even though this instrument is statistically validated,[20] we acknowledge that land area represents a general characteristic of the country that can directly affect inequality through correlations with other omitted variables. Thus, our tax competition measures are the preferred instruments for the most part of our empirical analysis.

3.4.2 Estimation results

In this section, we discuss the empirical results from a series of different regressions to assess the impact of (i) the levels of the tax rates, (ii) their ratios, and (iii) possible heterogeneous effects due to economic development. We first examine whether the panel is dynamic by estimating Eq. (3.1) using the generalized method of moments (GMM) of Blundell and Bond (1998). However, we find that the autoregressive term is not statistically significant and conclude that our panel is not dynamic. Thus, given the endogeneity of taxes we resort to a simple two stage least squares (2SLS) estimator.

Table 3.4 reports the results when using the levels of taxes as explanatory variables. In columns I and II the main explanatory variables are the effective and implicit labor taxes, respectively. In columns III and IV, we use effective and implicit consumption taxes instead. Finally, in columns V and VI we focus on effective and implicit capital taxes. In columns I and II the coefficients on labor taxes are negative and statistically significant. These effects are also economically important as they indicate that a one-unit absolute increase in effective (implicit) labor taxes is associated with a 1.9% (2.6%) decline in income inequality for the mean country in our sample.[21] An explanation for this finding is that as labor taxes increase,

[20]A simple OLS regression of income inequality on land area and the other controls described in subsection 3.3.3 shows that land area is statistically insignificant

[21] For log-linear models, $100 \times (e^{\beta} - 1)$ gives the percentage change in the dependent variable for a one-unit absolute increase in the related to β independent variable (Allison, 1999).

governments are able to spend more in social transfers for redistribution, thus narrowing the within-country distribution of income. Therefore, inequality decreases through the so-called *redistribution channel* of labor taxation. Naturally, one would argue that this result is driven by the fact that labor taxes include social contributions. We further explore this issue in Table 3.6.

In columns III-VI the equivalent effects of consumption and capital taxes on our inequality measure are statistically insignificant. This finding agrees with a series of related papers. Most notably, Nickell (1997) examines unemployment and rigidities in the labor markets of European and Northern American countries and argues that consumption taxes alone can be expected to have little impact on unemployment. He also suggests that it is the overall tax burden that may raise unemployment and reduce labor supply.[22]

The lower panel of Table 3.4 reports the first-stage results, which verify our prior expectation that the capital-based tax competition is the main determinant of taxation. More importantly, all selected instruments pass both the underidentification (UIT) and overidentification (OIT) tests. Specifically, we reject the null that the estimated regressions are underidentified at the $p<0.01$ confidence level in every case using the Kleibergen – Paap (2006) test statistic. In addition, we fail to reject the null of the Hansen's overidentification test at the $p<0.05$ confidence level for all specifications where more than one instruments are employed. Thus, the overidentification restrictions are valid.

As regards the control variables, we observe that *population* and *education* are negative and statistically significant at the 1% significance level. In OECD countries, population increases come mainly from increases in life expectancy. This implies that social contributions for pensions and health increase the redistribution of wealth, leading to lower income inequality. Further, greater access to education is associated

[22] This result derives from the logic of supply and demand. On the supply side, the only prices that interest the agents in an economy are labor costs per employee and post-tax wages. On the demand side, the employees are interested in what their wages can buy and, thus in the consumption taxes. So what really matters is the sum of payroll taxes, income taxes and consumption taxes; i.e., the total tax burden on individuals.

with lower income inequality. *Price stability* bears a negative and significant coefficient which is in line with the proposition that inflation volatility hurts primarily the poor (Atkinson and Brandolini, 2001). The coefficient on tariffs is positive and statistically significant in columns III – VI. This is a counterintuitive finding and we conjecture that it likely stems from the presence of non-linearity in the data. To explore this possibility, we add in our specifications the squared term of tariffs and find that tariffs and tariffs squared bear a negative and a positive coefficient, respectively. This suggests that the impact of trade freedom on income inequality is negative up to a certain point and becomes positive thereafter. These results (available on request), however, do not alter the impact of taxes on inequality.

Economic globalization carries a negative and significant coefficient. This implies that as economic interdependence among the OECD countries increases, competition and economic activity also rise, leading to lower income inequality. On the contrary, the coefficient on *political globalization* has a positive sign and is statistically significant in the first two specifications. This is in line with the proposition that higher political globalization increases lobbying and favoritism of political and economic elites, thus resulting in higher income inequality.

In the last four specifications of Table 3.4, the coefficient of *growth* is positive and statistically significant at the 5% level. This finding indicates that as the real GDP of OECD countries increases, more income is allocated primarily to the top part of the income distribution (Deininger and Squire, 1998).[23] Finally, *size of government* and *polity* are insignificant determinants of income inequality in our sample of OECD countries. This might stem from the fact that these countries have a relatively uniform size of the public sector and level of democracy.

[Insert Table 3.4 about here]

[23]In unreported regressions, the squared term of growth is insignificant, while the level term retains its positive sign. Thus, we do not find any evidence for the Kuznets hypothesis (Kuznets, 1955). Of course a detailed analysis of the causal effect of growth on inequality requires a much better disaggregation of the elements of growth and the economic forces that shape the distribution of income. Such an analysis can be found in studies with detailed micro-level data (e.g., Frank, 2009).

We now turn to the impact of relative taxes on inequality. In columns I and II of Table 3.5 we regress the ratio of labor to capital tax on inequality. The coefficient on the implicit tax ratio (column II) is positive and statistically significant at the 10% level indicating that a 0.1 absolute increase in the ratio of labor to capital taxes (the mean of this tax ratio is 1.8) leads to a 0.5% rise in inequality for the average country. Thus, it appears that the corporate income tax cut cum base broadening strategy adopted by the OECD countries in the 1980s and 1990s resulted in higher within country income inequality. In other words, the benefits from the reduced tax rates on corporate income, which were intended to spur economic activity, were not equally shared among income groups.

In columns III and IV we use the ratios of labor to consumption taxes (effective and implicit, respectively). The labor to consumption tax ratio is of interest because it measures the relevant tax burden for choices between supplying labor or enjoying leisure (Carey and Rabesona, 2002). In column III the coefficient on the ratio of effective tax rates is negative and statistically significant at the 5% level, while in column IV the corresponding ratio of the implicit tax rates is negative but only significant at the 10% level. The coefficient in column III is also economically significant: the 0.416 reduction in income inequality due to a 0.1 absolute increase in the tax ratio (the mean of this tax ratio is 1.33) is equivalent to a 3.4% reduction in inequality for the country with an average income inequality. This finding shows that when the increase in labor taxes is higher than the increase in consumption taxes (and thus the tax burden for labor is relatively higher than the tax burden for leisure) inequality decreases.

In this respect, our findings are in line with the observed trends in the OECD. The share of tax revenue that comes from taxes on consumption has declined but this fall has been balanced by an increase in the share of taxes on income. This rise has come mainly from a strong increase in the share of social security contributions. Thus, although the incentives to work may have decreased, the higher labor taxes have promoted the redistributive effect of taxation and decreased inequality (OECD, 2007). Combined with the findings of Table 3.4, this result implies that higher progressive taxation (such as labor taxes) along with lower regressive taxation (such as consumption taxes) exert a much stronger positive effect on income equality than when considering these types of taxation separately.

The results in columns V and VI show the effects of the ratio of consumption to capital tax on income inequality. The coefficients of interest are positive and significant: a 0.1 absolute increase in the ratio of consumption to capital taxes increases income inequality by 1.07% and 2.7%, for the effective and implicit taxes, respectively (the means of these tax ratios are 1.31 and 1.05 respectively). Therefore, when governments opt for an increase in consumption taxes relative to capital taxes, the tax system becomes more regressive and income distribution worsens. Again, these results, when compared to those reported in Table 3.4, highlight that it is the tax policy mix that really matters when considering the impact of taxation on income inequality.

[Insert Table 3.5 about here]

As mentioned in section 3.3.2, the effective labor taxes include social security contributions, which may lead to income redistribution and reduced inequality (Ferrarini and Nelson, 2003). Therefore, it is important to examine whether our findings remain robust when using labor taxes without social contributions. We present these regressions in Table 3.6. In column I we regress the effective labor tax without contributions on inequality. The coefficient on the tax rate is positive and statistically significant at the 10% level. Comparing this result with the equivalent result of column I in Table 3.4, we conclude that when we remove the part of the tax that is attributed to social contributions, the coefficient of effective labor tax on income inequality changes sign. Taken together, these findings show that an increase in labor taxes excluding social contributions increases income inequality, whereas the opposite holds when labor taxes include social contributions (Joumard, Pisu, and Bloch, 2012).

Column II of Table 3.6 reports the corresponding results when using the ratio of labor taxes without contributions to capital taxes. The coefficient is positive and economically significant: a 0.1 absolute increase in the ratio (the mean of this tax ratio is 0.8) yields a 1.4% increase in income inequality for the mean country. This effect is significantly stronger than the one reported in column II of Table 3.5. Finally, the impact of the ratio of the labor tax without contributions to the consumption tax on inequality is insignificant (column III). Therefore, it is indeed the existence of social contributions, i.e., the redistribution channel that leads to a significant effect of the relevant tax ratio in columns III and IV of Table 3.5.

[Insert Table 3.6 about here]

Table 3.7 places the spotlight on the potential heterogeneous effect of economic development on the nexus between income inequality and tax structure. To identify this channel we estimate the following equation:

$$y_{i,t} = a_0 + a_1 tax_{i,t} + a_2 x_{i,t} + a_3 tax_{i,t} * GDPpc_{i,t\text{-}1} + u_{i,t} \tag{3.5}$$

where *GDPpc* stands for *GDP per capita* of country *i* at *t-1.* We mean-center the variables involved in the interaction terms to interpret the coefficient on the tax ratio as its effect on income inequality at the mean value of *GDP per capita*. Column I reports the results when using the ratio of effective labor to capital tax as the explanatory variable of interest. We find that economic development tends to lessen the adverse effects of the relevant tax ratio on income equality. The same holds for the consumption to capital tax ratio as evidenced by the statistically significant coefficients of the main and interaction terms in column III.

The estimated coefficients of the statistically significant main and interaction terms allow us to calculate the threshold of economic development above which the impact of tax structure on income inequality turns negative, i.e., income distribution improves. By setting the partial derivative with respect to *tax* in column I equal to zero, we find that the *GDP per capita* threshold equals 0.525. This corresponds to a value of 19,233.38 in constant 2000 $US, or in other words, the average GDP per capita of Germany during our sample period.[24] In column III the corresponding threshold is 0.929, equivalent to 28,825.05 in constant 2000 $US.

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[24] The value 0.525 is the value of the centered logarithm of GDP per capita. To express this value in constant 2000 $US we re-add its mean value (9.339401) and we calculate its exponential ($e^{9.339401}$). This

These findings indicate that, as countries become more economically developed, the adverse effects of tax ratios on income distribution diminish. As any variable characterizing institutional quality (such as property rights protection and bureaucratic efficiency) is highly correlated with economic development, we may consider the latter as a proxy for the former. Furthermore, institutional quality crucially determines the efficiency of redistribution policies. It is argued, for example, that weak institutions prevent developing countries to raise sufficient tax revenues (Acemoglu, 2005; Chong and Gradstein, 2007a), thus justifying the premise for a positive association between quality of institutions and redistribution (Chong and Gradstein, 2007b). This reasoning allows us to understand the underlying mechanisms linking economic development, institutional quality, redistribution policies, and income (in)equality.

Our findings, therefore, imply that more economically developed countries are more likely to spur economic activity (*via* lower capital tax rates) and improve the distribution of income (*via* higher labor tax rates and more efficient redistribution policies) at the same time. This, in turn, raises the issue of weak versus strong states in the sense that poor institutions weaken the efficiency of redistribution policies. Consider for example the case of Northern and Southern European countries. In Southern European countries, any attempts to increase labor taxes (or consumption taxes such as VAT) to compensate for the decline in tax revenues stemming from lower capital taxes, are deemed to result in greater inequality due to poorer institutions and inefficient redistribution policies. In contrast, in Northern European countries, which are characterized by higher development and stronger institutions, the redistributive policies implemented *via* higher labor (or consumption) taxes are more effective, thus ultimately improving the income distribution.[25]

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yields 19,233.38, which we compare with our summary statistics for the GDP per capita in constant 2000 $US for each country.

[25] Notably, any variable characterizing institutional development (e.g., the rule of law variable from the World Bank or the International Country Risk Guide databases) is highly correlated with GDP per capita. Thus, we do not use institutional variables in our estimations to avoid multicollinearity.

3.5 Conclusions

In most OECD countries the gap between the rich and the poor has widened over the past decades. This chapter analyzes whether and to what extent their tax rate structure has contributed to this trend. This is an interesting question because over the last decades almost all OECD countries have made major structural changes to their tax systems.

We use data on effective labor, capital and consumption tax rates, which are directly comparable across countries, as well as a measure of income inequality that combines information from both the Gini and Theil indices. Our objective is to establish causality rather than a simple correlation, which is always a difficult task given the usual endogeneity problems.

We find that only the effective labor tax rate exerts a negative impact on income inequality, a result stemming primarily from the redistributional effects of the incorporated social contributions. In contrast, almost all relative tax rates seem to significantly affect income inequality. Specifically, increasing the tax burden on labor relative to capital leads to higher income inequality. This finding is amplified when social contributions are excluded from the effective labor tax rate. Similar findings are obtained when (i) the labor to consumption tax rate ratio declines and (ii) the ratio of consumption to capital tax rate ratio increases. Finally, we find that as countries become more economically developed and, thus, institutionally stronger, the impact of the relative tax rates on income inequality declines or even reverses in sign.

The findings of this chapter have important policy implications. Understanding the link between the tax rate structure and income inequality can help design tax policies that pursue the dual mandate of incentivizing economic activity and tackling growing income inequality. Our findings indicate that this dual objective is particularly challenging for the less wealthy countries as they show that any attempt to increase the relative tax burden on labor or consumption (to counterbalance the decline in capital tax rates) are likely to increase income inequality. This means that one of the most important aspects of today's tax reform proposals will be the ways in which they affect the distribution of income, not in absolute but rather in relative terms. Our results also point to the crucial role of institutions, in the sense that the quality of institutions can increase the efficiency of redistributive policies, thereby alleviating any undesirable effects of tax rate changes on income distribution. Therefore, policy makers should aim for a more efficient use of relative taxation by enhancing its reach and making sure spending is not wasted.

Table 3.1
Variable definitions and sources

Notation	Measure	Data source
A. Dependent variables		
Gross household income inequality	The natural logarithm of the predicted values from the regression of the GINI coefficient on the Theil index.	Texas inequality project
B. Explanatory variables		
Effective labor tax	The ratio between the tax revenues from particular taxes and the corresponding tax bases obtained from national accounts. A proxy for the tax burden faced by the employed labor (includes the taxation of the imputed wage of self-employed labor).	ECFIN's Effective tax rates by Carlos Martinez-Mongay (2000)
Implicit labor tax	The ratio between the tax revenues from particular taxes and the corresponding tax bases obtained from national accounts. A proxy for the tax burden faced by the employed labor (excludes the taxation of the imputed wage of self-employed labor).	ECFIN's Effective tax rates by Carlos Martinez-Mongay (2000)
Effective consumption tax	Effective tax constructed as above. The difference between the consumer price (post tax price) and the producer price (pretax price) expressed as a percentage of the producer price.	ECFIN's Effective tax rates by Carlos Martinez-Mongay (2000)
Implicit consumption tax	Implicit tax constructed as above. The difference between the consumer price (post tax price) and the producer price (pretax price), expressed as a percentage of the consumer price.	ECFIN's Effective tax rates by Carlos Martinez-Mongay (2000)
Effective capital tax	Effective tax constructed as above. Proxy for the tax burden on capital income where the wage of self-employed income is not concerned as capital income and depreciation is included as part of capital tax base.	ECFIN's Effective tax rates by Carlos Martinez-Mongay (2000)
Implicit capital tax	Implicit tax constructed as above. Proxy for the tax burden on capital income where the whole income of self-employed labor is concerned as capital income and depreciation is included as part of capital tax base.	ECFIN's Effective tax rates by Carlos Martinez-Mongay (2000)
Effective labor tax without contributions	General measure of tax on labor income where social contributions are not included.	Adam and Kammas (2007)
Population	The natural logarithm of total population.	World Development Indicators
Education	School enrollment, secondary (% gross). The ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education shown.	World Development Indicators
Growth	Annual percentage growth rate of GDP at market prices based on constant local currency. Aggregates are based on constant 2005 U.S. dollars.	World Development Indicators

Table 3.1 (continued)

Price stability	Standard deviation of inflation, with higher values reflecting higher price stability. Value 10 results when there is no variation in the rate of inflation.	Economic Freedom of the World, Frazer Institute (2012 annual report)
Economic globalization	Actual flows (trade, foreign direct investment, stocks, portfolio investment, income payments to foreign nationals), restrictions (hidden import barriers, mean tariff rate, taxes on international trade, capital account restrictions). Higher values reflect higher economic globalization.	KOF Index of Globalization
Political globalization	Embassies in country, membership in international organizations, participation in U.N. security council missions, international treaties. Higher values reflect higher political globalization.	KOF Index of Globalization
Size of government	Government consumption as a share of total consumption, transfers and subsidies, government enterprises and investment, top marginal tax rate. Higher values reflect smaller size of government and higher political freedom.	Economic Freedom of the World, Frazer Institute (2012 annual report)
Polity	Combined polity score using indices of institutionalized democracy and autocracy; the resulting unified polity scale ranges from +10 (strongly democratic) to -10 (strongly autocratic).	Polity IV Project: Political Regime Characteristics and Transitions, 1800-2012
Tariffs	Revenue from trade taxes (% of trade sector), mean tariff rate, standard deviation of tariff rates. Higher values reflect more trade freedom.	Economic Freedom of the World, Frazer Institute (2012 annual report)
GDP per capita	Natural logarithm of GDP per capita (constant 2000 US $).	World Development Indicators
<u>C. Instruments</u>		
Land	Natural logarithm of land area (in sq. km).	World Development Indicators
Effective labor tax competition effect	Measure of labor tax competition using the weight with distance and population as described in text. Higher values reflect higher tax competition.	Own calculations
Effective consumption tax competition effect	Measure of consumption tax competition using the weight with distance and population as described in text. Higher values reflect higher tax competition.	Own calculations
Effective capital tax competition effect	Measure of capital tax competition using the weight with distance and population as described in text. Higher values reflect higher tax competition.	Own calculations

Table 3.2
Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Gross household income inequality	734	3.52	0.16	2.99	4.13
Effective labor tax	544	30.70	9.89	9.80	54.10
Implicit labor tax	544	33.23	9.35	11.70	54.20
Effective consumption tax	544	24.26	7.91	10.00	45.70
Implicit consumption tax	544	19.20	5.10	9.10	31.40
Effective capital tax	544	20.41	6.41	6.80	38.00
Implicit capital tax	544	20.45	6.60	5.30	38.70
Effective labor to capital tax ratio	544	1.62	0.59	0.35	4.08
Implicit labor to capital tax ratio	544	1.80	0.74	0.70	4.79
Effective labor to consumption tax ratio	544	1.33	0.42	0.38	2.39
Implicit labor to consumption tax ratio	544	1.78	0.46	0.57	3.00
Effective consumption to capital tax ratio	544	1.31	0.56	0.43	3.36
Implicit consumption to capital tax ratio	544	1.05	0.46	0.40	2.98
Effective labor tax without contributions	557	16.07	9.09	2.00	48.00
Effective labor tax without contributions to capital tax ratio	489	0.80	0.47	0.19	2.52
Effective labor tax without contributions to consumption tax ratio	489	0.65	0.28	0.14	1.50
Population	1218	2.93e+07	5.16e+07	301996	3.12e+08
Education	982	94.60	15.75	37.41	162.35
Growth	1062	2.76	3.91	-32.12	20.27
Price stability	1039	8.66	2.11	0	10.00
Economic globalization	1032	66.86	17.67	21.38	98.88
Political globalization	1032	77.37	19.36	12.33	98.56
Size of government	1004	4.86	1.44	1.60	9.50
Polity	1019	7.80	5.27	-9.00	10.00
Tariffs	989	8.29	1.01	2.10	10.00
GDP per capita	1074	9.34	0.83	7.17	10.94
Land	1129	11.54	1.76	5.77	16.03
Effective labor tax competition effect	1189	14.29	9.91	0	41.82
Effective consumption tax competition effect	1189	11.16	7.71	0	33.22
Effective capital tax competition effect	1189	8.55	6.10	0	25.70

Notes: The table presents the number of observations (obs.), the mean, the standard deviation (std. dev.), the minimum (min.) and the maximum (max.) of the variables used in the empirical analysis. The variables are defined in Table 3.1. The sample covers the period 1970-2001 for 17 OECD countries.

Table 3.3
Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) Effective labor tax	1.00																	
(2) Implicit labor tax	0.94	1.00																
(3) Effective consumption tax	0.64	0.63	1.00															
(4) Implicit consumption tax	0.64	0.64	1.00	1.00														
(5) Effective capital tax	0.04	-0.14	0.05	0.04	1.00													
(6) Implicit capital tax	0.49	0.26	0.29	0.28	0.84	1.00												
(7) Effective labor tax without contrib.	0.61	0.48	0.73	0.71	0.24	0.49	1.00											
(8) Effective labor tax with contrib.	0.38	0.51	-0.07	-0.04	-0.33	-0.12	-0.45	1.00										
(9) Population	-0.33	-0.41	-0.69	-0.71	0.25	0.08	-0.57	0.12	1.00									
(10) Education	0.50	0.40	0.37	0.36	0.20	0.45	0.46	0.09	-0.27	1.00								
(11) Growth	-0.28	-0.30	-0.05	-0.05	0.01	-0.12	-0.08	-0.16	-0.07	-0.04	1.00							
(12) Price stability	0.35	0.26	0.16	0.15	0.15	0.35	0.16	0.18	0.12	0.34	-0.07	1.00						
(13) Economic globalization	0.46	0.43	0.46	0.47	0.17	0.42	0.42	0.11	-0.53	0.51	0.00	0.18	1.00					
(14) Political globalization	0.61	0.50	0.35	0.36	0.30	0.59	0.32	0.20	0.06	0.27	-0.26	0.30	0.41	1.00				
(15) Size of government	-0.76	-0.73	-0.61	-0.62	-0.13	-0.44	-0.51	-0.22	0.33	-0.27	0.30	-0.12	-0.40	-0.56	1.00			
(16) Polity	0.24	0.17	0.12	0.12	0.31	0.38	0.25	-0.04	-0.01	0.32	-0.24	-0.05	0.19	0.30	-0.35	1.00		
(17) Tariffs	0.37	0.37	0.19	0.18	0.01	0.17	0.14	0.24	0.04	0.20	-0.08	0.07	0.07	0.27	-0.28	0.34	1.00	
(18) GDP per capita	0.38	0.18	0.13	0.10	0.55	0.69	0.41	-0.11	0.32	0.48	-0.08	0.49	0.06	0.40	-0.21	0.32	0.29	1.00

Notes: The table presents correlation coefficients for the full sample between the main explanatory variables of the study. The variables are defined in Table 3.1.

Table 3.4
Taxes and inequality

	I Effective labor tax	II Implicit labor tax	III Effective consumption tax	IV Implicit consumption tax	V Effective capital tax	VI Implicit capital tax
Tax $_t$	-0.019**	-0.026***	0.005	0.011	-0.006	-0.005
	(-2.156)	(-3.164)	(0.910)	(1.247)	(-1.398)	(-1.119)
Population $_t$	-0.680***	-0.704***	-0.497***	-0.443**	-0.838***	-0.759***
	(-5.368)	(-4.358)	(-2.835)	(-2.443)	(-4.270)	(-4.642)
Education $_{t-1}$	-0.002***	-0.002***	-0.001***	-0.001***	-0.001***	-0.001***
	(-3.561)	(-3.395)	(-3.907)	(-3.871)	(-3.239)	(-2.831)
Growth $_t$	-0.000	-0.003	0.003**	0.003**	0.003**	0.003**
	(-0.065)	(-1.062)	(2.278)	(2.220)	(2.306)	(2.285)
Price stability $_t$	-0.017***	-0.008	-0.026***	-0.027***	-0.019***	-0.022***
	(-2.966)	(-1.007)	(-5.909)	(-5.746)	(-3.439)	(-4.879)
Economic globalization $_{t-1}$	-0.002	-0.003***	-0.004***	-0.004***	-0.003***	-0.003***
	(-1.207)	(-2.680)	(-4.907)	(-4.913)	(-3.799)	(-3.324)
Political globalization $_{t-1}$	0.004**	0.006***	0.000	-0.000	0.001	0.001
	(2.275)	(3.110)	(0.018)	(-0.273)	(1.413)	(1.349)
Size of government $_t$	-0.011	-0.013*	0.005	0.006	0.005	0.003
	(-1.147)	(-1.728)	(1.345)	(1.393)	(1.492)	(0.633)
Polity $_{t-1}$	-0.000	0.000	-0.002	-0.002	0.001	0.000
	(-0.052)	(0.086)	(-0.718)	(-0.948)	(0.409)	(0.269)
Tariffs $_{t-1}$	0.005	0.005	0.017***	0.017***	0.014***	0.013***
	(0.829)	(0.759)	(5.273)	(5.137)	(4.386)	(3.542)
GDP per capita $_{t-1}$	0.098*	-0.049	0.023	0.013	0.051	0.104*
	(1.930)	(-0.687)	(0.472)	(0.269)	(1.279)	(1.870)
First-stage results						
Labor-tax competition					1.020***	0.622***
					(4.58)	(3.87)
Consumption-tax competition	0.522***	0.391*				0.358**
	(3.14)	(1.76)				(2.45)
Capital-tax competition		-0.610**	0.679***	0.504***	-0.694***	
		(-2.46)	(3.45)	(3.88)	(-2.64)	
Land area		385.28**	413.05***	199.15**		
		(2.23)	(3.17)	(2.47)		
Observations	373	373	373	373	373	373
UIT	0.003	0.007	0.000	0.000	0.000	0.000
OIT		0.441	0.128	0.158	0.064	0.297

Notes: The table reports coefficients and t-statistics (in parentheses) of the regression of the log of the Gini coefficient on various tax rates and control variables. The panel is unbalanced, it spans the period 1970-2001, and includes 16 countries. The specific tax rate used in each regression is given at the top of the table. All the variables are defined in Table 3.1. Estimation method is the two-stage least squares on the fixed effects model with robust standard errors. First-stage results on the instrumental variables are provided below the second-stage results. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a value lower than 0.05 to reject the null hypothesis at the 5% level. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to accept the null hypothesis at the 5% level. For this test to be calculated at least two instrumental variables are required. ***, ** and * denote statistical significance at the 1, 5 and 10% level, respectively.

Table 3.5
Relative taxes and inequality

	I Effective labor/ capital	II Implicit labor/ capital	III Effective labor/ consumption	IV Implicit labor/ consumption	V Effective consumption/ capital	VI Implicit consumption/ capital
Tax $_{t}$	0.057	0.049*	-0.416**	-0.111*	0.102**	0.240***
	(1.394)	(1.913)	(-2.017)	(-1.814)	(2.227)	(3.274)
Population $_{t}$	-0.750***	-0.783***	0.473	-0.317	-0.731***	-0.846***
	(-5.062)	(-5.823)	(0.843)	(-1.623)	(-5.481)	(-5.993)
Education $_{t-1}$	-0.001***	-0.001**	-0.002***	-0.002***	-0.001***	-0.000
	(-3.104)	(-2.536)	(-2.842)	(-3.827)	(-2.897)	(-0.485)
Growth $_{t}$	0.004**	0.003**	0.001	0.002	0.003**	0.001
	(2.486)	(2.576)	(0.233)	(1.086)	(2.310)	(0.846)
Price stability $_{t}$	-0.023***	-0.023***	-0.029***	-0.025***	-0.020***	-0.016***
	(-5.509)	(-5.875)	(-5.362)	(-6.552)	(-4.492)	(-3.431)
Economic globalization $_{t-1}$	-0.004***	-0.003***	-0.004***	-0.004***	-0.004***	-0.004***
	(-4.189)	(-4.077)	(-3.751)	(-5.507)	(-5.054)	(-4.854)
Political globalization $_{t-1}$	0.001	0.001	0.001	0.001	0.002*	0.003***
	(1.063)	(1.340)	(1.022)	(1.221)	(1.859)	(2.783)
Size of government $_{t}$	0.007*	0.005	-0.006	0.003	0.004	-0.002
	(1.826)	(1.301)	(-0.728)	(0.820)	(1.007)	(-0.562)
Polity $_{t-1}$	-0.000	0.001	-0.004	-0.001	-0.001	0.002
	(-0.228)	(0.461)	(-1.321)	(-0.787)	(-0.638)	(1.024)
Tariffs $_{t-1}$	0.016***	0.015***	0.008	0.014***	0.015***	0.013***
	(5.494)	(5.116)	(1.479)	(4.443)	(5.046)	(3.554)
GDP per capita $_{t-1}$	0.047	0.111**	0.053	0.018	0.006	0.137***
	(1.178)	(2.374)	(1.032)	(0.408)	(0.143)	(2.831)
First-stage results						
Labor-tax competition	-0.098***	-0.108***			-0.050**	-0.044***
	(-3.83)	(-4.59)			(-2.16)	(-3.24)
Consumption-tax competition		-0.093***	0.023*			-0.046**
		(-3.99)	(1.76)			(-2.44)
Capital-tax competition	0.067***		-0.041**	-0.079***	0.106***	0.041**
	(2.77)		(-2.30)	(-3.51)	(4.37)	(2.25)
Land area		-63.20***				-26.67**
		(-3.37)				(-2.41)
Observations	373	373	373	373	373	373
UIT	0.000	0.000	0.035	0.001	0.000	0.001
OIT	0.077	0.144	0.302		0.856	0.079

Notes: The table reports coefficients and t-statistics (in parentheses) of the regression of the log of the Gini coefficient on various tax rates and control variables. The panel is unbalanced, it spans the period 1970-2001, and includes 16 countries. The specific tax rate used in each regression is given at the top of the table. All the variables are defined in Table 3.1. Estimation method is the two-stage least squares on the fixed effects model with robust standard errors. First-stage results on the instrumental variables are provided below the second-stage results. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a value lower than 0.05 to reject the null hypothesis at the 5% level. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to accept the null hypothesis at the 5% level. For this test to be calculated at least two instrumental variables are required. ***, ** and * denote statistical significance at the 1, 5 and 10% level, respectively.

Table 3.6
Taxes and inequality: Distinguishing between taxes with and without social contributions

	I Effective labor tax without contributions	II Effective labor tax without contributions/ capital tax	III Effective labor tax without contributions/ consumption tax
Tax $_{t}$	0.016*	0.132*	0.414
	(1.834)	(1.759)	(1.467)
Population $_{t}$	-0.25	-0.485***	-0.732**
	(-1.381)	(-3.158)	(-2.446)
Education $_{t-1}$	0.00	-0.001*	0.00
	(-1.502)	(-1.885)	(-0.516)
Growth $_{t}$	0.004*	0.005**	0.00
	-1.78	-2.14	-1.62
Price stability $_{t}$	0.00	-0.01	0.01
	-0.18	(-0.596)	-0.67
Economic globalization $_{t-1}$	-0.003***	0.00	0.00
	(-2.777)	(-1.446)	(-1.388)
Political globalization $_{t-1}$	0.00	0.00	0.002*
	-0.88	-1.12	-1.69
Size of government $_{t}$	0.017**	0.009*	0.019**
	-2.21	-1.95	-2.03
Polity $_{t-1}$	-0.005*	-0.004*	-0.01
	(-1.688)	(-1.681)	(-1.511)
Tariffs $_{t-1}$	0.016***	0.014***	0.017***
	-4.16	-3.95	-3.78
GDP per capita $_{t-1}$	-0.13	-0.03	-0.10
	(-1.097)	(-0.372)	(-0.706)
Observations	372	346	346
UIT	0.00	0.00	0.00
OIT		0.74	

Notes: The table reports coefficients and t-statistics (in parentheses) of the regression of the log of the Gini coefficient on various tax rates and control variables. The panel is unbalanced, it spans the period 1970-2002, and includes 15 or 16 countries (based on the number of available observations). The specific tax rate used in each regression is given at the top of the table. All the variables are defined in Table 3.1. Estimation method is the two-stage least squares on the fixed effects model with robust standard errors. First-stage results on the instrumental variables are provided below the second-stage results. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a value lower than 0.05 to reject the null hypothesis at the 5% level. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to accept the null hypothesis at the 5% level. For this test to be calculated at least two instrumental variables are required. ***, ** and * denote statistical significance at the 1, 5 and 10% level, respectively.

Table 3.7
Relative taxes and inequality: Heterogeneous effects due to economic development

	I Effective labor/ capital	II Effective labor/ consumption	III Effective consumption/capital
Tax $_t$	0.042***	-0.028	0.039***
	(3.308)	(-1.378)	(3.772)
Tax $_t$ * GDP per capita $_{t-1}$	-0.080***	0.019	-0.042**
	(-4.029)	(0.734)	(-2.334)
Population $_t$	-0.787***	-0.514***	-0.723***
	(-6.611)	(-4.065)	(-6.155)
Education $_{t-1}$	-0.001***	-0.000	-0.001***
	(-3.729)	(-1.497)	(-3.445)
Growth $_t$	0.003**	-0.000	0.003**
	(2.173)	(-0.300)	(1.996)
Price stability $_t$	-0.024***	-0.002	-0.022***
	(-6.815)	(-0.306)	(-5.987)
Economic globalization $_{t-1}$	-0.003***	-0.003***	-0.004***
	(-4.807)	(-4.653)	(-5.780)
Political globalization $_{t-1}$	0.001**	0.000	0.001**
	(2.312)	(0.377)	(2.200)
Size of government $_t$	0.007*	0.010**	0.006*
	(1.941)	(2.408)	(1.716)
Polity $_{t-1}$	-0.001	-0.003**	-0.001
	(-0.923)	(-1.991)	(-0.373)
Tariffs $_{t-1}$	0.012***	0.010***	0.016***
	(4.161)	(2.771)	(5.362)
GDP per capita $_{t-1}$	0.001	0.065	0.039
	(0.034)	(1.548)	(0.981)
Observations	373	373	373
UIT	0.00	0.00	0.01
OIT	0.47	0.83	0.76

Notes: The table reports coefficients and t-statistics (in parentheses) of the regression of the log of the Gini coefficient on various tax rates and control variables. The panel is unbalanced, it spans the period 1970-2002, and includes 15 or 16 countries (based on the number of available observations). The specific tax rate used in each regression is given at the top of the table. All the variables are defined in Table 3.1. Estimation method is the two-stage least squares on the fixed effects model with robust standard errors. First-stage results on the instrumental variables are provided below the second-stage results. UIT is the p-value of the under-identification LM test by Kleibergen and Paap, which requires a value lower than 0.05 to reject the null hypothesis at the 5% level. OIT is the p-value of the over-identification test by Hansen, which requires a value higher than 0.05 to accept the null hypothesis at the 5% level. For this test to be calculated at least two instrumental variables are required. ***, ** and * denote statistical significance at the 1, 5 and 10% level, respectively.

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