DISCUSSION PAPER SERIES

No. 3677

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Laura Marsiliani and Thomas I Renström

PUBLIC POLICY

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ISSN 0265-8003

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Laura Marsiliani, University of Rochester
Thomas I Renström, University of Rochester and CEPR

Discussion Paper No. 3677
January 2003

Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: www.cepr.org

CEPR Discussion Paper No. 3677

January 2003

ABSTRACT

On Income Inequality and Green Preferences*

We derive conditions of individual preferences and technology that give rise to a negative correlation between income inequality and environmental protection. We present a class of models (which captures a static model as well as an overlapping-generations model) in which individuals differ in earning abilities, and where a representative takes the decisions on a pollution tax and a redistributive tax. We show that, if private consumption goods and the environment are non-inferior goods, and the decisive individual has lower ability than the average, they will prefer a higher redistributive tax and a lower pollution tax.

JEL Classification: D63, D72, H21 and H23
Keywords: environmental policy, inequality, political economy and redistribution

Laura Marsiliani
Wallis Institute of Political Economy
107 Harkness Hall
University of Rochester
Rochester, NY 14627
USA
Tel: (1 585) 275 7804
Fax: (1 585) 271 3900
Email: msni@troi.cc.rochester.edu

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Thomas I Renström
Wallis Institute of Political Economy
110 Harkness Hall
University of Rochester
Rochester, NY 14627
USA
Tel: (1 585) 275 6834
Fax: (1 585) 271 3900
Email: rnsm@troi.cc.rochester.edu

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=120183

*The first author gratefully acknowledges financial support from the Dutch Scientific Foundation, NWO. All errors and shortcomings are our own.

Submitted 01 November 2002

1. INTRODUCTION

Empirical evidence suggests that individual income is positively correlated with public support for environmental protection. For example, Elliot et al. (1997) find that both socio-demographic and economic factors are influential for individual support on environmental spending in the US, while Kahn and Matsusaka (1997) find that individual income and the price of the environmental good can explain most of the variation in voting on environmental policies in California. Nevertheless, a theoretical explanation of this relationship has not been carefully explored in the literature. In a tax competition framework Oates and Schwab (1988) develop a static model in which individuals are distinguished in wage and non-wage earners and the median voter takes decisions over a capital tax and a standard for local environmental quality. If the decisive individual is a wage earner, she will choose a negative capital tax and a higher environmental standard than the first-best optimal level. If the decisive individual is a non wage-earner, she will prefer a positive capital tax.[1] However, whether the environmental standard is higher or lower than the first-best optimum is not clear cut.

In this paper we explore the conditions which are sufficient to generate a negative relationship between income inequality and environmental protection. By using general preferences and technology, we show that, in a neighbourhood of no inequality, only non-inferiority of consumption goods and of the environmental good is needed to achieve this result. Our finding is robust to a class of models from a static model to an overlapping-generations economy model. In a companion paper (Marsiliani and Renström, 2000b), we are able to derive the same result globally but for specific preferences. In this paper, individuals differ in income-earning abilities, and the decisive individual (median voter or median candidate) implements her preferred policy choice over a pollution tax and a capital tax (used for redistributive reasons), which is in turn influenced by her characteristics such as income-earning ability. We examine the preferences of a hypothetical decision maker and abstract from voting.

The main finding is that there are two driving forces at work. First, environmental policy results in loss of production possibilities. Different individuals evaluate the production loss differently. Individuals with a higher marginal utility of consumption (the poorer ones) have

[1] The reason for their, at first sight, counter-intuitive results regarding capital taxation has to do with the open-economy model. A capital subsidy attracts capital from abroad and increases the wage of the wage earners. The subsidy is payed for through a lump-sum tax which also falls on the capial owners.

a lower marginal rate of substitution between environment and private consumption if environment is a non-inferior good. Second, a poorer individual typically wishes to redistribute (using tax instruments on income) from richer individuals. The redistribution causes the consumption-possibilities frontier to move inwards (due to efficiency losses). In such an equilibrium, if the environment is a normal good, the marginal rate of substitution between environment and private consumption decreases (for all individuals).

In conclusion, our general framework suggests that income inequality is one driving force in the determination of environmental policy and therefore ought to be included in any empirical analysis of environmental policy.

The paper is organised as follows. The general model is introduced in section 2. In section 3, the economic equilibrium is solved for. In section 4, individuals' preferences over taxation are characterised and explained and the main results stated. Section 5 concludes.

2. THE ECONOMY

We will specify a general model that contains three different cases. The first case (case I) is a static economy in which output is produced by labour and pollution. Labour and pollution are taxed at possibly different rates, and the tax receipts are redistributed lump-sum to the individuals. Individuals differ in time endowments. This implies that individuals with less productive time will supply less labour (than those with more productive time) if consumption is a normal good. There will then be a redistributive conflict, since the less endowed individuals gain from taxation of labour. This is similar to the Meltzer-Richard (1981) model, but augmented for pollution.

The second case (case II) is a sequence of two-period economies. Individuals live for two periods, consuming in both periods, but only working when they are young. Generations of different ages never co-exist. This is the same set-up used by Persson and Tabellini (1994), but augmented to allow for pollution. The period-one good is produced by labour (exogenous in supply), and the period-two good by capital (saved from the previous period) and pollution. Taxes are levied on capital income and on pollution, and a lump-sum transfer is given when the individuals are old.

The third case (case III) is an overlapping-generations economy (similar to Renström, 1996, but augmented for pollution). Output in each period is produced by labour (inelastically supplied by the young), capital (supplied by the old), and pollution. The decision about taxes is taken one period in advance (the young decide on taxes to be implemented when they are old). Taxes are levied on capital income and on pollution, and the transfer is given to the old generation.

In order to clearly understand how inequality may affect the pollution tax, we use a general utility specification and a general (constant returns-to-scale) production technology. In this paper, we will only look at one situation: this is when inequality is marginally increased from a situation with full equality.[2] Using general preferences and technologies to derive global results makes the problem untractable.

Denote the two consumption goods (consumed by individual *i*) as c_1^i and c_2^i, respectively. The individual may transfer some of commodity 1 (k_1^i) into commodity 2 at the after-tax rate *p*. The individual has an endowment of commodity 1, w_0^i, and receives a transfer of commodity 2, *S*. In case (I) (the static model), c_1^i is leisure, c_2^i is consumption, k_1^i is labour supply, *p* is the after-tax wage, and w^i is the individual's time endowment. In cases (II) and (III) (the dynamic economy with and without separation across generations), c_1^i and c_2^i are period 1 and 2 consumption respectively, k_1^i is savings, *p* is the after-tax return on savings, and w^i is period-1 labour income. We assume that $w_0^i = \gamma^i w_0$, and that the distribution of γ^i (denoted $\Gamma(\gamma^i)$) is continuous and, for cases (II) and (III), stationary over time. $\Gamma(\gamma^i)$ is also normalised so that the average γ^i equals unity, and so that averages equals aggregates. We will denote averages/aggregates by omitting superscript *i*. Throughout we will make one separability assumption: the pollution externality enters the individuals' utility functions in a weakly separable way. This will make the individuals' marginal rates of substitutions between private consumption units independent of the pollution externality. This will make the private consumption decisions independent of pollution; without such a separation, the problem becomes intractable. The weak separability will *not*, however, make the individuals' evaluation of the environment independent of their private consumption, and, consequently, we may explore this interaction in the analysis. We next state the assumptions.

[2] This is analogous to the optimal-tax literature. A situation in which one solves for an optimal tax system, and evaluates it at zero tax rates, is a situation in which one marginally introduces the second best from a first-best situation (no taxes).

2.1 Assumptions

A1 Individuals' preferences

We assume weak separability between private consumption and pollution

$$V^i = V\left(u(c_1^i, c_2^i), x\right) \tag{1}$$

where V and u are strictly concave, and $V_1>0$, $V_2<0$, $u_1>0$, $u_2>0$.

A2 Individuals' constraints

The individuals' budget constraints are

$$c_1^i + k^i = w_0 \gamma^i \qquad (2) \qquad\qquad c_2^i = pk^i + S, \quad p \equiv (1-\tau^k)R \qquad (3)$$

A3 Production

A large number of firms are operating under identical *constant-returns-to-scale* technologies. Therefore aggregate production, y_t, can be calculated as if there was a representative firm employing the aggregate quantity of the factors supplied by the individuals, ($k \equiv \int k^i d\Gamma(\gamma^i)$) and, in case (III) ($l \equiv \int \gamma^i \, l d\Gamma(\gamma^i)$), and the polluting factor.[3] For case (I) and (II)

$F(k, x)$ (4*a*), and for case (III) $F(k, x, l)$. (4*b*)

Firms take the factor prices of labour (w), capital (R), and the pollution tax τ^x, as given.[4]

A4 Government's constraint

The tax receipts are fully used for the lump-sum transfer

$$S = \tau^k R k + \tau^x x \tag{5}$$

A5 Government's decision

The tax rates, τ^k and τ^x, are determined by an individual taken from the population, one period in advance.[5]

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[3] The polluting factor is provided at no cost. Thus, in absence of a government taxing or regulating it, this factor would be used up until the satiation point.

[4] Note that w_0 is labour income in the previous period, and w is labour income earned by the next generation to come.

[5] In a full political-economy model the individual would be the majority elected one. See further section 4.

3. ECONOMIC EQUILIBRIUM

In this section, the individual and aggregate economic behaviour are solved for any given arbitrary sequences of tax rates.

3.1 Individual economic behaviour

Maximisation of (1) subject to (2)-(3) gives the individuals' optimal decision over k. The first-order condition forms an implicit function

$$\phi = -u_1\left(w_0^i - k^i, pk^i + S\right) + pu_2\left(w_0^i - k^i, pk^i + S\right) = 0 \tag{6}$$

which differentiated gives the following partial derivatives

$$\frac{\partial k^i}{\partial w_0^i} = N_2^i \quad (7) \qquad \frac{\partial k^i}{\partial p} = \frac{u_2^i}{D^i} - \frac{k^i}{p}N_1^i \quad (8) \qquad \frac{\partial k^i}{\partial S} = -\frac{N_1^i}{p} \quad (9)$$

where

$$N_1^i \equiv \frac{pu_{12}^i - p^2u_{22}^i}{D^i} \quad (10) \qquad N_2^i \equiv \frac{-u_{11}^i + pu_{21}^i}{D^i} \quad (11) \qquad D^i \equiv -u_{11}^i + 2pu_{12}^i - p^2u_{22}^i > 0 \quad (12)$$

N_1 is positive (negative) if c_1 is a *normal* (*inferior*) consumption good, and N_2 is positive (negative) if c_2 is a *normal* (*inferior*) consumption good. Furthermore, $N_1 + N_2 = 1$, implying that, at most, one of the goods can be inferior. We will see later what role the normality of the private consumption goods plays in the analysis.

3.3 Firms' behaviour

Firms take prices as given. Profit maximisation implies that the before-tax prices are given by $r=F_k$ (in cases (I), (II), and (III)), and $w=F_l$ (in case (III)). Notice that in case (III), w is the wage received by the next generation (the present generation receives w_0, which is labour's marginal product in the previous period). The first-order condition for the use of factor x, $F_x(k,x,l)=\tau^x$, gives (aggregate/average) x as a function of (aggregate/average) k and τ^x (and of l which, however, is fixed), with the following property

$$dx = d\tau^x/F_{xx} - (F_{xk}/F_{xx})dk \tag{13}$$

3.4 Government's budget

The budget may alternatively be written as

$$S = F - F_l l - pk \tag{14}$$

We will define environmental strictness as the level of τ^x, which implies that if the government operates an emissions standard, the strictness measure is the (equilibrium) marginal product of pollution, F_x.

4. PREFERENCES OVER POLICY

We assume that policy will be chosen by a representative.[6] In a political-economy framework this individual would be the majority elected one. Since individuals differ in only one dimension one can construct a median-voter equilibrium where the median individual cannot lose against any other candidate.[7] In this paper we will not model the political equilibrium, we will just examine the preferences of a hypothetical representative and see how her optimal choice changes as we change the ability of this individual. We do so for the case in which a candidate is "close" to the average. In this way we analyse a situation where we move from the first best (all individuals being the same) to the second best. The aim is to understand the driving forces behind inequality and environmental policy.

The problem of the decision maker i is to

$$\max_{p,s,x} \; V\big((w^i - k^i, pk^i + S), x\big) + \lambda\big[F(k,x,l) - pk - F_l l - S\big] \tag{15}$$

The problem is written as if the individual was to choose x directly (for example, imposing an emissions standard); however, it is just an equivalent representation of the situation where the pollution tax is chosen. The first-order conditions are

$$V_1 u_2 k^i + \lambda\left[(F_k - F_{lk} l - p)\frac{\partial k}{\partial p} - k\right] = 0 \tag{16}$$

$$V_1 u_2 + \lambda\left[(F_k - F_{lk} l - p)\frac{\partial k}{\partial S} - 1\right] = 0 \tag{17}$$

$$V_2 + \lambda\big[F_x - F_{lx} l\big] = 0 \tag{18}$$

We may observe the following. Since the pollution tax is pollution's marginal product, (18)

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6 As in the citizen-candidate models [Osborne and Slivinski (1996), and Besley and Coate (1997)], where a representative takes the policy decision in all dimensions.

7 The elected individual would choose policy so as to maximise her own utility. This policy would be a function of the type of the individual, say γ^*. Substituting this policy into any other individual's utility function one obtains an indirect utility function of γ^* only. It is clear, since individuals differ only in one dimension, the political equilibrium would be of the median-voter type. This is a political equilibrium if individuals' indirect utilities over γ^* are single peaked. This is modelled in Marsiliani and Renström (2000b) for specific utility and production functions.

may be written as $\tau^x = F_{lx}l + (-V_2)/\lambda$. Everything being equal, an increase in λ (the decisive individual's marginal utility of lump-sum income at the optimum) reduces the pollution tax. Environmental policy comes at the expense of production possibilities. This tends to make poorer individuals (with lower marginal rate of substitution between environment and private consumption) wanting a lower pollution tax. Furthermore, λ is also evaluated at equilibrium production.

The argument put forth above is just to illustrate what we believe are the driving forces. We need to prove that λ is larger for a poorer individual if she was to choose policy than it would be for a richer individual if the latter were to choose policy. We also need to take into account how individuals evaluate the environment. If V is not additively separable, then V_2 depends on the private consumption of the decisive individual (at the optimum) as well. For example, it could be the case that a poorer individual values the environment more (for example, $-V_2$ could be larger for poorer individuals). Furthermore, there is also an effect (in case (III)) regarding the return to labour of the young generation, which the present decisive individual does not care about, but would rather use the tax system so as to reduce the next generation's labour income. In order to formally prove the link between the income of the decisive individual and environmental protection, we need to take into account the whole system (16)-(18). We will do so by performing comparative statics, by changing γ^i of the decision maker, and evaluating the consequences on τ^x in a situation with no inequality. We can then see the consequences of making the decision maker (marginally) poorer or richer than average.

Combining (16) and (17) gives

$$k - k^i = \left(F_k - F_{lk}l - p\right)\left(\partial k/\partial p - k^i \partial k/\partial S\right) \tag{19}$$

In the RHS of (19), the second expression in round brackets is unambiguously positive because k is very close to k^i (from equations (8) and (9)). We need to evaluate the first term in round brackets in the RHS of (19). First, in case (I) and (II), F_{lk} is zero (production technology (4a)). Then the capital tax is positive (zero/negative) if the decisive individual supplies less (equal/more) of k than the average.[8] In case (II), the future generation will earn wage income, and by choosing a larger capital tax, labour income is reduced (if $F_{lk}>0$) and

[8] If Engel curves are linear, and period-two consumption normal, this is the case if the individual has γ smaller (equal/greater) than unity (i.e. average).

an implicit transfer from the future young is accomplished. Thus, here, even if the decisive individual owns capital exactly equal to the average (e.g., if full equality), capital would be taxed. Equation (19) forms an implicit function in γ^i, p, k, and x (the latter two being functions of policy). Differentiating and evaluating at k^i=k (full equality) gives

$$-\frac{\partial k^i}{\partial w} dw_0^i = \left[(F_{kk} - F_{lkl}l)dk + (F_{kx} - F_{lkx}l)dx - dp\right]\left(\frac{\partial k}{\partial p} - k^i \frac{\partial k}{\partial S}\right) \tag{20}$$

Using (8)-(9) to substitute for the expression in parenthesis, and using (13) to substitute for dx yields

$$u_2^{-1} N_2 D dw_0^i = \sigma dk + \eta d\tau^x + dp \tag{21}$$

where

$$\sigma \equiv -\left(F_{kk} - F_{lkk}l - (F_{kx} - F_{lkx}l)F_{xk}/F_{xx}\right) \quad (22) \qquad \eta \equiv -(F_{kx} - F_{lxk}l)/F_{xx} \quad (23)$$

Equation (21) gives the after-tax return p as a function of the decisive individual's endowment w_0^i, of the pollution tax τ^x, and of the level of k (in turn a function of p and τ^x). If we consider cases (I) and (II), (production technology (4*a*)), σ=0. Then for each level of τ^x, the after tax return p is increasing in w_0^i if commodity 2 is a normal good. If factor k's marginal product increases with pollution (F_{kx}>0) η>0, then an increase in τ^x (everything else equal) reduces p. The reason is that an increase in τ^x reduces x and thereby reduces F_k, and it is not optimal to reduce the tax on k so as to leave $p=(1-\tau^k)F_k$ unaffected.

Next, we combine (17) and (18) to obtain the optimality condition for τ^x

$$\frac{V_1 u_2}{-V_2} = \frac{1 - (F_k - F_{lk}l - p)\frac{\partial k}{\partial S}}{\tau^x - F_{lx}l} \tag{24}$$

We need to know how the marginal rate of substitution between private consumption and the environment changes with the underlying variables. Let V_j denote the derivative of V with respect to argument j={1,2}, we then have

$$dV_j = V_{j1}\left[u_1 dw_0^i + u_2(k^i dp + dS)\right] + V_{j2}dx \tag{25}$$

where the derivatives of k^i drop out (Envelop condition). Differentiating (14) gives

$$dS = (F_k - p - F_{lk}l)\,dk + (F_x - F_{lx}l)\,dx - kdp \tag{26}$$

Equation (19) evaluated at k^i=k gives F_k=p+$F_{lk}l$, then (26) becomes

$$kdp + dS = (F_x - F_{lx}l)dx = -V_2/(V_1 u_2)dx \tag{27}$$

where the last inequality follows from (18), evaluated at no inequality (i.e. λ=$V_1 u_2$).

Substituting the last equality of (27) into (25) gives

$$dV_j = V_{j1}\left[u_1 dw_0^i - (V_2/V_1)dx\right] + V_{j2}dx \tag{28}$$

or by combining the partial derivatives we have

$$\frac{dV_1}{V_1} - \frac{dV_2}{V_2} = \left(\frac{V_{11}}{V_1} - \frac{V_{21}}{V_2}\right)u_1 dw_0^i - \frac{V_2}{V_1}Qdx \tag{29}$$

where $$Q = \frac{V_{11}}{V_1} - 2\frac{V_{12}}{V_2} + \frac{V_1}{V_2}\frac{V_{22}}{V_2} < 0 \tag{30}$$

Equation (30) is a quadratic form in the Hessian of V and is negative since V is strictly concave. Equation (29) gives the change in the individual's marginal rate of substitution between the private consumption index, u, and the environment. If the environment is a normal consumption good, the first term on the right-hand side is negative, implying, at the optimum, that a richer individual has a lower marginal rate of substitution and thus prefers to substitute less from the environment to private consumption. This effect makes a poorer individual wishing to protect the environment less. The second term on the right-hand side is negative, implying that the marginal rate of substitution is decreasing in pollution (i.e., increasing in the environment). That is, if the level of the environment is large at the optimum, the individual is willing to substitute less private consumption for the environment. Finally, we need to find du_2 in order to find the change in the marginal rate of substitution between private consumption of commodity 2 and the environment. We have (see Appendix)

$$du_2 = -\tilde{D}\left[pdw_0^i + kdp + dS\right] - u_2 N_1 dp/p \tag{31}$$

where $$\tilde{D} \equiv (u_{11}u_{22} - u_{12}u_{21})/D > 0. \tag{32}$$

$\tilde{D}$ is positive since u is strictly concave. From (31) we see that, at the optimum, the marginal utility of commodity 2 is declining in the commodity-1 endowment (a richer individual has a lower marginal utility of commodity 2 at the optimum). The rest of the terms reflect the income effect of the tax-transfer system. An increase in the return on factor k, and in the transfer, reduces the marginal utility of commodity 2.

Equation (13) gives dx as a function of dk and $d\tau^x$; equation (21) gives dp as a function of dk, $d\tau^x$, and dw_0^i. Since dk can be written as a function of dp and dx (see equation (39) in Appendix), we have a system of three equations that gives us dk, dx, dp as functions of $d\tau^x$ and dw_0^i. Substituting for those in (29) and (31) gives $d(\ln[V_1u_2/(-V_2)])$ as a function of $d\tau^x$

and dw_0^i (see equation (44) in Appendix). If the environment is non-inferior (i.e., V_{11}/V_1-$V_{21}/V_2 \leq 0$), commodity 1 and 2 non-inferior ($N_1 \geq 0$, $N_2 \geq 0$), [and $F_{xk} \geq 0$, $\sigma \geq 0$, and $\eta \geq 0$], then the marginal rate of substitution between the environment and commodity-2 consumption is unambiguously decreasing in w_0^i. This implies that, at the optimum, a poorer individual will have a lower value of the environment as compared to private commodity-2 consumption. If we analyse cases (I) and (II) (production (4*a*)), then $F_{xk}>0$, $\sigma=0$, and $\eta=x/k>0$, then it is sufficient that the environment is non-inferior, and the two private goods are non-inferior. Thus, the key is the non-inferiority of goods.

Next, if a higher pollution tax at the optimum reduces pollution, and if the marginal rate of substitution is non-decreasing in the pollution tax, a richer individual prefers a higher pollution tax. If commodity 1 is non-inferior and $\sigma \geq 0$ and $\eta \geq 0$, then the marginal-rate of substitution is increasing in the pollution tax (by inspection of the second term in (44) in the Appendix). Again the non-inferiority of commodities plays a role. A richer individual typically wishes a higher environmental tax if she is decisive. The following propositions state sufficient conditions.

Proposition 1 *Assume* A1-A5 *and* $F=F(k,x)$ (*i.e., case* (I) *or* (II)), *then sufficient for an individual marginally poorer (richer) than average (in a situation in which all individuals are the same) to prefer a lower (higher) pollution tax is that*

(i) *the environment is non-inferior* (*i.e.,* V_{11}/V_1-$V_{21}/V_2 \leq 0$),

(ii) *private commodities* 1 *and* 2 *are non-inferior* (*i.e.,* $N_1 \geq 0$ *and* $N_2 \geq 0$).

Proof: See Appendix.

Proposition 2 *Assume* A1-A5 *and* $F=F(k,x,l)$ (*i.e. case* (III)), *then sufficient for an individual marginally poorer (richer) than average (in a situation where all individuals are the same) to prefer a lower (higher) pollution tax is that*

(i) *the environment is non-inferior* (*i.e.,* V_{11}/V_1-$V_{21}/V_2 \leq 0$),

(ii) *private commodities* 1 *and* 2 *are non-inferior* (*i.e.,* $N_1 \geq 0$ *and* $N_2 \geq 0$).

(iii) $u_{12} \leq 0$, (iv) $F_{xk} \geq 0$, (v) $F_{lxk}l - F_{lxl}l\, F_{xk}/F_{xx} \geq 0$

(vi) $1 - F_{xll}l/F_{xx} \geq 0$, (vii) $F_{xk} - F_{lxk}l \geq 0$, (viii) $-F_{kk}+F_{lkl}l \geq 0$

Proof: See Appendix.

There are a number of technology assumptions which are sufficient (though not necessary) for a richer individual wanting a higher pollution tax in case (III), (but not in cases (I) and

(II)). The reason is that an individual here wishes to redistribute from factor *l*, that is the labour supply by the future young generation, and the available instruments would be set so as to achieve that. We have now identified the forces at work in a link between inequality and environmental protection. First, it is the period-1 endowment of the decisive individual in relation to the average. Thus, it is inequality in terms of skewness. Second, the non-inferiority of both environmental and private commodities plays a role.

5. CONCLUSIONS

We have found a negative relationship between income inequality (in terms of the distance between the decisive individual and the mean individual) and the stringency of environmental policy (the level of an environmental tax) in a wide class of models. Sufficient for this result is that consumption goods and the environment are non-inferior (for a sub-class of models also some conditions, mainly on technology, are needed). The reason why normality of consumption goods play a role is as follows. Any increase in environmental protection comes at a loss of production possibilities. Individuals with higher marginal utility of consumption (the poorer ones) are less willing to substitute private consumption for provision of the environment. Second, a poorer individual also uses the redistributive tax instrument to a greater extent. The inefficiency caused reduces consumption possibilities. If environment is a normal good, this causes all individuals to demand less of it.

We can only derive this result with general preferences and technologies for marginal changes in skewness from a position of full equality. Extending it globally generally makes the problem intractable. The reason is that when analysing the problem for general inequality, two things may happen. First, with or without government taxes, the competitive equilibrium may be a function of the distribution. This occurs if Engel curves are non-linear. If one changes the median-mean distance of the distribution, not only the decisive individual's identity changes, but also the competitive equilibrium prices. It is then difficult to assess the political channel.[9] The second consequence may be that decisions are not monotone in the individual's type, and single-peakedness may be violated. Then we may fail to have a median-

[9] In general it is desirable to analyse a situation where the competitive equilibrium is invariant with respect to the underlying distribution and only the political channel is at work. This is the case when the individual utility function is such that aggregation occurs. There is a broad class of preferences which allows for that. A special case occurs when utility is additively separable and homothetic (logarithmic), which are the preferences restricted to in Marsiliani and Renström (2000b).

voter equilibrium. We would then have to look for political institutions that can overcome that problem. That is, however, beyond the scope of this paper and it is left for future research.

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APPENDIX

Derivation of (31)

Differentiating du_2 gives

$$du_2 = u_{21}\left(dw_0^i - dk^i\right) + u_{22}\left(pdk^i + k^i dp + dS\right) \tag{33}$$

or

$$du_2 = u_{21}dw_0^i + \left(pu_{22} - u_{21}\right)\left[\frac{\partial k^i}{\partial p}dp + \frac{\partial k^i}{\partial S}dS + \frac{\partial k^i}{\partial w_0^i}dw_0^i\right] + u_{22}\left(k^i dp + dS\right) \tag{34}$$

or by using (7)-(9), and N_1+N_2=1,

$$du_2 = \left[u_{22}N_2 + u_{21}N_1/p\right]\left(pdw_0^i + kdp + dS\right) + D^{-1}(pu_{22} - u_{21})u_2 dp \tag{35}$$

Using (10)-(11) gives (31).

Proof of Propositions 1-2

Using the first equality in (27) to substitute for kdp+ds in (31), and combining with (29) gives

$$d\ln\left(\frac{V_1 u_2}{-V_2}\right) = \left[\left(\frac{V_{11}}{V_1} - \frac{V_{21}}{V_2}\right)u_1 - p\frac{\tilde{D}}{u_2}\right]dw_0^i - \left[\frac{V_2}{V_1}Q - \frac{\tilde{D}}{u_2}F_{xx}\pi\right]dx - \frac{N_1}{p}dp \tag{36}$$

where

$$\pi \equiv \left(F_x - F_{lx}l\right)/(-F_{xx}) \tag{37}$$

Next, differentiating aggregate k (not the individual decision maker's)

$$dk = \frac{\partial k}{\partial p}dp + \frac{\partial k}{\partial S}dS = \frac{u_2}{D}dp - \frac{N_1}{p}(kdp + dS) \tag{38}$$

where the last equality follows from (8)-(9). Then, by using the first equality in (27), and the definition (37), we have

$$dk = D^{-1}u_2 dp + p^{-1}N_1 F_{xx}\pi dx \tag{39}$$

Equations (39), (13), (21) form a system, such that dk, dx, and dp can be solved for, that is

$$\begin{bmatrix} -p^{-1}N_1F_{xx}\pi & 1 & -u_2D^{-1} \\ F_{xx} & F_{xk} & 0 \\ 0 & \sigma & 1 \end{bmatrix} \begin{bmatrix} dx \\ dk \\ dp \end{bmatrix} = \begin{bmatrix} 0 \\ d\tau^x \\ -\eta\, d\tau^x + u_2^{-1}N_2Ddw_0^i \end{bmatrix} \tag{40}$$

The solution to dx and dp are

$$F_{xx}(1+m)dx = \left[1 + D^{-1}u_2(\sigma + \eta F_{xk})\right]d\tau^x - F_{xk}N_2dw_0^i \tag{41}$$

and

$$(1+m)dp = N_2Du_2^{-1}(1+F_{xk}N_1\pi/p)dw_0^i - \left[\eta + \frac{N_1}{p}\pi(\sigma + \eta F_{xk})\right]d\tau^x \tag{42}$$

respectively, where

$$m \equiv \sigma D^{-1}u_2 + F_{xk}N_1\pi/p \tag{43}$$

Substituting (41) and (42) into (36) gives

$$d\ln\left(\frac{V_1u_2}{-V_2}\right) = \left[\left(\frac{V_{11}}{V_1} - \frac{V_{21}}{V_2}\right)u_1 + \frac{V_2}{V_1}\frac{F_{xk}}{F_{xx}}\frac{QN_2}{1+m} - \frac{\tilde{D}}{u_2}\left(p + \frac{F_{xk}\pi N_2}{1+m}\right) - \frac{N_1N_2D}{p(1+m)u_2}\left(1 + F_{xk}\frac{N_1}{p}\pi\right)\right]dw_0^i$$
$$- \left[\left(\frac{V_2}{V_1}Q - \frac{\tilde{D}}{u_2}F_{xx}\pi\right)\frac{1 + u_2D^{-1}(\sigma + \eta F_{xk})}{F_{xx}(1+m)} - \frac{N_1}{p(1+m)}\left(\eta + \frac{N_1}{p}\pi(\sigma + \eta F_{xk})\right)\right]d\tau^x \tag{44}$$

Next differentiating the log of the numerator and the denominator of the right-hand side of (24) gives, respectively

$$d\ln\left[1 - (F_k - F_{lk}l - p)\frac{\partial k}{\partial S}\right] = -\frac{\partial k}{\partial S}d(F_k - F_{lk}l - p) = \frac{\partial k}{\partial S}N_2\frac{D}{u_2}dw_0^i = -\frac{N_1N_2D}{pu_2}dw_0^i \tag{45}$$

$$d\ln(\tau^x - F_{lx}l) = \frac{d\tau^x - F_{lxk}l\,dk - F_{lxx}l\,dx}{F_x - F_{lx}l} \tag{46}$$

The second equality in (45) follows from (20), (7), (8), and (9).[10] The third equality of (45) follows from (9). Next, combining (44), (45), and (46), the differential of the log of (24) is

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[10] Notice that $d(F_k\text{-}p\text{-}F_{lk}l)$ is the expression in square brackets in (20), and therefore equals $-(\partial k^i/\partial w_0^i)dw_0^i/(\partial k/\partial p\text{-}k^i\partial k/\partial S)$. Using (7),(8), and (9) gives the second equality in (45).

$$d\ln\left(\frac{V_1 u_2}{-V_2}\right) - d\ln[1-(F_k - F_{kl}l - p)\frac{\partial k}{\partial S}] + d\ln(F_x - F_{lx}l) =$$

$$= \left[\left(\frac{V_{11}}{V_1} - \frac{V_{21}}{V_2}\right)u_1 + \frac{V_2}{V_1}\frac{F_{xk}}{F_{xx}}\frac{QN_2}{1+m} - \frac{\tilde{D}}{u_2}\frac{p+F_{xk}\pi}{1+m} + \frac{\sigma}{1+m}\frac{u_{12}}{D}\right]dw_0^i$$

$$+\left[\left(\frac{-V_2}{V_1}\frac{Q}{F_{xx}} + \frac{\tilde{D}}{u_2}\pi\right)\frac{1+\frac{u_2}{D}(\sigma+\eta F_{xk})}{1+m} + \frac{N_1}{p}\frac{\eta+\frac{N_1}{p}\pi(\sigma+\eta F_{xk})}{1+m} + \frac{1}{-F_{xx}\pi}\right]d\tau^x \tag{47}$$

$$+ \frac{F_{lxk}l\,dk + F_{lxx}l\,dx}{F_{xx}\pi}$$

In obtaining (47) we have used the following relation

$$-\frac{\tilde{D}}{u_2}p - \frac{\tilde{D}}{u_2}F_{xk}\pi\frac{N_2}{1+m} - \frac{N_1N_2D}{p(1+m)u_2}\left(1+F_{xk}\frac{N_1}{p}\pi\right) + \frac{N_1N_2D}{pu_2} =$$

$$= -\frac{\tilde{D}p}{u_2(1+m)}\left[1+m+F_{xk}\pi\frac{N_2}{p}\right] + \frac{N_1N_2D}{p(1+m)u_2}\left(m-F_{xk}\frac{N_1}{p}\pi\right)$$

$$= -\frac{\tilde{D}p}{u_2(1+m)}\left[1+\sigma\frac{u_2}{D}+F_{xk}\frac{\pi}{p}\right] + \sigma\frac{N_1N_2}{p(1+m)} \tag{48}$$

$$= -\frac{\tilde{D}p}{u_2(1+m)}\left[1+F_{xk}\frac{\pi}{p}\right] - \frac{\sigma p}{1+m}\left(\frac{\tilde{D}}{D} - \frac{N_1}{p}\frac{N_2}{p}\right)$$

$$= -\frac{\tilde{D}p}{u_2(1+m)}\left[1+F_{xk}\frac{\pi}{p}\right] + \frac{\sigma}{1+m}\frac{u_{12}}{D}$$

The second equality i (47) follows by using (43), and he fact that $N_1+N_2=1$. The last equality follows from (10), (11), and (32).

We need to evaluate the last term in (47). Using (41) and (42) in (39) gives

$$(1+m)dk = N_2 dw_0^i - \left(\eta D^{-1}u_2 - N_1\pi/p\right)d\tau^x \tag{49}$$

Since $F_{lxk}\geq 0$, dk enters with negative sign in (47), and since $F_{lxl}\leq 0$, dx enters with positive sign. dk and dx are positively and negatively related, respectively, to dw^i. Therefore, the last term will add dw^i negatively, and the function (47) is unambiguously negative in dw^i. The terms in τ^x are at first sight ambiguous, and we have to add those terms carefully. Use (4) and (49) to obtain

$$\frac{F_{lxk}l}{F_{xx}\pi}dk + \frac{F_{lxx}l}{F_{xx}\pi}dx = \frac{d\tau^x}{-F_{xx}\pi(1+m)}\left[F_{lxk}l\left(\eta\frac{u_2}{D} - \frac{N_1}{p}\pi\right) - \frac{F_{lxx}l}{F_{xx}}\left(1+\frac{u_2}{D}(\sigma+\eta F_{xk})\right)\right] - Mdw_0^i \tag{50}$$

where

$$M \equiv \frac{N_2}{-F_{xx}\pi(1+m)}\left[F_{lxk}l - F_{lxx}l\frac{F_{xk}}{F_{xx}}\right] \tag{51}$$

Substituting (50) into (47) gives

$$\begin{aligned}&\left[\left(\frac{V_{11}}{V_1} - \frac{V_{21}}{V_2}\right)u_1 + \frac{V_2}{V_1}\frac{F_{xk}}{F_{xx}}\frac{QN_2}{1+m} - \frac{\tilde{D}}{u_2}\frac{p+F_{xk}\pi}{1+m} + \frac{\sigma}{1+m}\frac{u_{12}}{D} - M\right]dw_0^i \\ &+\left[\left(\frac{-V_2}{V_1}\frac{Q}{F_{xx}} + \frac{\tilde{D}}{u_2}\pi\right)\left(1+\frac{u_2}{D}(\sigma+\eta F_{xk})\right) + \frac{N_1}{p}\left(\eta + \frac{N_1}{p}\pi(\sigma+\eta F_{xk})\right) + \tilde{M}\right]\frac{d\tau^x}{1+m} = 0\end{aligned} \tag{52}$$

where

$$\tilde{M} \equiv \frac{1}{-F_{xx}\pi}\left[\left(1+\sigma\frac{u_2}{D}\right)\left(1-\frac{F_{lxx}l}{F_{xx}}\right) + \frac{N_1}{p}\pi(F_{xk}-F_{lxk}l) + \eta\frac{u_2}{D}\left(F_{lxk}l - F_{lxx}l\frac{F_{xk}}{F_{xx}}\right)\right] \tag{53}$$

Propositions 1 follows by inspection of (52), [as well as (51) and (53)]. The bracketed term multiplied by dw_0^i is negative (N.B. here σ=0, and constant returns-to-scale and concavity of F implies F_{xk}>0), and the bracketed term multiplied by $d\tau^x$ is positive, so $\partial\tau^x/\partial w_0^i > 0$. Under the extra assumptions listed in Proposition 2 equation (52) gives $\partial\tau^x/\partial w_0^i > 0$. QED