

**Channels of Transmission of
Environmental Policy to Economic
Growth: A Survey of the Theory**

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Channels of Transmission of Environmental Policy to Economic Growth: A Survey of the Theory

Summary

Economists generally hold that environmental regulations impose constraints on the production possibilities set and are therefore potentially harmful to economic growth. In recent years, however, it has been recognized that environmental regulation can enhance the prospects for growth if improved environmental quality increases the productivity of inputs or the efficiency of the education system. It is also held that environmental regulation promotes pollution abatement activity and can lead to the exploitation of increasing returns to scale in abatement. Furthermore, expectations of a better environment may encourage households to save. Finally, it has been conjectured that environmental regulations can stimulate innovation because R&D is a relatively clean activity and because the market share of clean innovations increases.

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1 Introduction

Two parallel developments have marked the past fifteen years. On the one hand, environmental policy was confronted with global challenges, and the international community responded by shaping a number of restrictive environmental policies. These include the 1987 Montreal Treaty banning the use of the chemical products that damage the ozone layer, the earth summits of Rio de Janeiro in 1992 and Johannesburg in 2002, and the 1997 Kyoto protocol to regulate the emissions of greenhouse gases. On the other hand, economic research on the determinants of economic growth gained fresh momentum from the seminal contributions of Romer (1986, 1990), Lucas (1988), Barro (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). This new research direction has been labelled *endogenous growth theory*, because it tackles the basic issue of technological progress, analyzing directly how market imperfections, institutions, policies, demographics, trade and preferences affect the rate of growth of total factor productivity and, ultimately, of per capita value added.

Over the past decade, the economic analysis of sustainable development and environmental policy has gained new impetus from endogenous growth theory. A great deal of attention has been given to the conditions under which sustainable growth is feasible and/or desirable. If substituting other factors of production for emissions is easy enough, growth of value added is compatible with a constant, or even decreasing, flow of polluting emissions, provided that the process generating technological progress does not itself create (too much) pollution. For instance, education enables society to increase labor productivity and, similarly, research and development (R&D) activity spurs innovation which in turn increases the quality of services and consumption goods, the productivity of intermediate goods, or the efficiency of pollution abatement. From a macro perspective environmental services to production are rival goods, and can in principle be excluded, while the environment that absorbs pollution and provides amenity value is a public good, affecting the welfare of society. A socially efficient environmental policy should ensure that polluters pay the social cost of emissions. This goal can be attained either directly by levying a tax on emissions, or indirectly by implementing a market for tradable pollution permits. From the perspective of endogenous growth theory, the additional presence of intertemporal externalities - due to the accumulation of pollution, physical and human capital, and knowledge - is relevant for the design of an optimal environmental policy. Much of the literature has focused on the study of optimal dynamic environmental policies. For a survey of the results concerning these issues see Smulders (1995b, 2000), Beltratti (1997), Chev e and

Ragot (1998), Bretschger and Egli 2001.

The effects of environmental policy on investment, education, R&D and - through these channels - on economic growth have been addressed in several papers. This paper attempts to bridge the gap in the literature by surveying the mechanisms put forward in this strand of literature. In a static context, it is quite obvious that a restrictive environmental policy lowers aggregate output because it imposes an additional constraint on the production possibilities set. In fact, in order to decrease pollution firms undertake abatement activities which result in increased production costs. In a dynamic context, a similar argument claims that higher production costs reduce return on capital and incentives to investment and that lower investment leads to slower economic growth. This is a negative, *direct input effect*. However, as we move from a static to a dynamic context this argument is not quite so evident. In fact, as in the long run technology and crucial factors such as human capital tend to become endogenous it is difficult to forecast how the production possibilities set of the economy would react to a restrictive environmental policy. As argued by Michael Porter (1991, 1995), the additional constraint imposed on firms by environmental policy could trigger technological adjustments capable of expanding production possibilities. According to this *Porter hypothesis*, environmental policy can have a *win-win* outcome: i.e. it can improve the quality of the environment while fostering the rate of growth of value added.

Setting out from endogenous growth theory, this survey addresses each of the various channels of transmission of environmental policy to economic growth. In the section that follows I present the negative direct input effect. The remainder of the paper deals with channels of transmission which either mitigate the negative direct effect or generate win-win environmental policies. One possibility is to make the most of increasing returns in the pollution abatement sector or in the environment's natural capacity to assimilate pollution. Section 4 considers the case in which improved environmental quality significantly increases total factor productivity or the efficiency of education. Next, I will set forth the more subtle argument that environmental policy modifies the levels of savings or the assets portfolios available to households in a way conducive to productive investment. Section 6 is concerned with multi-sector endogenous growth models, i.e. those with education or R&D as the dynamic sector. In these model economies, environmental policy spurs growth indirectly if it increases (reduces) the cost of business in the dynamic sector less (more) than its reward. A few concluding remarks are presented in the last section.

2 The trade-off between environmental quality and growth

Diminishing returns on capital rule out the possibility of sustaining the growth of per capita output using capital accumulation only (Solow, 1956). In the long run, growth is due to technological progress, which sustains the productivity of capital, hence returns on capital and the incentive of households to save and invest in capital. This implies that the aggregate production function is characterized by constant returns to scale with respect to physical capital. This means that along a balanced growth path capital and production will grow at the same rate - a rate which increases with the propensity to save and invest and, therefore, with the rate of return on capital (i.e. capital productivity).

The negative impact of a restrictive environmental policy on economic growth stems from the additional costs that it imposes on the production sector, as can be easily illustrated. The pursued improvement in environmental quality requires a permanent reduction in the flow of polluting emissions, one of the implicit or explicit inputs of the production process. In a model with constant returns on aggregate capital (K), e.g. $Y = AP^\alpha K$, any permanent reduction in the flow of emissions, P , weakens the productivity of capital, AP^α ,¹ and this leads to a lower rate of investment and slower growth of production.

Using the following simple specification of the law of motion of the ecosystem:

$$\dot{E} = N(E) - P \tag{1}$$

where $N' > 0$ and E measures environmental quality, Musu (1995) shows that the flow of emissions must be constant at a level $P = N(E^*)$ if the quality of the environment is to be kept at any arbitrary level E^* and growth is to be sustainable. Any improvement in environmental quality implies a smaller flow of emissions as input in the production process, reducing the return on investment and, ultimately, slowing the pace of growth. In this context, a continuous improvement in environmental quality is obviously incompatible with economic growth, because the productivity of capital would tend to zero.

The same mechanism is at work when current expenditure is enough to finance abatement activities to increase the efficiency of emissions as inputs of production. Van Marrewjik et al. (1993) and Gradus and Smulders (1993) propose a formalization of pollution abatement where

emissions represent an undesirable by-product of the production process, as follows

$$\begin{aligned}
 Y &= AK \\
 P &= \left(\frac{K}{D}\right)^\eta \\
 \dot{K} &= Y - D - c
 \end{aligned}
 \tag{2}$$

and D measures current expenditure on abatement activity in terms of output, with $\eta > 0$. One can see that output net of abatement activity, y , is:

$$y = Y - D = \left(A - P^{-\frac{1}{\eta}}\right) K$$

The net marginal product of capital ($A - P^{-\frac{1}{\eta}}$) is thus an increasing function of the flow of emissions. A restrictive environmental policy, which shifts the economy onto a path characterized by a constant and lower flow of emissions, reduces the productivity of capital and, consequently, investment and the rate of growth.

Some papers present abatement activities as using specific abatement capital stock. This approach broadens the scope of economic planning in terms that abatement activities are directly targeted at the existing level of pollution and may possibly generate a negative net flow of pollution.

In Cazzavillan and Musu (1998) this feature is not exploited and their results are similar to those obtained with abatement financed by current expenditure. Their paper considers a production function $Y = AK_P$ and a pollution function $P = Y/K_D$, where $K = K_P + K_D$. Rearranging the production function as $Y = A(K_P/K)K$, one can see that the marginal product of aggregate capital, $A(K_P/K)$, is a decreasing function of the share of capital employed in the abatement sector. A reduction in the flow of emissions requires an increase in the share of capital devoted to abatement activity, since $P = A(K_P/K_D)$, and will thus result in a lower productivity of capital. This in turn implies a trade-off between the conservation of the quality of the environment and economic growth.²

3 Increasing returns in the pollution abatement sector

In general, increased investment in abatement activity reduces productive investment and hampers economic growth. But the presence of increasing returns to scale in pollution abatement technology may reconcile (regulated) economic growth with the protection of the ecosystem. As

Andreoni and Levinson (2001) clearly explain, an expanding economy is able to more efficiently exploit economies of scale in abatement activity. The initial adoption of a dirty path of growth makes environmental quality scarce relative to consumption. At some point in time, therefore, investment in abatement will become optimal, and a regulated economy would adopt a sustainable growth path along which consumption increases and the flow of polluting emissions is reduced through an ever-increasing abatement effort (at ever lower unit cost).

Assuming constant returns to scale in the pollution abatement sector, Michel and Rotillon (1995) rule out the conflict between environmental policy and growth. They consider the model:³

$$\begin{aligned} Y &= AK_P \\ P &= BK_P - DK_D \\ K &= K_P + K_D \end{aligned}$$

with $\dot{K} = Y - c$. Rearranging, output as a function of aggregate capital and emissions is:

$$Y = \frac{A}{B+D}P + \frac{AD}{B+D}K$$

This representation of the production function clearly shows that the approach is based on the assumption of an implicitly perfect substitutability between emissions and capital. Hence any pattern of input intensity (P/K) is feasible. Although the allocation of aggregate capital between the two sectors depends on preferences and policies, the marginal product of capital depends only on the contribution of capital to the production sector and its role in generating net emissions. Within this framework, a restrictive environmental policy will permanently decrease the flow of emissions, P , and reduce the initial level of output, but has no influence on the rate of growth of the economy.

In this first example there is no conflict between the goal of environmental protection and economic growth. The remainder of the survey addresses the different, individual channels of transmission of environmental policy counteracting the negative direct input effect on the prospects of economic growth. Xepapadeas (1994) considers an implicit pollution abatement function characterized by regions of increasing returns to scale. Each of the n symmetric firms generates emissions according to:

$$P = z(k_D, nk_D)f(k_P, nk_P)$$

where $f(\cdot)$ is the production function and is characterized by constant returns with respect to aggregate capital, because of the positive externality linked to the accumulation of productive

capital $K_P = nk_P$ (as in Romer, 1986). The function $z(\cdot)$ defines the emission intensity of output. It decreases in proportion to a firm's investment in specific abatement capital, k_D , but also, through an externality, with the aggregate stock of specific capital, $K_D = nk_D$. Xepapadeas studies the case where the abatement function is characterized by increasing returns starting from a critical threshold level of K_D , and by decreasing returns for lower levels.

The effect of a tax on emissions varies according to the level of aggregate abatement capital in the economy. When this is below the critical threshold, firms respond by reducing their production. When it is above the threshold, the tax triggers firms' investment in abatement activity and the resulting increase in aggregate returns enables firms to reduce emissions and to free resources for investment in production capital.⁴ In this case, restrictive environmental policy is win-win. Xepapadeas' argument recalls the "poverty traps" of Azariadis and Drazen (1990): a policy stimulating investment in the abatement sector can permanently shift the economy from an equilibrium where environmental policy hampers economic growth, to an equilibrium where the same policy is win-win.

Smulders (1995a) argues that the function describing the natural assimilation capacity of the environment, $N(E)$ in (1), is concave with a maximum and two minima in zero. In fact, when environmental quality tends to zero, so does its ability to assimilate pollution. Vice versa, if the environment is a stable system, in the absence of any emissions ($P = 0$) environmental quality would tend to a maximum E^{\max} , a rest point. Figure 1 illustrates this type of natural assimilation function. If this is the case, it follows that the regions of E are two: one where $N' > 0$ and the other where $N' < 0$. We can therefore compare two sustainable steady states (i.e. with E constant), before and after environmental policy restriction, $E_1 < E_2$. If this policy is put in place when the ecosystem is particularly dirty (i.e. when $N' > 0$), the long run sustainable flow of emissions could ultimately be increased, generating a permanent increase in one of the inputs of production, $P_2 = N(E_2) > N(E_1) = P_1$. A larger supply of this input increases the return on capital, and therefore the rate of growth. This is a case where environmental policy enables the economy to exploit the region of increasing returns in the natural capacity to assimilate polluting emissions. The environment is a public good (factor) which is being excessively exploited as in the Tragedy of Commons, so that public intervention is called for due to the presence of this negative production externality.

4 External effects of the environment on productivity

Most theories which try to account for the positive impact of restrictive environmental policy on economic growth assume that environmental quality generates external effects which enhance productivity, either directly within the production sector, or indirectly in the core sector driving the growth process.

Bovenberg and Smulders (1995), Smulders and Gradus (1996), Michel (1993), Smulders (1995a), Rosendahl (1996), Rubio and Aznar (2000) all assume that an improvement in the quality of the environment has a positive effect on total factor productivity, so that the aggregate production function can be represented as:

$$Y = A(E) F(K, P)$$

with $A_E, F_K, F_P > 0$. Along a sustainable balanced growth path P and E are constant which means that prerequisites for growth are either constant returns on capital or pollution-augmenting technological progress.

The direct negative effect of reduced emission inputs is partially offset by the increase in total factor productivity. Consider for instance the production function $Y = AE^\eta P^\alpha K$. Using (1), the immediate impact of environmental policy on the productivity of capital is:

$$\frac{dY_K}{d\tau} = AE^\eta P^\alpha \left(\eta \frac{\dot{E}}{E} + \alpha \frac{\dot{P}}{P} \right) = AE^{\eta-1} P^\alpha \left[\eta (N(E) - P) + \alpha \frac{\dot{P}}{P} E \right]$$

Suppose that initially $N(E) = P$. The policy implies a direct negative input effect ($\dot{P}/P < 0$), but also a positive effect afforded by improved environmental quality (as $N(E) - P$ becomes positive). The productivity of capital - hence growth - increases if this externality outweighs the role of emissions as inputs.

This kind of situation is characterized by the typical inefficiency of decentralized economies which is found to arise when one of the factors of production is a public good (here E). Firms exploit in an excessive manner those services from the environment that are rival (P) without internalizing the social cost inherent in the resulting reduction of environmental quality. A good example of this kind of inefficiency at the sectorial level is agriculture, a sector where firms both generate and suffer water pollution.

This channel of transmission seems plausible for economies relying heavily on the exploitation of natural resources, such as agriculture, forestry or fishing, and for the study of communities living in particularly dirty environments. But as far as industrialized economies are concerned,

one may argue that an improvement in environmental quality can only have a marginal (direct) impact on aggregate production.

The indirect negative externality of pollution on the core sector driving the growth process is the most appropriate for theories of growth based on human capital accumulation, along the lines of Uzawa (1965) and Lucas (1988). Consider the problem of a representative -infinitely lived- household in a decentralized economy, using the standard iso-elastic utility function:

$$\begin{aligned} \max_{\{c_\tau\}_0^\infty} \int_0^\infty e^{-\rho\tau} \frac{c_\tau^{1-\varepsilon} - 1}{1-\varepsilon} d\tau \\ \dot{K}_\tau &= Y_K K_\tau + Y_{(1-n)} (1 - n_\tau) - c_\tau \\ \dot{B}_\tau &= f(n_\tau, P_\tau) B_\tau \\ Y &= AP^\alpha K^{1-\beta} [B(1-n)]^\beta \end{aligned}$$

where: the mass of labor is normalized, with a share n employed in knowledge accumulation (i.e. education and training) and the complement $(1 - n)$ in production; B measures the stock of human capital and knowledge, determining labor productivity; $f_n > 0$, with the externality given by $f_P < 0$; savings are entirely invested in capital, and the return on savings equals the net marginal product of capital Y_K . In this case human capital is a private good and the wage matches effective labor productivity, $Y_{(1-n)}$. Knowledge accumulation is thus an intentional process resulting from the decisions of households. The balanced growth path solution gives the following equilibrium rate of growth of consumption and production:⁵

$$\frac{\dot{c}}{c} = \frac{1}{\varepsilon} [f(n, P) + f_n(1 - n) - \rho]$$

This rule equalizes the opportunity cost of foregoing consumption ($\rho + \varepsilon \frac{\dot{c}}{c}$) to the rate of return on human capital investment ($f(n, P) + f_n(1 - n)$), which in turn takes into account the arbitrages, on the one hand, over the allocation of labor between production and education, and on the other hand, over the alternative assets.

Gradus and Smulders (1993) consider the case where the flow of emissions P causes depreciation of the stock of human capital in a linear fashion. This is the case, for instance, when pollution reduces life expectancy. The authors posit the function for human capital accumulation: $f(n, P) = \gamma n - g(P)$, with $g' > 0$, leading to the rate of growth:

$$\frac{\dot{c}}{c} = \frac{1}{\varepsilon} [\gamma - g(P) - \rho]$$

As a result a reduction in emissions increases the rate of economic growth in the long run by augmenting the return on human capital accumulation.

The case in which pollution reduces directly the productivity of investment in human capital by damaging the cognitive abilities of pupils is considered in van Ewijk and van Wijnbergen (1995) and in Kany and Ragot (1998). Specifying the function for human capital accumulation as $f(n, P) = \gamma g(P) n$, with $g' < 0$, one gets:

$$\frac{\dot{c}}{c} = \frac{1}{\varepsilon} [\gamma g(P) - \rho]$$

Lower emissions improve the efficiency of the education system and increase the growth rate of productivity.

5 Environmental policy and savings decisions

Improvements in environmental quality can affect the saving behavior of households and, therefore, the investment rate and the pace of economic growth. To show this, let us consider a representative -infinitely lived- household that values consumption, c , and environmental quality, E . It will choose its savings (consumption) strategy with intent to solve the problem

$$\max_{\{c_\tau\}_0^\infty} \int_0^\infty e^{-\rho\tau} U(c_\tau, E_\tau) d\tau$$

$$\dot{W}_\tau = w_\tau + r_\tau W_\tau - c_\tau$$

where ρ is the subjective discount rate, W is wealth, w is exogenous income unrelated to savings and r is the rate of return on savings. The solution is the Ramsey rule, $r = \rho - \frac{\dot{U}_c}{U_c}$, which states that the return on savings must compensate for impatience and for the expected change in the value of consumption. Developing the rule, one gets :

$$r = \rho - \frac{U_{cc}c \dot{c}}{U_c c} - \frac{U_{cE}E \dot{E}}{U_c E}$$

For growth to be balanced, i.e. with $\frac{\dot{c}}{c} > 0$ and $r > 0$ constant, it is necessary that $U_{cc}c/U_c = -\varepsilon$ (CRRA utility function), so that:

$$\frac{\dot{c}}{c} = \frac{1}{\varepsilon} \left[r - \rho + \frac{U_{cE}E \dot{E}}{U_c E} \right]$$

Mohtadi (1996) shows that, ceteris paribus, an expected improvement in environmental quality is conducive to growth only if $U_{cE} > 0$. Assuming that consumption and environmental quality

are complements, households will be willing to postpone part of their consumption if they expect environmental quality to improve. To do so, they increase their levels of saving. A higher savings rate entails more investment and faster growth. Michel and Rotillon (1995) refer to it as the “distaste” effect because an increase in the stock of pollution, S , reduces the marginal utility of consumption ($U_{cS} < 0$). In most cases this channel of transmission cannot be predominant, that is it cannot reverse the direct negative input effect of a restrictive environmental policy.

This analysis emphasizes some non trivial consequences of environmental policy, though the argument seems weak because it is based on the influence of environmental policy on saving behavior. In fact, this behavior is mainly dependent on other considerations and is influenced by much more direct policies.

Environmental policy can also modify the assets portfolios available to households, with implications for their investment decisions. To the extent that emissions are inputs in a production function with globally constant returns, the absence of a price, e.g. a tax, implies that polluting firms earn a rent. If factors are paid their marginal product, profits are positive:

$$\pi = F(K, L, P) - F_K K - F_L L = F_P P > 0$$

Using an overlapping generations model, Fisher and van Marrewijk (1998) show that levying a tax on emissions increases the rate of growth by promoting investment in productive capital. In fact, in this context firms ownership entitles an household to a stream of dividends originating from the “pollution” rent. Each generation can purchase this asset when young to finance consumption during retirement. By levying a tax on emissions, the government compels households to entirely invest their savings in capital. While this policy is costly for the initial owners of firms, Fisher and van Marrewijk show that this higher cost can be refunded by running a public deficit that can be financed using the dividends of a faster economic growth. This restrictive environmental policy is thus Pareto welfare improving.⁶

6 Induced adjustment in two-sector endogenous growth models

In multi-sector growth models there are two types of distinct sectors: the production sector, characterized by a technology with constant returns to scale and the employment of some fixed factor; and the dynamic sector, where costly and targeted efforts are made to constantly improve the efficiency of the fixed factor. The dynamic sector can be modelled as the education sector employing two crucial factors: the stock of human capital (the labor productivity index) as a

public input and with a constant returns technology, and a certain amount of spare time which households would otherwise be in a position to use for working or to enjoy leisure. The decision concerning the time devoted to the accumulation of human capital (education and training) will determine the rate of growth.

An alternative approach views R&D activity as the dynamic sector. R&D laboratories employ some tradable factors in competition with the production sector (most often skilled labor) and public knowledge, which evolves according to the flow of innovations. The quantity of factors employed in the R&D sector determines the innovation rate and thus the pace of productivity growth and, ultimately, the rate of growth of the economy. Education or R&D are rewarded with wages or local monopoly rents (accruing from patent protection), but no reward is envisaged for the contribution they make to the supply of knowledge to future education or R&D activities.

6.1 Human capital accumulation: stimulating education

Hettich (1998) presents an endogenous growth model based on human capital accumulation where labor supply is endogenous and emissions are a side product of the stock of capital, but can be kept under control with abatement expenditure, as in (2).⁷ In this case a restrictive environmental policy can induce the substitution of clean human capital for dirty physical capital at the aggregate level. A tax on emissions forces firms to engage in costly abatement activities which reduce output net of abatement expenditure. Lower household consumption raises the opportunity cost of leisure. Furthermore, firms' relative demand for factors of production shifts toward clean human capital, countering the depressive impact of reduced production on wages. This change, together with a lower net return on capital due to costly abatement, increases the relative return on human capital. As a result, households reduce their leisure and increase their education. More time spent on education and training stimulates productivity growth and hence the growth of per capita income.

The result is driven by the ability of environmental policy to discriminate against physical investment and in favor of education and training. Therefore a crucial assumption is that polluting emissions are linked to the stock of capital and not directly to the level of production. The reduction in leisure implies that higher growth may not be socially optimal.

6.2 R&D driven growth: distorting competition on factor markets

A number of papers have studied environmental policy in R&D-driven models of growth, but few have detected channels of transmission favorable to growth (see Hung, Chang and Blackburn 1994, Grimaud 1999, Grimaud and Ricci 1999, Schou 2000, da Costa 2003, van Zon and Yetkiner 2003).

Elbasha and Roe (1996) use a model with two fixed factors (e.g. skilled and unskilled labor) and four sectors. There are two final goods sectors, differentiated only in their factor intensity, both employing the two fixed factors along with intermediate goods. The intermediate goods sector, where firms are local monopolists protected by patents, employs the two fixed factors. The expansion in the mass of these goods results from the activity of competitive R&D labs which employ the same two factors of production factors, along with public knowledge. This approach, due to Romer (1990), describes a process of Smithian growth, where the division of labor raises total factor productivity: with a larger mass of goods, economies of specialization are exploited since each intermediate good uses a smaller quantity of one fixed factor, increasing its productivity.

In Elbasha and Roe the production and R&D sectors compete on factor markets. Environmental policy distorts the terms of competition and may affect the rate of growth through this channel. The authors find that taxing emissions stimulates economic growth, if the tax on emissions has a disproportionate impact on one of the two final goods sectors: the one which is the most intensive in the crucial input to R&D.⁸ The mechanism at work is simple, though not trivial. Supposing that skilled labor is the crucial factor for R&D, if a tax is levied on the relatively skilled-labor-intensive sector, demand for skilled labor diminishes and this reduces the corresponding wage and thus the cost of R&D. In other words, this policy frees skilled labor to the advantage of R&D. Elbasha and Roe's analysis draws our attention to the distortions in the competition between sectors that environmental policy can introduce. Nevertheless, the authors have failed to provide an accurate picture of environmental policy, arbitrarily limiting its scope and confusing it with public R&D policy.

Bretschger (1998) pushes the analysis of general equilibrium adjustments to a restrictive environmental policy even further by assessing substitutability between emissions and other inputs of production.⁹ He uses a model with two types of consumption goods: a traditional good and a composite one assembled from differentiated intermediate goods generated by R&D

activity. All three activities - R&D, production of intermediate goods, and production of the traditional good - employ labor and emissions as inputs. R&D and the traditional sector are the least and the most intensive in emissions, respectively.

In this context, a higher tax on emissions will depress the demand for labor from the production sector, thus reducing wages and (indirectly) the cost of R&D. This will encourage R&D activity, increase the innovation rate, and promote a rise in productivity. A crucial assumption for this result to hold is reduced demand for labor in the production sector and this will only be the case if its ability to substitute emissions for labor is poor, i.e. only if the elasticity of substitution between inputs of production is low enough (below unity).¹⁰ This result is quite surprising and opposite to the one obtained with a one-sector model, where a high degree of substitutability of emissions for other inputs is necessary to reconcile growth with a declining use of natural resources or emissions (see Dasgupta and Heal 1974).¹¹

The result is also based on the independence of the value of innovations from environmental policy. This property of independence holds because the policy has no influence on the distribution of profits between the traditional good and the composite good, nor on the distribution of profits among patent holders within the composite good sector.¹²

6.3 R&D driven growth:

induced technological change and distorted competition across vintages

Over the last few years a strand of literature allowed for endogenous R&D activity and technical targets into dynamic macroeconomic models, to simulate the economic and ecological impact of restrictive environmental policies (e.g. Goulder and Mathai 2000, van der Zwaan et al. 2002, Popp 2004). In general these analysis aim at assessing quantitatively the scope for induced technological change in scaling down the social cost of reducing emissions of green-house gases (for early surveys of this field see Weyant and Olavson 1999, Grubb and Ulph 2002). Their attention is concentrated therefore on the transition path, and rely on a framework of analysis where growth is ultimately exogenous, or in any case independent of environmental policy. For this reason and for a lack of space, I have chosen to present in this subsection only the endogenous growth models that account for induced technological change, capable of rationalizing a positive effect of environmental policy on growth.

In Verdier (1995), the direction of technological change is endogenous because innovations can be more or less environmental friendly. Reducing the demand for polluting goods, a tax on

emissions creates incentives for R&D labs to target cleaner innovations, i.e. innovations with lower pollution intensity levels. This additional objective raises the marginal cost of the R&D program (or reduces its prospects of success). Along a balanced growth path R&D employment is constant and stands at a level where marginal costs (wages) equal marginal rewards (proportional to the value of a patent). The burden of the emissions tax, which is a combination of the level of the tax and of the pollution intensity embodied in the innovation, decreases the value of a patent.

An environmental policy will only be of the win-win type if the level of the tax on emissions is so low that no R&D lab finds it worthwhile to target cleaner innovations. In this case, instead of directly increasing the cost of R&D, a marginal increase in the tax will indirectly reduce it by depressing demand for labor from the production sector and, therefore, wages. On the contrary, R&D labs adopting clean technologies will incur greater costs and no win-win outcome can emerge.

As Verdier relies on the endogenous growth model driven by variety expansion a la Romer (1990) he reduces the scope of his analysis to the symmetric case in which all goods are assumed to have the same pollution intensity. This is inappropriate for the study of induced technological change.¹³ The alternative approach to model R&D based growth assumes that innovations improve the quality - or productivity - of existing goods and drive out of business incumbent producers (Aghion and Howitt 1992, Grossman and Helpman 1991). With this framework it is possible to extend the analysis to intermediate goods with different pollution intensity level.¹⁴

In Hart (2004) and Ricci (2002) designing cleaner innovations entails a loss of the potential productivity of innovations either because emissions are inputs complementary to the intermediate good, or because the researchers' effort is diverted away from productivity maximization. If the emissions tax is not high enough, R&D labs do not improve on the cleanliness of intermediate goods. Conversely, if taxes are high enough R&D labs introduce environmental friendly innovations. In this case a restrictive environmental policy tends to have an adverse impact on economic growth, by reducing the contribution of innovation to productivity growth.

However, if innovations are consistently cleaner than the goods they replace, the goods present on the market at a given date will have different pollution intensity levels, with the older vintages being dirtier and recent vintages being cleaner. Hart (2004) and Ricci (2002) show that this differentiation of goods in their pollution intensity allows environmental policy to stimulate R&D activity through an additional channel. In fact, an emissions tax reduces the relative

competitiveness of older and dirtier vintages of intermediate goods and increases the market shares of recent vintages. A more intensive use of recent and more productive intermediate goods increases the average productivity of the intermediate goods employed in production (as in Xepapadeas and de Zeeuw 1999). *Ceteris paribus*, capital productivity increases, thereby stimulating investment and growth.¹⁵

The latter, i.e. the original channel of transmission of environmental policy, stimulates R&D and spurs innovation. The comprehensive impact of environmental policy on productivity growth depends on the balance between this proliferation of innovations and the decline in their productivity advantage over older goods. Hart assumes that R&D labs face a discontinuous trade-off between productivity and cleanliness of innovations. When this trade-off is not too steep, win-win environmental policies are attained. Ricci instead considers a case where R&D labs face a continuous trade-off between productivity and cleanliness.¹⁶ A restrictive environmental policy induces a significant adjustment of the pollution intensity targeted by R&D labs, which explains its globally negative impact on growth. Nevertheless, the channel of transmission based on the structural change in market shares is operational and mitigates the cost of environmental policy.

7 Concluding remarks

This survey presents the channels of transmission of environmental policy to growth discussed in the economic literature over the past ten years. It shows that a restrictive policy can operate through a variety of possible mechanisms. The breadth of this set of possibilities calls for two final questions.

What plausible channels of transmission have been ignored by theoretical analysis? I see two possible lines of research. First of all, it seems possible to extend to an endogenous growth framework the original argument of Michael Porter: namely, that managers do not act as fully-rational profit maximizers, so that the burden of environmental regulation may force them to adapt to, adopt and introduce innovative production processes. To model this environmental policy stimulus without dropping the assumption of rationality, we can assume informational asymmetries between shareholders and creditors on the one hand, and managers on the other, along the lines of the literature on competition and growth (see Aghion et al. 2001 and the references therein). Secondly, it would be rewarding to go beyond balanced growth path analysis.

In fact, environmental problems, and the policies that seek to solve them, are transitional phenomena in many respects and there is substantial evidence that they are linked to structural change (e.g. Hettige et al., 2000). To the extent that “the structural transformations that accompany growth have beneficial side-effects on the environment” (Grossman, 1995, p.21), the influence of environmental policy on the process of growth is likely to vary through the stages of development. Only a few papers take this stance, e.g. Bretschger and Smulders (2001).

The other obvious question is: what does empirical evidence tell us about the significance and relative magnitude of the different channels of transmission? This is an impelling question, given the diversity of the mechanisms suggested by theorists and the absence of any empirical study that tackles the issue. There is, however, indirect evidence concerning a number of the mechanisms reviewed in this article. For instance, Andreoni and Levinson (2001) provide evidence of increasing returns to scale in abatement activity, using US industry data relating to the period 1974-1994. There is also evidence of considerable pollution-related damage on children’s health (Ostro et al. 1998, Chay and Greenstone 2003) which could support the claim of an improved efficiency of the education channel. Finally, a number of studies indicate that innovation in the energy and environment areas is induced by relative price changes, and hence, potentially, by policies (for a survey see section 3 in Jaffe et al., 2002). But this is only sketchy evidence which cannot adequately account for the relative importance of the alternative channels of transmission.

Notes

¹It is assumed that firms use a finite quantity of emissions in the absence of any price on emissions, as they pollute “as much as they wish”, but in a finite amount.

²This link is made even more explicit in Musu (1994), where the production function is $Y = A(DP)^\alpha K_P^{1-\alpha}$, with $D = K_D$ determining the efficiency of emissions. The marginal product of capital is $(1 - K_P/K)^\alpha (K_P/K)^{1-\alpha} P^\alpha$, an increasing function of the level of emissions. A limit of this formalization is the implicit assumption that production comes to an end if abatement is inactive.

³Michel (1993) makes the same assumption of constant returns to scale in the abatement sector, but within an overlapping generations model.

⁴The size of the investment in abatement, necessary to marginally decrease the emissions intensity of output, falls with the quantity of aggregate specific capital, K_D .

⁵Upon request the author can provide the proof.

⁶Fisher and van Marrewijk (1998) also argue that a tax on emissions does not necessarily reduce production on impact, to the extent that it fosters the entry of new firms.

⁷Oueslati (2002) studies the transitional dynamics of this model, to accomplish a comprehensive normative analysis of environmental policy.

⁸The multisector structure, the differentiation in factor intensity and the tax levied asymmetrically across sectors are all necessary elements for this result. In fact in sections II.3 and III of Elbasha and Roe (1995) these three properties are absent and as a result the tax on emissions does not affect the rate of growth.

⁹The paper considers a decreasing flow of natural resources as inputs to production, which can be interpreted as a flow of emissions.

¹⁰Also Bovenberg and de Mooij (1997) find that environmental policy can promote growth if the elasticity of substitution between emissions and the other inputs is low. Their argument is very different as they consider a model with productive public expenditure a la Barro (1990), financed through distortionary taxation of capital income. It is then optimal to levy a tax on emissions above its pigouvian level, in order to collect tax revenues to decrease the tax rate on capital income. This second-best fiscal policy increases the rate of growth and improves the quality of the environment.

¹¹In Bretschger, instead, if substitution is easy, firms react to environmental policy by increasing their demand for labor, a harmful behavior for R&D and, ultimately, for economic growth.

¹²The value of innovations is independent of environmental policy because the emissions tax does not influence (i) patent holders mark-up over marginal costs (a CES assembly function), nor (ii) household expenditure share on the composite good (a Cobb-Douglas utility function).

¹³The Romer (1990) framework implies that no good can ever become obsolete. Hence, any change in the technology embedded in innovations implies some degree of differentiation across goods, even in the very long run, at least between goods introduced before and after the change in the pollution intensity of innovations.

¹⁴Actually, only the framework of Aghion and Howitt (1998), chapter 3, makes it possible to generate an endogenous distribution of market shares across vintages of intermediate goods.

¹⁵Let us interpret the result in terms of costs and rewards to R&D. In Ricci (2002) when innovations are not environmental friendly, the cost of R&D (the wage) and its reward fall in the same amount, and R&D activity is unaltered by a tax on emissions. Vice versa, when innovations are environmental friendly, a rise in the tax reduces the wage more than the value of an innovation. The reason for this asymmetry is that the tax burden weighs more heavily on older goods which means that for the innovator the loss of profits is relatively concentrated in the distant future. But the innovator is much more interested in near-future profits which instead benefit from the gain in market shares.

¹⁶This trade-off results from the assumption that emissions are inputs complementary to intermediate goods in a Cobb-Douglas production function.

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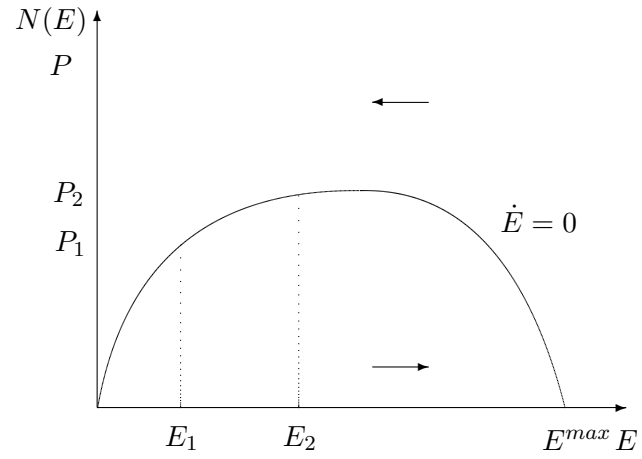


Figure 1: Non-linear natural emissions assimilation capacity of the environment

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