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“Energy Price and Redistribution in Czech Republic”

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Abstract

This paper studies environmental taxation in a Mirrlees setting when energy, a polluting good, is used both as a factor of production and a final consumption good. The model is calibrated for the Czech economy. We study two different tax systems. Both consider a non-linear income tax but the first one considers a linear energy tax, while the second one allows for a non-linear taxation of energy. We show that: (i) households' energy consumption should be subsidized except if the environmental external costs of energy consumption are sufficiently high (ii) The subsidy applied to energy consumption should decrease with income.
JEL classification: H21; H23.

Keywords: energy tax, Pigouvian tax, redistributive concerns.

1 Introduction

In the recent years, the undesired redistributive consequences of energy taxes has been studied in several theoretical and empirical papers. This paper is in the continuation of the previous empirical studies by Cremer and al. (2003, 2010 and 2012).

We model an open economy with three factors of production and two categories of consumption goods. The factors of production are labor, capital, and energy. Labor is homogeneous in efficiency units, but different individual types have different endowments of efficiency units. All workers are immobile and no labor is either exported or imported. Capital inputs are rented from outside so that all capital incomes go to "foreigners"; energy inputs are also imported.[1] Emissions come from two sources: the use of energy input on the production side, and the consumption of one category of final goods on the consumption side (designated as polluting goods). The specific emissions we are concerned with are carbon emissions (dioxide and monoxide). The production process consists of two stages. First, a constant returns to scale production technology uses the three inputs to produce a "general-purpose" output. Second, a linear technology transforms the output into the two categories of consumption goods at constant marginal (equal to average) costs. The first-stage production function is "nested CES". Consumers' preferences are also nested CES, being a function of labor and the two final goods.

The model is calibrated for the Czech economy on the basis of the data from *EU KLEMS database* (*March 2008 edition*) for the production sector and on micro-data from "*Living Conditions 2006*" survey for the household sector

We identify four groups of households who differ not only in earning abilities but also in tastes. The segmentation is made in two ways. In the first one households groups are

[1] There are two reasons for assuming capital is rented from outside. One, we do not have data on holdings of capital by different types of workers. Second, taxation of capital in a static setting is not an interesting question. The similar assumption on energy inputs is for simplicity in exposition and of no relevant consequence.

identified as “Low skilled in services”, “Low skilled crafts”, “Quite skilled” and “High skilled”. This segmentation is similar to the segmentation used for France in Cremer and & al. (2003, 2010) and US in Cremer and & al. (2011) and allows comparison with these studies. In the second one, the segmentation is based on total gross earnings earned by all economic-active persons in a family.[2] The first group includes households that earned 10% lowest total earnings [*poor*], the second one cover the households with 10% to 50% lowest earnings [*semi-poor*], and the third one with 50% to 90% [*semi-reach*], while the last, fourth, group describes the households with the top 10% highest gross earnings [*reach*]. Because we focus on the redistributive consequences of energy taxation, this last segmentation of households is more relevant than the former one.[3]

We consider two values for the marginal social damage of emissions. The first value corresponds to the case in which there is no externality ($\phi = 0$), the second is calculated in such a way that the first best Pigouvian tax is equal to 10% of energy price.

We model the behavior of the government as one of setting *optimal* tax policies in light of the constraints that it faces. We use an iso-elastic social welfare function for this purpose. Moreover, we consider two values of an inequality aversion index that dictates the desired degree of redistribution in the economy. Two tax regimes are analyzed, both of them are formed around a general tax schedule. in the first one the polluting good tax is linear while it is non-linear in the second one. The paper is organized as follows: the second section describes the model, the section 3 is devoted to the data description, the fourth shows how is performed the calibration and finally the last section gives and comments the results.

[2]Households without any revenue from labor are excluded from our analysis (such units include households of retired persons, unemployed, disabled).

[3]We however highlight that households in which all its members are economically non-active are not included in the analysis.

2 The model

This model is based on Cremer and *al.*'s (2010). To make this paper self-contained, we first review its main features.[4]

Consider an open economy wherein people consume two produced goods: a composite consumption good, x, and "energy", y. The composite consumption good is produced domestically using "energy inputs", D, capital, K, and labor, L. Energy, whether used as a consumption good or as a factor input, is imported from overseas. Capital services and energy inputs are imported at constant world prices of r and p_D. Labor is supplied domestically. All imports are financed through exports of the portion of the general output that is not consumed domestically. Energy, both as a consumption good and factor input, is polluting; the composite consumption good is not.

Consumers have heterogeneous preferences. Different groups of individuals having different productivity levels and different tastes are considered in the model. Denote a person's type by j, his productivity factor by n^j, and the proportion of people of type j in the economy by π^j (where the population size is normalized at one). Preferences of a j-type person is represented by an utility function that depend on his consumption of non-polluting goods, x^j, consumption of polluting goods, y^j, labor supply, L^j, and the total level of emissions in the atmosphere, $E \equiv \sum_{j=1}^{4} \pi^j y^j + D$. [5]. This utility function is denoted,

$$\mho^j = \boldsymbol{U}(x, y, L^j; \theta^j) - \phi E, \qquad j = 1, 2, 3, 4. \tag{1}$$

where θ^j reflects the "taste parameter". [6]

The production process consists of two stages. First, a constant returns to scale production technology uses three inputs to produce a "general-purpose" output, O.

[4]For more details, see Cremer *et al.* (1998, 2003 and 2010).

[5]Note that population size is normalized to 1, E is therefore the total level of energy consumption or emissions in the economy.

[6]Note that the emissions enter the utility function lineraly, therefore the marginal desutility of emissions, ϕ, is assumed to be constant.

Second, a linear technology transforms the output into the two categories of consumption goods, x and y, at constant marginal (equal to average) costs. The production function is given by,

$$O = \boldsymbol{F}(L, K, D)$$

where,

$$L = \sum_{j=1}^{4} \pi^j n^j L^j.^7$$

The government is interested in designing an optimal tax system consisting of a general income tax, and taxes on energy as a consumption good and as an intermediate good. The design of an optimal tax structures must be based on some underlying social welfare function. For this purpose, we will use an iso-elastic social welfare function of the form

$$W = \frac{1}{1-\eta} \sum_{j=1}^{4} \pi^j (\mho^j)^{1-\eta} \qquad \eta \neq 1 \qquad \text{and} \qquad 0 \leq \eta < \infty, \tag{2}$$

where η is the "inequality aversion index". The higher is η the more the society values equality.[8]

The feasibility of a particular tax instrument is determined by the information that is available to the tax administration. We consider here that the government does not observe productivities and tastes but that the individual incomes are known by the tax administration. This means that a general income tax is feasible. In practice the government is not able to observe individuals purchases of goods and services and is thus constrained to apply linear commodity tax. This situation is analyzed in a first version of our model. A second version considers that consumption levels are known at an

[7] As different types of people have different productivities, labor is an heterogeneous factor of production. When a j-type person with productivity n^j works for L^j hours, his effective labor is $n^j L^j$ resulting in aggregate supply $\sum_{j=1}^{4} \pi^j n^j L^j$. Equating this with aggregate demand gives $L = \sum_{j=1}^{4} \pi^j n^j L^j$.

[8] As is well-known, $\eta = 0$ implies a utilitarian social welfare function and $\eta \to \infty$ a Rawlsian. When $\eta = 1$, the social welfare function is given by $W = \sum_{j=1}^{4} \pi^j \ln(\mho^j)$.

individual level (i.e. who buys how much) and consequently that non-linear commodity taxation is feasible.

2.1 Linear commodity taxes

Under linear commodity taxation, all consumers face the same commodity prices. The social welfare function (2) must thus be written as a function of the prices of goods.

Denote c^j the after-tax income (outlay) of a j-type household, p and q the consumer prices of x and y respectively. Maximizing, the utility function (1) with respect to the budget constraint

$$px^j + qy^j = c^j,$$

we obtain the demand functions for x^j and y^j as $x^j = \boldsymbol{x}\left(p, q, c^j; \theta^j\right)$ and $y^j = \boldsymbol{y}\left(p, q, c^j; \theta^j\right)$. Substituting these equations in the j-type person utility function (1), we have

$$\boldsymbol{V}\left(p, q, c^j, \frac{I^j}{wn^j}; \theta^j\right) = \boldsymbol{U}\left(\boldsymbol{x}\left(p, q, c^j; \theta^j\right), \boldsymbol{y}\left(p, q, c^j; \theta^j\right), \frac{I^j}{wn^j}, \theta^j\right),$$

where[9]

$$I^j = w^j L^j = wn^j L^j.$$

We have four feasible tax instruments in our model: two commodity taxes, an input tax and an income tax. As the demand functions for goods and the labor supply function are all homogeneous of degree zero, there is no loss of generality when setting one tax rate to zero. Since energy consumption creates an externality we choose to impose a zero tax on non-energy goods.

The optimal tax structure is derived as the solution to

$$\max_{q, c^j, I^j, K, D, w} \frac{1}{1-\eta} \sum_{j=1}^{4} \pi^j \left[\boldsymbol{V}\left(p, q, c^j, \frac{I^j}{wn^j}; \theta^j\right) - \phi \sum_{j=1}^{4} \pi^j \boldsymbol{y}\left(p, q, c^j; \theta^j\right) - \phi D\right]^{1-\eta} \quad (3)$$

[9] $w^j \equiv wn^j$ is individual j's wage rate; so w represent the price of 1 unit of effective labor.

under the resource constraint,

$$\boldsymbol{O}(L,K,D)-\sum_{j=1}^{4}\pi^{j}\left[\boldsymbol{x}\left(p,q,c^{j},\frac{I^{j}}{wn^{j}};\theta^{j}\right)+\boldsymbol{y}\left(p,q,c^{j},\frac{I^{j}}{wn^{j}};\theta^{j}\right)\right]-rK-p_{D}D-\bar{R}\geq 0, \tag{4}$$

the incentive compatibility constraints,

$$\boldsymbol{V}\left(p,q,c^{j},\frac{I^{j}}{wn^{j}};\theta^{j}\right)\geq\boldsymbol{V}\left(p,q,c^{k},\frac{I^{k}}{wn^{j}};\theta^{j}\right), \tag{5}$$

the endogeneity of wage condition,

$$w-\boldsymbol{O}_{L}(L,K,D)=0, \tag{6}$$

with

$$L=\sum_{j=1}^{4}\pi^{j}n^{j}L^{j}=\sum_{j=1}^{4}\pi^{j}\frac{I^{j}}{w}.$$

It can be shown analytically that first, the constraint (6) is always binding, and second, that the optimal tax on energy input is Pigouvian and equal to its marginal social damage of emissions. The optimal tax on the *consumption* of energy, on the other hand, is generally different from its Pigouvian level (see appendix in Cremer and *al.*'s (2013)).

2.2 Non linear commodity taxes

The optimal tax structure when individual purchases are not observable is the solution to,

$$\max_{x^{j},y^{j},I^{j},D,K,w}\frac{1}{1-\eta}\sum_{j=1}^{4}\pi^{j}\left[\boldsymbol{U}\left(x^{j},y^{j},\frac{I^{j}}{wn^{j}};\theta^{j}\right)-\phi\sum_{j=1}^{4}\pi^{j}y^{j}-\phi D\right]^{1-\eta} \tag{7}$$

under the resource constraint,

$$\boldsymbol{O}(L,K,D)-\left[\sum_{j=1}^{4}\pi^{j}\left(x^{j}+y^{j}\right)+rK+D+\overline{R}\right]\geq 0, \tag{8}$$

the incentive compatibility constraints,

$$\boldsymbol{U}\left(x^j, y^j, \frac{I^j}{wn^j}; \theta^j\right) \geq \boldsymbol{U}\left(x^k, y^k, \frac{I^k}{wn^j}; \theta^j\right) \quad j \neq k, \tag{9}$$

the endogeneity of wage condition,

$$w - \boldsymbol{O}_L\left(L, K, D\right) = 0, \tag{10}$$

with

$$L = \sum_{j=1}^{4} \pi^j n^j L^j = \sum_{j=1}^{4} \pi^j \frac{I^j}{w}.$$

3 Data Description

3.1 Data Sources

Two sources of data are used in our tax model of the Czech economy.

The production side is described by macroeconomic data from the *EU KLEMS database* (*March 2008 edition*)[10] . The production in the model is specifically calibrated on data for the years 1995 and 2005.

A micro-data from "*Living Conditions 2006*" survey is used to describe incomes and expenditures of the household sector. This survey has been conducted by the Czech Statistical Office as a national module of the EU-SILC (European Union – Statistics on Income and Living Conditions) survey project. [11] [12]

[10] In the time of running our model, EU KLEM (March 2008 release) was the latest available dataset that provided volume indices for intermediate energy inputs for the Czech Republic that we use in our calibration process. The volume indices are available until 2005.

[11] The EU-SILC is an instrument aiming at collecting timely and comparable both cross-sectional and longitudinal data on income, economic activity, poverty and living conditions (CSO 2014). The SILC survey consists of three questionnaires: the household instrument contains information on housing, consumer durables or financial situation of the, family social benefits or so, the personal questionnaire asks each household member aged 16 years or over for information on labour status and employment, personal income and selected biographical information and health, and the dwelling questionnaire records demographic characteristics of dwelling and composition of the household. The EU-SILC has the form of compulsory data collection in all EU Member States and is guided by the European legislation (framework Regulation (EC) 1177/2003 and its implementing Commission regulations).

[12] An alternative data source complied by Czech Statistical office to describe the household sector in

Information on economic activity in EU-SILC includes data on earnings and working hours for each household member that we need to describe household labour supply and labour incomes. Since all incomes are reported for the previous year, we base our model on the SILC 2006 survey to match household data with data on production sector.

Despite the fact the EU-SILC does not aim at recording expenditures, except housing expenditures, the Czech SILC allows disaggregating the housing expenditures further on expenditures on electricity, gas, district heating, hot water, and solid fuels that we use in our model. The Czech-SILC records the monthly payments for energy in a month of the interview was conducted. The amount that given household should pay monthly is set by the utility according to the consumption in the previous year. The recorded amount in the Czech SILC therefore does not reflect household energy consumption of the year of surveying, but it rather indicates its consumption in the previous year. Using the Czech SILC for the year 2006 thus provides consistent source of income, labour and energy expenditure data with production data based on KLEMS 2005.

3.2 Sample descriptive statistics

In total, the Czech SILC 2006 contains information for 7,483 dwellings and 17,830 individuals. The total number of dwellings selected in each region is proportional to region's size. The response rate is 76%. [13]

In order to link our tax model to data, we need to restrict our sample to only those units who are active on the labour market. We thus first delete households with

our model – *Household Budget Survey* – records expenditures in more detail, it does not however record working hours and record wage income for the head and spouse separately only (incomes of others are recorded together).

[13] The SILC survey was carried out on the whole territory of the Czech Republic during February and April 2006. In total 5,750 new dwellings entered the survey and 4,406 dwellings were revisited. Getting 75.8 % response rate, 7,483 dwellings are recorded in the final sample.

The Czech-SILC sample is obtained by applying a two-stage probability sampling scheme on each of the 14 administrative NUT3-level regions independently. Municipality size was used as an additional stratification variable. Dwellings are thus selected using the two-stage design – small geographical areas are first sampled as primary sampling units with probability proportional to their size, at the second stage, ten dwellings are sampled in each sampled CEU (CSO 2006).

no expenditures on energy (N=28, 0.37%). Then we removed the households which gets their income mainly outside of labour market (that is, if total gross earnings of all economic active persons in a family are lower than 50% of total gross incomes of the family). Such households present families with non-economic active persons, such as households of retired or unemployed (N=3,780, 50.5%). Last, we delete households with the maximal personal earnings earned by all household members are lower than the minimal wage set by the government. Although such households get most of their incomes from their labour, these labour incomes are in most cases earned irregularly for occasional job. These job incomes are also very small in absolute magnitude (mean of 94,000 CZK vs. 349,000 CZK for the whole restricted sample) that indicates on quite income poor families (with annual mean of 115,000 CZK vs. 316,872 CZK for the whole restricted sample). There are 99 such dwellings (1.3%) that we exclude from our sample. Our cleaning results in the restricted sample that provides information in total for 3,595 dwellings and 10,299 individuals. Our tax model is just built around this sample.

The restricted sample used in our model consists of households with some economic-active persons earning significant share at labour market on total incomes of their family. Table 1 describes statistics for key socio-demographic variables, expenditures, and variables linked to labour market. All statistics are weighted by household's proportion in total Czech population; the SILC variable PKOEF is used to weight our data properly.

On average, there are almost 3 persons living in the dwelling [$OSOB$], with 1.7 economic active persons [EA] and 0.8 children [$DETI$]. About a half of households has at least one child.

Average annual gross incomes [$HPRIJMY$] are 417,526 CZK (€14,020), annual net incomes [CP_PRIJ] are 327,372 CZK (€10,993). About 48% of households receive social allowances to support financially their children with average bonus of 4,610 CZK a year [$BONUSch$], which corresponds to 1.1% of average gross incomes. This bonus is provided in a form of a refundable tax credit of 6,000 CZK per one child and year (is provided as a benefit if the bonus exceeds calculated personal income tax); about 23% of households in our sample receive 6,000 CZK just for one child, 22% get 12,000 CZK for two children, and 3.5% get up to three 30,000 CZK.

Annual gross earning received by all household members [$Wall$] are, on average, 361,496 CZK, and on average these earnings represent 87% of total annual gross incomes of given household [$wage\_sh$]. In more than half dwellings the gross earnings exceed 91% of total household incomes, and there are 18% of household that receives income from labour only.

Average monthly housing costs are about 4,000 CZK [$NAKLADY$], out of it 2,587 CZK households spent on energy for heating, powering appliances, cooking and lighting. Mean annual expenditures on energy [$ENERGY$] represent about 10% of total net incomes, in absolute terms about 31,000 CZK.

Mean hourly wage rate of the head [wrate1] is 118 CZK (€4.0), while the spouse earned on average 88 CZK per an hour (€3.0) [$wrate2$]. Maximal wage rate among all wage rates earned by each family member is 119 CZK [$Wratemax$], mean of means of all wage rate across economic active family members is 109 CZK [$Wratemean$]. Households worked on average 3,442 hours a year [$HOURS$] and 49% of total time endowment [$HOURS\_sh$] that we define by 16 hours a day over 5 working days a week and for 52 weeks a year (that is 4,160 hours per each working person earned in the year 2005 certain wage).

3.3 Computation of household labour tax payments

TAX is computed personal income tax payments and obligatory contributions to social and health insurance that given household would pay if the tax system rules as enforced in the year 2005 were followed. Specifically, we follow personal income tax system with three tax bands (109,200 CZK; 218,400 CZK; and 331,200 CZK) and four PIT rates (12%, 19%, 25%, and 32%). Tax deductibles of 38,040 CZK per each tax payer in the

Table 1: Descriptive statistics of the reduced Czech SILC-2006 sample, N=3,595.

Variable	Variable description	Type	Mean	s.d.	Min	Max
Socio-demographics						
OSOB	*number of household members*	count	2.89	28.16	1	9
EA	*number of economic active persons*	count	1.73	17.68	0	4
DETI	*number of children*	count	0.77	21.86	0	5
childless	*=1 if there is no child*	dummy	0.52	11.85	0	1
BONUSCH	*social allowances for children, in CZK per year*	continuous	4 610	131 151	0	30 000
CP_PRIJ	*total household next incomes, in CZK per year*	continuous	327 372	3 707 917	79 379	1 630 359
HPRIJMY	*total household gross incomes, in CZK per year*	continuous	417 526	5 253 133	98 350	2 597 500
Household expenditures						
NAKLADY	*housing costs, in CZK per month*	continuous	4 073	38 841	563	22 876
ELEKTR	*monthly expenditures on electricity, in CZK*	continuous	1 052	15 733	0	9 000
PLYN	*monthly expenditures on gas, in CZK*	continuous	731	22 029	0	5 800
UT	*monthly expenditures on district heating, CZK*	continuous	610	18 038	0	5 420
PALIVA	*monthly expenditures on heating fuels, in CZK*	continuous	193	10 450	0	4 583
ENERGY	*energy expenditures, in CZK per year*	continuous	31 043	302 743	3 684	117 108
REST	*household expenditures on the rest (non-energy) goods, CZK per year*	continuous	296 329	3 630 746	19 632	1 579 959
Labour supply and earnings						
Wall	*annual gross earnings from labour of all household members, in CZK*	continuous	361 496	5 092 600	96 300	2 597 500
TAX	*annual tax on personal income from labour, in CZK*	continuous	85 893	2 001 048	-3 823	1 078 474
Wallmax	*maximal annual wage earnings out of all working person in the household, in CZK*	continuous	256 137	3 598 248	96 300	2 597 500
wage_sh	*share of earnings from labour (from all working persons) on total gross incomes of a household*	share	0.86	3.54	0.50	1
wrate1	*hourly wage rate of the head, in CZK*	Continuous (N=3,238)	118	4 281	26.4	7 418
wrate2	*hourly wage rate of the (female) spouse, in CZK*	Continuous (N=1,722)	88	1 168	25.9	750
wratemax	*maximal hourly wage rate out of all working persons in the household, in CZK*	continuous	119	4 117	0	7 418
wratemean	*average hourly wage rate out of all working persons in the household, in CZK*	continuous	109	3 620	0	6 487
HOURS	*working hours per year of all working persons*	hours	3 442	37 172	0	10 400
HOURS_sh	*share of working hours on total time endowment of all working persons in a household (52weeks x 5days x 16hours)*	share	0.49	2.79	0	1.13

Note: To translate CZK in Euro, the average exchange rate in 2006 can be used: 29.78 Czech crown per 1 Euro.

family and tax bonus linked to children [$BONUSch$] of 6,000 CZK per a dependent child, with 30,000 CZK per year set as the maximum, are applied.

If a couple is married and has at least one dependent child, then joint taxation of couples is allowed, i.e. gross earnings are sum up and the tax bands are doubled, keeping the tax rates.

Obligatory payment to social and health insurance are computed as 15% of gross earnings.

A routine in SAS was programmed to compute household-specific taxes paid from labour earning. The TAX is computed for each person in a family who received any regular labour income in the year 2005, that is, TAX is a sum of TAX payments we derived for each person in a family.

Marginal tax rate, tau, is defined as the largest marginal tax we derived for the head and his spouse. Fixed part of the tax payment [GG] is a difference between the marginal tax rate multiplied by all gross earnings from labour and TAX, this part might get both positive or negative values, i.e.

$$GG = tau * Wall - TAX.$$

Other incomes, for instance social allowances [MM], are then defined as total net incomes minus total net earnings minus the fixed part of the labour tax payments, i.e.

$$MM = CP\_PRIJ - (1 - tau) * Wall - GG.$$

The identity holds, that is the sum of expenditures on energy and non-energy equals to the sum of total net earnings, other incomes, and Fixed part of the tax payment, i.e.

$$(ENERGY + REST) = (GG + MM + net\_Wall).$$

Table 2: Definition of the segments based on working profession

Name	Description	ISCO code	No. observations
ISCO-1	service workers	5,6	340 (10%)
ISCO-2	no skilled crafts	7,8,9	1,520 (43%)
ISCO-3	quite skilled - technicians and skilled clerks	3,4	1,122 (32%)
ISCO-4	high skilled - managers and professionals	1,2	545 (15%)

3.4 Definition and data for household groups

In this paper, we analyse the optimal tax for two distinct groups of household segments[14]. First definition follows the household segmentation based on working profession, as defined by ISCO codes, following Cremer and al. (2003). Specifically, we define four segments according to working profession classified by ISCO codes of the family member with the largest earnings, as described in Table 2. There are about 10% of service workers, 43% no skilled, 32% intermediate skilled and remaining 15% of high skilled households.

Descriptive statistics for the four household segments are displayed in table 3. The household composition of the four segments, on average, does not differ much. Total incomes, gross earnings are monotonically increasing along the four groups. The first three groups spent almost same amount on energy bills (about 30,000 CZK a year), the high skilled segment pays for energy about 15% more. Higher variation is in non-energy expenditures; low skilled spent less than two third and quite skilled spent about three thirds of what high skilled spent.

About 90% of the heads are earning money for their job and there are about half of spouses that are also receiving incomes from working. The highest share of working

[14]In both groups, households with all members taht are not economically active, such as with retired persons, are excluded, and hence are not considered in our analysis.

heads and spouses appear in the high skilled (92% and 56%), followed by low skilled crafts (ISCO-2), the households containing low skilled persons working in services work the least (84% and 42%).

On average, total hours spent on work do not vary much across the four groups and the working hours range between 3,374 to 3,536 hours a year. Time spent in work, as the share on total time endowment of all persons receiving earnings, does not vary either; it is about 50%, that is equivalent of 8 hours a day per 5 days a week and 52 weeks a year. Only highly skilled work more, but their share is only about 4% larger than the shares in remaining groups.

Households with more skilled persons get, however, significantly larger hourly wage rates. Average hourly wage rate of the heads is same in both low skilled segments, about 94 CZK, while the heads in the quite skilled households earned 121 CZK and in the high skilled earned even 187 CZK an hour, on average. The hourly wage rate of the spouses is lower than the wage rate of their heads and their wage rates are also increasing across working skills; the rate is about 70 CZK in ISCO-1 and ISCO-2 group, and reaches 112 CZK in ISCO-4.

The segmentation of households by ISCO codes is similar to the segmentation used for France in Cremer and & al. (2003, 2010) and US in Cremer and & al. (2011) and allows comparison with these studies. Because we have individual data at our disposal, we are able here to consider many different definitions of households segments. As we focus on the redistributive consequences of energy taxation, it seems to be relevant to use households segments based on total gross earnings earned by all economic-active persons in a family. We define again four groups; first group includes households that earned 10% lowest total earnings [*poor*], the second one cover the households with 10% to 50% lowest earnings [*semi-poor*], and the third one with 50% to 90% [*semi-reach*],

Table 3: Descriptive statistics for the four segments defined by the occupation.

		ISCO-1 *[low skilled in services]*	ISCO-2 *[low skilled crafts]*	ISCO-3 *[quite skilled]*	ISCO-4 *[high skilled]*
share	share in the sample	0.10	0.43	0.32	0.15
OSOB	household members	2.78	3.00	2.75	2.90
DETI	number of children	0.69	0.79	0.73	0.90
EA	number of economic active persons	1.72	1.75	1.75	1.72
CP_PRIJ	net incomes, CZK a year	283 322	286 530	339 594	432 496
ENERGY	energy expenditures, CZK a year	30 620	30 079	30 400	34 853
REST	non-energy expenditures, CZK a year	252 702	256 451	309 194	397 644
Wall	earning, CZK a year	298 438	306 988	380 700	513 860
wagejobsh	share of earnings on gross incomes, %	0.83	0.85	0.87	0.89
wr1	hourly wage rate of the head, CZK	94	95	121	187
wr2	hourly wage rate of the spouse, CZK	77	70	101	112
wr1sh	share of heads earning money, %	0.84	0.93	0.87	0.92
wr2sh	share of spuses earning money, %	0.42	0.48	0.52	0.56
BONUS_sh	social allowances for children, CZK	4 158	4 725	4 377	5 428
TAX	tax payments (PIT+SSC), CZK a year	65 138	61 818	91 755	151 909
HOURS	hours spent on work	3 374	3 507	3 384	3 536
HOURS_sh	time spent working, %	0.51	0.49	0.49	0.52

while the last, fourth, group describes the households with the top 10% highest gross earnings [*reach*].

Descriptive statistics for the four household groups defined by total gross earnings is displayed in Table 4. Household composition in these groups varies more than in the previous household classification based on ISCO-coded working professions. The higher gross earnings the segment receives, the larger family, the more children and the more economic active persons are in a family.

The net incomes, total gross earnings and expenditures on non-energy goods are also increasing along the groups but with greater increase than in the ISCO-based groups. Net incomes of "*poor*" are only a quarter of the rich, "semi-poor" gets about 38% of what rich gets. Expenditures on energy also vary more than among the ISCO-groups; "*poor*", "*semi-poor*" and "*semi-reach*" spent 68%, 85% or 79%, respectively, of the amount that is spent by "*rich*" households on energy.

Gross earnings vary across the groups even more for total gross earnings; "poor" and "semi-poor" earn only 16%, or 28%, respectively, of what did earn the "rich", and "semi-reach" still earn about a half of that only. These differences are caused by two factors. First, there are more persons in rich households who are working; especially the shares of working spouses differ quite much, for example, there are only 10% and 28% of working spouses in "poor" or "semi-poor", respectively, while there are 77% working spouses in the "rich" group. Second, the richer also earn larger hourly wages; while on average the heads earned 63 CZK in "poor" group and 92 CZK in "semi-poor", the heads from "rich" group received 229 CZK per hour, that is, 3.6 times more what the "poor" earn. Job earnings are also contributing with higher share to total gross incomes in the rich group; the share is 95% in "rich" and only 74% in "poor" group. Poor also worked less, about 47% of their time endowment, while rich spent 52% of their time at

Table 4: Descriptive statistics for the four segments defined by total gross earnings.

		richpoor=1 *[with 10% lowest earnings]*	richpoor=2 *[10% to 50% lowest earnings]*	richpoor=3 *[50% to 90% lowest earnings]*	richpoor=4 *[with 10% highest earnings]*
share	share in the sample	0.10	0.40	0.40	0.10
OSOB	household members	2.17	2.63	3.13	3.43
DETI	number of children	0.58	0.73	0.84	0.76
EA	number of economic active persons	1.05	1.37	2.00	2.48
CP_PRIJ	net incomes, CZK a year	155 198	237 860	363 201	624 606
ENERGY	energy expenditures, CZK a year	25 397	29 680	31 735	37 376
REST	non-energy expenditures, CZK a year	129 801	208 180	331 466	587 229
Wall	earning, CZK a year	127 735	222 951	415 426	801 793
wagejobsh	share of earnings on gross incomes, %	0.74	0.80	0.91	0.95
wr1	hourly wage rate of the head, CZK	63	92	119	229
wr2	hourly wage rate of the spouse, CZK	60	69	84	127
wr1sh	share of heads earning money, %	0.83	0.84	0.93	0.94
wr2sh	share of spuses earning money, %	0.10	0.28	0.69	0.77
BONUS_sh	social allowances for children, CZK	3 465	4 397	5 067	4 559
TAX	tax payments (PIT+SSC), CZK a year	20 286	41 180	93 031	257 097
HOURS	hours spent on work	1 987	2 572	4 067	5 174
HOURS_sh	time spent working, %	0.47	0.48	0.50	0.52

work. In absolute terms, the poor spent about 2,000 hours a year at work, while the economic active persons from the rich households spent almost 5,200 hours at work.

4 Calibration of the parameters

4.1 The consumers' utility function

For the purpose of calibration, we use nested CES utility functions to represent consumers' preferences; we have,

$$\boldsymbol{U}(x, y, L^j, \theta^j) = \left(b^j {Q^j}^{\frac{\rho-1}{\rho}} + (1-b^j)(1-L^j)^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}, \tag{11}$$

$$Q^j = \left(a^j x^{\frac{\omega-1}{\omega}} + (1-a^j) y^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}}. \tag{12}$$

The above equations show that consumers have identical elasticities of substitution between leisure and non-leisure goods, ρ, and between energy and non-energy goods, ω. The value of these parameters has been chosen by help of very simple econometric estimations and values found in the literature. Differences in tastes are captured by the parameters a^j and b^j. To estimate these parameters we follow the procedure already used in Cremer and *al.* (2010) and (2013). Maximizing the j-type individual utility function defined by (11) and (12) under the linearized budget constraint,

$$px^j + qy^j = G^j + M^j + w_n^j L^j, \tag{13}$$

where G^j is the income adjustment term (virtual income) needed for linearizing the budget constraint and M^j is the individual's exogenous income. The first-order conditions for a j-type's optimization problem are,

$$\frac{1-a^j}{a^j} \left(\frac{x^j}{y^j} \right)^{\frac{1}{\omega}} = \frac{q}{p}, \tag{14}$$

$$\frac{(1-b^j)\big(x^j/(1-L^j)\big)^{\frac{1}{\rho}}}{a^j b^j \left[a^j + (1-a^j)(x^j/y^j)^{\frac{1-\omega}{\omega}} \right]^{\frac{\omega-\rho}{\rho(1-\omega)}}} = \frac{w_n^j}{p}. \tag{15}$$

Using the observed values of x, y, p, q and w_n and the value chosen for ρ and ω, equations (13)–(15) allow to estimate the a^j and the b^j.

This calibration process has been used successively with the two data set described above.

4.2 The producer

The technology of production is represented by a nested CES,

$$\begin{aligned} O &= \boldsymbol{O}(L, K, D) = B\left[(1-\beta)\, L^{\frac{\sigma-1}{\sigma}} + \beta \Gamma^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, & (16) \\ \Gamma &= A\left[\alpha K^{\frac{\delta-1}{\delta}} + (1-\alpha)\, D^{\frac{\delta-1}{\delta}}\right]^{\frac{\delta}{\delta-1}}, & (17) \end{aligned}$$

where A and B are constants, σ and δ represent the elasticities of substitution between L and Γ and between K and D (given Γ) respectively. Substituting (17) in (16) yields,

$$O = B\left[(1-\beta)\, L^{\frac{\sigma-1}{\sigma}} + \beta A^{\frac{\sigma-1}{\sigma}} \left[\alpha K^{\frac{\delta-1}{\delta}} + (1-\delta)\, D^{\frac{\delta-1}{\delta}}\right]^{\frac{\delta(\sigma-1)}{\sigma(\delta-1)}}\right]^{\frac{\sigma}{\sigma-1}}. \quad (18)$$

Let w denotes the price of one unit of *effective labor*, τ_D denotes the tax on energy input, and assume that there are no *producer taxes* on labor and capital.[15] The first-order conditions for the firms' input-hiring decisions are, assuming competitive markets,

$$\begin{aligned} \boldsymbol{O}_L(L, K, D) &= w, & (19) \\ \boldsymbol{O}_K(L, K, D) &= r, & (20) \\ \boldsymbol{O}_D(L, K, D) &= p_D + \tau_D. & (21) \end{aligned}$$

Using analytical expressions as derived from the nested CES form (18) for $\boldsymbol{O}_L(L, K, D)$, $\boldsymbol{O}_K(L, K, D)$ and $\boldsymbol{O}_D(L, K, D)$, the parameters α, β, A and B are the solution of the system of equations (18)–(21). The observed values of O, L, K, D , w, r and $p_D + \tau_D$ used in this calibration process are from the EUKLEMS database (www.euklems.net).

[15] It is not optimal to tax capital in this setting.

4.2.1 Data summary and parameters

Table 5: Data summary and parameters

	Low skilled in services (ISCO 1)	Low Skilled Crafts (ISCO 2)	Quite Skilled (ISCO 3)	High Skilled (ISCO 4)
π	10%	43%	32%	15%
I	298438	306988	380700	513860
px	30620	30079	30400	34853
qy	252702	256451	309194	397644
n	0.75945	0.81563	0.99956	1.9669
L	0.35560	0.34060	0.34466	0.35861
t	16%	16%	20%	24%
G	-15371	-11264	-15290	-27247
M	50022	41360	50650	70546
a	0.000289	0.000256	0.000133	0.000087
b	0.277479	0.259964	0.283205	0.324660
	10% lowest earnings (RP 1)	10% to 50% lowest earnings (RP 2)	50% to 90% lowest earnings (RP 3)	10% highest earnings (RP 4)
π	10%	40%	40%	10%
I	127216	222159	412725	807451
px	25415	29316	31732	37262
qy	128279	206304	327500	587864
n	0.35080	0.60557	1.06638	2.00736
L	0.32817	0.33198	0.35023	0.36400
t	0.11774	0.14608	0.18794	0.25793
G	-5453	-8379	-14408	-51928
M	46910	54293	38484	77871
a	0.00179	0.00052	0.00013	0.00003
b	0.21929	0.24988	0.28678	0.36200
	Type-independent figures			
	$p = 1.11762$	$q = 1.00000$	$\sigma = 0.8$	$\delta = 0.28697$
	$\rho = 0.66490$	$\omega = 0.26892$	$\alpha = 0.94848$	$\beta = 0.52907$
	$A = 1.58606$	$B = 1.98476$		

5 Results

5.1 Linear commodity taxation

The results presented here are obtained for $\eta = 0.5$ (low inequality aversion index) and $\eta = 2$ (high inequality aversion index). Two values of ϕ have also been considered. The first value corresponds to the case in which there is no externality ($\phi = 0$), the second is calculated in such a way that the first best Pigouvian tax is equal to 10% of energy price. Table 1 and 2 give the Pigouvian energy tax[16] and the optimal linear energy tax for the different values of η and ρ. The upper part of the table has been obtained with ISCO data (based on occupation of the head) while the lower part has been obtained with RP data (i.e. reach-poor groups based on earnings). Remember that the polluting input tax is strictly equal to the Pigouvian tax consequently, it is not reported in those tables.

Table 6:

Optimal linear energy tax and Pigouvian tax with ISCO Data				
	First Best tax =0%		First Best tax =10%	
	$\eta = 0.5$	$\eta = 2$	$\eta = 0.5$	$\eta = 2$
Pigouvian tax	0.0	0.0	9.9	9.8
Optimal energy tax	−6.9	−9.6	2.3	−0.6
Optimal linear energy tax and Pigouvian tax with RP Data				
	First Best tax =0%		First Best tax =10%	
	$\eta = 0.5$	$\eta = 2$	$\eta = 0.5$	$\eta = 2$
Pigouvian tax	0.0	0.0	8.8	10.2
Optimal energy tax	−39.6	−42.1	−33.9	−35.6

Our results show that the optimal linear energy tax is significantly lower than the Pigouvian tax. When there is no externality the tax is negative, that is energy should be subsidized. Even with a negative externality (10% of price), energy must be subsidized if the government care a lot about equity (for $\eta = 2$).

[16] Note that the Pigouvian tax reported in table 1 is generally not equal to 10%. This is because as lump sum taxation is not feasible, we are in a second best world.

In the case of ISCO data, productivities differ among individuals but not as much than with RP data where the first category corresponds to the 10% poorest people in the economy. This is why, the energy subsidy is significantly higher with RP data.

5.2 Non-linear commodity taxation

We turn now to the case in which the government has the information it needs to implement a non-linear energy tax. This is equivalent to say that a non-linear tariff of energy is feasible. Let us note that the tariff is a non-separable function of the quantity of energy consumed and the income. The implementation of such a tariff in practice is not easy or impossible, even if individual transactions are fully observable. Indeed, it need to mix two different sources of information: energy producers, which are holding information on individual purchases, and government, holding information on individual incomes. Note that among the technical difficulties that can be met for regrouping the different information is the prohibition by law of such a process. Nevertheless, some attempts to apply, or to approximate, such a system exist, a French project of electricity pricing, currently abandoned, is an example. Another example comes from the Czech Republic. To date, support of electricty generation from renewable resources in the Czech Republic provided via a feed-in-tariffs is financed through a (linear) fee levied on each kWh consumed. Recently, a new governmental proposal suggests that this support scheme is replaced by and increase in payment for a circuit breaker, i.e. the fixed part of electricity price. The new scheme would in fact imply a non-linear tariff scheme in electricity pricing in the Czech Republic.[17].

Table 3 show the optimal energy tax with and without externality and under the different values of η. We first note that, in any case, the usual non-distortion at the top rule applies. As nobody tries to mimic the high income individuals, there is no need to distort their behavior. Second, the results from ISCO data and RP data are contrasted.

[17] The issue of social tariffs for electricity is analyzed in Crampes and al. (2014).

Qualitatively speaking, our results are similar to the one obtained in our previous studies for France [18]. The subsidy does not change monotonically with income. This is because individuals 1 and 2 try to mimic each other. Not only adjacent self selection constraints are binding. The pattern is the following: 1 mimics 2, 2 mimics 1, 3mimics 4 and 4 mimics 2.

With ISCO data, individuals are segmented more with respect to their tastes than with respect to their productivities. As we are mainly concerned by the impact of energy taxes on income redistribution the segmentation used in RP data is much more appropriated. But such a data base can be produced only with individual data that was not available in our previous studies. We show in table 7 that, with RP data, the energy subsidy (the optimal tax is always negative) is decreasing with income.

Table 7:

Optimal non-linear energy tax with ISCO Data				
FB tax =0%				
Types	ISCO1	ISCO2	ISCO3	ISCO4
Optimal energy tax when $\eta = 0.5$	-2.8	-8.8	-6.2	0.0
Optimal energy tax when $\eta = 2$	-6.6	-11.8	-8.3	0.0
FB tax =10%				
Types	ISCO1	ISCO2	ISCO3	ISCO4
Optimal energy tax when $\eta = 0.5$	6.7	0.3	3.1	9.9
Optimal energy tax when $\eta = 2$	2.6	-2.9	0.8	9.8
Optimal non-linear energy tax with RP Data				
FB tax =0%				
Types	RP1	RP2	RP3	RP4
Optimal energy tax when $\eta = 0.5$	-53.0	-38.7	-20.5	0.0
Optimal energy tax when $\eta = 2$	-51.2	-41.1	-23.0	0.0
FB tax =10%				
Types	RP1	RP2	RP3	RP4
Optimal energy tax when $\eta = 0.5$	-48.4	-32.9	-13.3	8.8
Optimal energy tax when $\eta = 2$	-45.2	-34.5	-14.9	10.2

[18] See for instance Cremer and al. (2003).

6 Conclusion

This paper has explored the design of an optimal general income tax system when earning abilities are endogenous, and when energy is used both as a polluting consumption good and a polluting input. The paper has shown that the optimal tax on energy inputs is Pigouvian and equal to its marginal social damage. The optimal tax on the consumption of energy, on the other hand, is less than its marginal social damage. In fact, energy consumption should be subsidized, the case in which the environmental cost of energy consumption is sufficiently high being an exception. The reason for this is the fact that the poor spend proportionally more of their income on energy consumption than the rich.

The case of a non-linear tax on energy is particularly interesting because it usefully completes the results of our previous studies. The households segmentation by ISCO codes is comparable to the segmentation of our previous studies and the corresponding results are also very similar (qualitatively speaking) to the one obtained for US and France. This is not the case when the households' segmentation is based on total gross earnings. Indeed we show that in this case the subsidy must decrease with income.

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