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Does Technical Progress Increase Long-Run Welfare?

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Abstract: We study an economy where households invest in capital and cause negative externalities on a renewable resource entering their utility function. There are also endogenous technical progress boosting labor productivity and the possibility of investing in resource-saving technical progress. Within this setup, we compare two regimes. Under "laissez-faire", households ignore the externalities they cause: the resource is asymptotically depleted and perpetual economic growth is generated, but households' welfare remains stagnant in the long run. Under an authority imposing the internalization of the externalities, long-run growth tends to be depressed but the resource is preserved and households' welfare increases forever.

Key Words: Endogenous growth, Induced technical progress, Market failures, Externalities.

JEL Classification Numbers: H23, O30, O41, Q55.

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1. Introduction

Scope of this paper is to confute the idea that technical progress is necessarily welfare increasing. We show indeed that in a laissez-faire economy the incentives determining the allocation of the inventive activity can lead to advances in inputs efficiency which allow an unbounded growth in the production of private goods but do not increase long-run individual well-being. At the root of this failure, we identify the inability of the laissez-faire economy to address innovative efforts in the direction that is socially desirable. With this regard, a major result of the paper is that the correction of this distortion creates the possibility for individual well-being to grow forever by devoting more research to improve the management of social and environmental assets constituting important sources of individual welfare. We also demonstrate that this correction may lower the long-run rate of economic growth since fewer resources are allocated to enhance inputs efficiency in the production of private goods.

The paper relates to three strands of literature.

It is well known that the quality of many natural assets, like air or water, or social ones (like that of the social capital or of interpersonal relations) can hardly be the object of market transactions. Thus, it is often the case that the quality of the natural and social environments are affected by negative externalities which tend to increase with the expansion of market activities. Environmental economics is fully aware of the complex relationship linking economic growth to natural assets (see Smulders, 2000, 2003). In contrast, only recently economic theory has started focusing on the interaction between the quality of the social environment and the performances of a market economy. This rapidly flourishing literature has to deal with the large body of evidence showing that growth generates social as well as environmental cleavages. For instance, the evidence cited by Putnam (2000) of a decline in social capital in the USA since World War II confirms that the advanced rich societies are experiencing a *relational failure*. Loneliness is regarded as a great social and personal problem, and so too is the poor quality of relations (e.g. Lane, 2000). This statistical evidence echoes the theme of the destructive impact of market society on social relationships and cohesion developed by a large and multi-disciplinary literature (Polanyi, 1968; Hirsch, 1976; Hirschman, 1982), which probably began with the conservative and socialist critiques of the Industrial Revolution. The idea that this destructive process sets the conditions for a further expansion of market transactions, thus stimulating economic growth, is common to this literature and was analyzed by Bartolini and Bonatti (2002, 2003), who model growth as a substitution process in which private goods progressively replace declining natural and social assets as sources of individual well-being. In the present paper, we follow this line of research by assuming that consumer activities impose negative externalities on these assets, which enter the households' utility function. It is plausible to interpret these negative externalities as the damage caused on natural resources by the waste and the pollution produced by consumer activities, or as the detrimental impact on social values due to the diffusion and strengthening of consumerist attitudes.

The second area of research to which this paper relates is the theory of induced technical change (ITC) and the recent attempts to reformulate this theory in endogenous growth models. Originally suggested by Hicks (1932),[1] ITC was formally developed in the 1960s and integrated in a growth framework (see Kennedy, 1964; Samuelson, 1965; Drandakis and Phelps, 1966) in order to explain why technical progress has been largely labor saving. Subsequent applications studied the degree to which the energy efficiency of production processes, machinery and consumer durable goods responded to changes in energy prices. At the core of the theory, which was criticized because of its weak micro-foundations (Ruttan, 2001), it is the key role of relative prices in the allocation of private inventive activities. More recently, ITC was embodied in endogenous growth models of innovations and knowledge spillovers (Acemoglu, 2002, 2003). These growth models, however, do not introduce environmental or social assets, although ITC has been also applied to the development of new technologies that can alleviate the impacts of human activities on the environment (see Grübler et al., 2002). In this context, one can argue that given the incompleteness of markets—and especially in the absence of markets for open-access resources--price signals distort the direction of technical progress, with detrimental effects on the introduction of new technologies and organizational innovations that can improve the quality of environmental and social assets. Consistently with this approach, this paper develops a formal setup in which the possibility of devoting R&D efforts to the improvement of the quality of environmental and social assets is not actualized in the laissez-faire because of the lack of adequate

[1] "The real reason for the predominance of labor saving inventions is surely that which was hinted at in our discussion of substitution. A change in the relative prices of the factors of production is itself a spur to invention and to inventions of a particular kind—directed at economizing the use of a factor which has become relatively expensive." (Hicks, 1932, 124-125)

incentives. This possibility of allocating efforts to improve environmental and social quality coexists with the presence of technical progress aimed at enhancing inputs efficiency in the production of private goods. With this regard, we consider two alternative modalities though which this technical change boosting inputs productivity can occur, depending on whether it is the result of purposive R&D efforts whose fruits can be fully appropriated by private agents, or the unintended result of the positive externalities generated by private investment activities aimed at accumulating capital. The model shows that a possible shift from the laisse-faire regime to the Pareto-optimal case reduces the long-run rate of economic growth when the inputs-augmenting technical progress is the result of purposive R&D efforts, while it has ambiguous effects on long-run growth when it is the result of positive externalities. More important, this shift allows to avoid the stagnancy of individual well-being that occurs in the long run under laissez-faire.

The result that—in the absence of adequate regulatory interventions--individual well-being can stagnate in spite of the incessant output growth taking place in advanced economies can be relevant for the so-called “debate on happiness”. This debate was ignited by the increasing evidence that self-evaluations of well-being do not appear to be positively correlated with the spectacular technical progress and economic growth that has occurred in the last decades in Western societies.[2] One can argue that our paper contributes to explain this evidence by conjecturing that these individual perceptions reflect the decline in the quality of natural and social assets that has accompanied the growing availability of private goods because of the lack of adequate collective actions.

The paper is organized as follows: section 2 presents the model, section 3 compares the balanced growth path emerging in the laissez-faire regime to the balanced growth path consistent with the Pareto-optimal solution when the labor-augmenting technical progress is intentional, while section 4 makes a similar comparison for the case when the labor-augmenting technical progress is unintentional, section 5 concludes.

2. The model

We consider an economy in discrete time with an infinite time horizon. This economy is populated by a

[2] ‘Classical’ papers by economists on the topic are Easterlin (1974, 1995) and Oswald (1997). The “debate on happiness” has also involved sociologists (e.g. Veenhoven, 1993), psychologists (e.g. Argyle, 1987; Kanheman, 1999, 2000) and political scientists (e.g. Lane 2000).

large number (normalized to unity) of identical households. For simplicity and without loss of generality, it is assumed that population is constant and that each household contains one adult, working member of the current generation. Thus, there is a fixed and large number of identical adults who take account of the welfare and resources of their actual and perspective descendants. Indeed, following Barro and Sala-i-Martin (1995) we model this intergenerational interaction by imaging that the current generation maximizes utility and incorporates a budget constraint over an infinite future. That is, although individuals have finite lives, we consider immortal extended families ("dynasties").[3] Again for simplicity and without loss of generality, it is assumed that bequests are accidental.[4] Expectations are rational (in the sense that they are consistent with the true processes followed by the relevant variables). In this framework in which there is no source of random disturbances, this implies perfect foresight.

Households' utility

The period utility function of the representative household, U_t, increases in consumption:

$$U_t = \ln(x_t), \tag{1}$$

where x_t is the amount of service generated by a consumer activity in period t. Households generate x_t by adopting a consumer technology that combines a resource to which all individuals have free access in every period and a consumer good that can be privately appropriated:[5]

$$x_t = x(R_t, C_t) = R_t C_t,\ R_t \geq 0, C_t \geq 0, \tag{2}$$

where R_t is the endowment (or an index of the quality) in t of an open-access resource that cannot be produced, and C_t is the amount of the unique good produced in this economy that is devoted to consumption

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[3] As Barro and Sala-i-Martin (1995, p. 60) point out, "this setting is appropriate if altruistic parents provide transfers to their children, who give in turn to their children, and so on. The immortal family corresponds to finite-lived individuals who are connected via a pattern of operative intergenerational transfers that are based on altruism".

[4] In other words, it is ruled out the existence of actuarially fair annuities paid to the living households by a financial institution collecting their wealth as they die: the wealth of someone who dies is inherited by some newly born individual.

[5] In the household production function approach, the quality of a household's personal environment is treated as a function of the quality of the collective environment and of goods that can be privately appropriated. For applications of this approach to measuring the demand for environmental attributes, see Kerry Smith (1991).

in t. Note that there is non-rivalry in the consumers' use of the resource R_t, from which no consumer can be excluded: it has the nonexclusive nature typical of a public good. Moreover, it is worth to emphasize that R_t and C_t are complements in the production of x_t, in the sense that the marginal (consumer) production function $\frac{\partial}{\partial C_t} x(R_t, C_t)$ is increasing in R_t holding C_t fixed. Finally, both R_t and C_t are essential, since the consumer service can be produced only if the consumer has a strictly positive quantity of both R_t and C_t.

The consumer technology in (2) applies to a broad variety of situations. Adopting an environmental interpretation of R_t, one can think of C_t as a man-made consumer good from which the households can draw some utility only if they are endowed with some amount of natural resources like air or water.

Renewable resource

We assume that the ability of the free resource to regenerate declines with the level of consumers' activities. In particular, we modify the logistic model--which is one of the simplest and best known functional specification for the law of motion of a renewable resource (see Conrad, 1987)--by assuming that environmental quality declines whenever the pollution generated by the consumers' activities surpasses a certain threshold ("the environmental carrying capacity"), which is normalized to be one:

$$R_{t+1} - R_t = rR_t(1 - p_t), \quad r > 0, \; R_0 \text{ given,} \tag{3}$$

where the parameter r can be interpreted as the intrinsic growth rate and p_t as the total level of pollution generated in t by the households. Total pollution p_t increases with the amount of "dirtiness" generated by the consumers' activities:

$$p_t = \frac{x_t}{E_t}, \; E_t > 0, E_0 \text{ given ,} \tag{4}$$

where E_t is a technical variable on which depends the amount of "dirtiness" generated by the activity of each single consumer.[6] Note that each single household can ignore the negative impact of its consumer activity on the future environmental quality, since its own contribution to the generation of total pollution is negligible.

[6] An alternative approach leading to the same result amounts to use (2) and (4) in order to rewrite the consumer production function as $x_t = \min(R_t C_t, E_t p_t)$ (see Smulders, 2000). In this way, it is more immediately apparent that consumers treat the renewable resource as an input entering their production function, and that E_t measures the efficiency with which the consumers utilize this resource.

However, the aggregate impact of the consumers' activities on the future endowment of the renewable resource is significant because of the large number of households populating the economy.

Production

The single good that is produced in this economy is denoted by Y_t. Each household produces it according to the technology

$$Y_t = K_t^{1-\alpha}(A_t L_t)^{\alpha}, \; K_t \geq 0, 0 \leq L_t \leq 1, \; A_t \geq 0, 0 < \alpha < 1, \tag{5}$$

where K_t is the stock of capital existing in t, L_t are the units of time devoted in t to the production of Y_t (the total time available to each household is normalized to unity) and A_t represents the state of technical (or organizational) knowledge affecting labor productivity.

Capital

The stock of capital evolves according to

$$K_{t+1}=Y_t+(1-\delta)K_t-C_t, \;\; 0\leq\delta\leq 1, \, K_0 \text{ given}, \tag{6}$$

where δ is a capital depreciation parameter.

Labor-augmenting technical progress

We consider two alternative modalities though which labor-augmenting technical progress can occur.

In the first framework, the knowledge affecting labor productivity is household-specific (it has no value for other households), and technical (or organizational) advances take place if households devote some of their time to the experimentation and implementation of new technologies or forms of organization aimed at augmenting their labor productivity:

$$A_{t+1}-A_t=\beta A_t N_t, \;\; \beta>0, \, 0\leq N_t\leq 1, \, A_0 \text{ given}, \tag{7a}$$

where N_t is the time devoted by the representative household to the activity aimed at increasing its own knowledge base, and β is a parameter measuring the efficiency with which households' time can be used to increase its own knowledge base. In this case, private agents can appropriate all the fruits of their activities increasing the economy's knowledge base.

In the alternative scenario, the variable A_t is assumed to be a positive function of the stock of capital existing in the economy:

$$A_t=K_t. \tag{7b}$$

Consistently with Frankel (1962), it is supposed that each household takes A_t as given, since a single household's investment decision has only a negligible effect on the aggregate stock of capital. This amounts to say that technological progress is endogenous to the economy, although it is an unintended by-products of households' capital investment rather than the result of purposive R&D efforts. In this case, private agents cannot appropriate all the fruits of their investment activities.

Resource-saving technical progress

We suppose that—together with labor-augmenting technical progress—it is possible also a household-specific technical progress aimed at reducing the impact of the consumers' activities on the future endowment of the renewable resource. We assume that this resource-saving technical progress occurs if households devote some of their time to the experimentation and implementation of new resource-saving technologies:

$$E_{t+1}-E_t=\gamma E_t(1-L_t-N_t),\ \gamma>0,\ E_0 \text{ given,} \tag{8}$$

where γ is a parameter measuring the efficiency with which households' time can be used to reduce the impact of the consumers' activities on the future endowment of the renewable resource.

Households' objective

In each period, the representative household maximizes its discounted sequence of utilities:

$$\sum_{i=0}^{\infty}\theta^{i}U_{t+i},\ 0<\theta<1, \tag{9}$$

where θ is a time preference parameter.

3. The laissez-faire balanced growth path (BGP) and the Pareto-optimal BGP when the labor-augmenting technical progress is intentional

In this section we compare the laissez-faire BGP to the Pareto-optimal BGP when the labor-augmenting technical progress is intentional.

Laissez-faire

Under laissez-faire, the households have no interest in taking into account the externalities that they cause and in investing in resource-saving technical progress. Indeed, even if the resource-saving technical progress is possible, any single household has no incentive to invest in it under laissez-faire since this investment would have a negligible (private) return. Thus, $E_t = E_0$ $\forall t$, and the problem of the representative household in period t can be solved by maximizing

$$H_t = \sum_{i=0}^{\infty} \theta^i \left\{U_{t+i} - \lambda_{t+i}\left[K_{t+i+1} - K_{t+i}^{1-\alpha} A_{t+i}^{\alpha} L_{t+i}^{\alpha} - (1-\delta)K_{t+i} + C_{t+i}\right] - \mu_{t+i}\left[A_{t+i+1} - \beta A_{t+i}(1-L_{t+i}) - A_{t+i}\right]\right\}$$ with

respect to C_t, L_t, K_{t+1}, A_{t+1} where λ_{t+i} and μ_{t+i} are Lagrange multipliers.[7] Hence, one obtains the conditions that each household must satisfy for optimality:

$$C_t^{-1} = \lambda_t, \tag{10a}$$

$$\lambda_t \alpha A_t^{\alpha} K_t^{1-\alpha} L_t^{\alpha-1} = \mu_t \beta A_t, \tag{10b}$$

$$\lambda_t = \lambda_{t+1}\theta[(1-\alpha)K_{t+1}^{-\alpha}(A_{t+1}L_{t+1})^{\alpha} + 1 - \delta], \tag{10c}$$

$$\mu_t = \mu_{t+1}\theta[\beta(1-L_{t+1}) + 1] + \lambda_{t+1}\theta\alpha K_{t+1}^{1-\alpha} A_{t+1}^{\alpha-1} L_{t+1}^{\alpha}. \tag{10d}$$

A path maximizing (9) must also satisfy the laws of motion (3), (6) and (7a), and the transversality conditions:

$$\lim_{i\to\infty} \theta^i \lambda_{t+i} K_{t+i} = 0, \tag{11a}$$

$$\lim_{i\to\infty} \theta^i \mu_{t+i} A_{t+i} = 0. \tag{11b}$$

By using (10a) and (10b) to eliminate λ_t and μ_t, one can rewrite (3), (6), (7a), (10c) and (10d) as:

$$\frac{Z_{t+1}}{1+\omega_t} - Z_t = rZ_t\left(1 - \frac{Z_t V_t}{E_0}\right),\ Z_t \equiv R_t K_t,\ \omega_t \equiv \frac{K_{t+1} - K_t}{K_t},\ V_t \equiv \frac{C_t}{K_t}, \tag{12a}$$

$$1 + \omega_t = (D_t L_t)^{\alpha} + 1 - \delta - V_t,\ D_t \equiv \frac{A_t}{K_t}, \tag{12b}$$

$$(1+\omega_t)D_{t+1} - D_t = \beta D_t(1-L_t), \tag{12c}$$

$$(1+\omega_t)V_{t+1} = V_t\theta[(1-\alpha)(D_{t+1}L_{t+1})^{\alpha} + 1 - \delta], \tag{12d}$$

$$\frac{\alpha V_t (D_{t+1}L_{t+1})^{\alpha-1}}{\beta}\theta[\beta(1-L_{t+1}) + 1] + V_t\theta\alpha D_{t+1}^{\alpha-1} L_{t+1}^{\alpha} = \frac{\alpha V_{t+1}(D_t L_t)^{\alpha-1}(1+\omega_t)}{\beta}. \tag{12e}$$

Thus, (12) constitutes a system of five equations in Z_t, ω_t, V_t, D_t and L_t which governs the

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[7] Since under laissez-faire households do not invest in resource-saving technical progress, we use the households' time

equilibrium path of the economy under laissez-faire. Along a BGP one must have Z_{t+1}=Z_t=Z, ω_t=ω, V_{t+1}=V_t=V, D_{t+1}=D_t=D and L_{t+1}=L_t=L in (12). In particular, along a BGP the growth rate of the output is

$$\rho^* = \pi^* = \omega^* = \theta(1+\beta) - 1 > 0, \quad \rho_t \equiv \frac{Y_{t+1} - Y_t}{Y_t}, \pi_t \equiv \frac{A_{t+1} - A_t}{A_t},^{8} \tag{13}$$

where "*" denotes the BGP value of a variable under laissez-faire.

Moreover, along a BGP the period utility of the representative household is given by

$$U^*=\ln (Z^*V^*)= \ln\left\{1+\frac{[\theta(\beta+1)-1]}{r\theta(\beta+1)}\right\} +\ln(E_0). \tag{14}$$

Notice that the steady-state utility level of the representative household is constant in spite of the fact that the steady-state rate of output growth is strictly positive. This is because along a BGP displaying perpetual growth the renewable resource entering the households' utility function is asymptotically depleted. Therefore, the positive impact on the households' welfare of the steady increase in per capita output and per capita (private) consumption is offset along a BGP by the diminishing endowment of R_t. Long-run growth is fed by a substitution process in which the private good progressively replaces the declining renewable resource as a source of individual well-being.

Pareto-optimality

Suppose now that there is a regulatory authority that has the instruments to induce the economic agents to internalize the effects of their activities on the future endowment of the renewable resource. In this context, this possibility of resource-saving technical progress has long-term consequences for the rate of economic growth and for the households' well-being, and the economy can move along its Pareto-optimal path. This path can be characterized by maximizing

$$H_t = \sum_{i=0}^{\infty}\theta^i\Big\{U_{t+i} - \lambda_{t+i}\left[K_{t+i+1} - K_{t+i}^{1-\alpha}A_{t+i}^{\alpha}L_{t+i}^{\alpha} - (1-\delta)K_{t+i} + C_{t+i}\right] - \mu_{t+i}\left[A_{t+i+1} - \beta A_{t+i}N_{t+i} - A_{t+i}\right] -$$

$$- \eta_{t+i}\left[R_{t+i+1} - rR_{t+i}\left(1-\frac{C_{t+i}R_{t+i}}{E_{t+i}}\right) - R_{t+i}\right] - \upsilon_{t+i}\left[E_{t+i+1} - \gamma E_{t+i}(1 - L_{t+i} - N_{t+i}) - E_{t+i}\right]\Big\}$$ with respect to C_t, L_t, N_t, K_{t+1}, A_{t+1}, R_{t+1}, E_{t+1} where λ_{t+i}, μ_{t+i}, υ_{t+i} and η_{t+i} are Lagrange multipliers. Hence, a Pareto-optimal

constraint to substitute 1-L_{t+i} for N_{t+i}.

[8] We impose θ(1+β)>1, which is necessary to have an interior solution to the representative household's problem.

path in the presence of resource-saving technical progress must satisfy (10c),

$$C_t^{-1} = \lambda_t + \frac{\eta_t r R_t^2}{E_t}, \tag{15a}$$

$$\lambda_t \alpha A_t^{\alpha} K_t^{1-\alpha} L_t^{\alpha-1} = \upsilon_t \gamma E_t, \tag{15b}$$

$$\upsilon_t \gamma E_t = \mu_t \beta A_t, \tag{15c}$$

$$\mu_t = \mu_{t+1}\theta(\beta N_{t+1} + 1) + \lambda_{t+1}\theta\alpha K_{t+1}^{1-\alpha} A_{t+1}^{\alpha-1} L_{t+1}^{\alpha}, \tag{15d}$$

$$\eta_t = \eta_{t+1}\theta r\left(1 - \frac{2C_{t+1}R_{t+1}}{E_{t+1}}\right) + \eta_{t+1}\theta + \frac{\theta}{R_{t+1}}, \tag{15e}$$

$$\upsilon_t = \eta_{t+1}\theta r\frac{C_{t+1}R_{t+1}^2}{E_{t+1}^2} + \upsilon_{t+1}\theta[\gamma(1 - L_{t+1} - N_{t+1}) + 1], \tag{15f}$$

the laws of motion (6), (7a), (8) and

$$R_{t+1} - R_t = rR_t\left(1 - \frac{C_t R_t}{E_t}\right), \quad R_0 \text{ given}, \tag{16}$$

and the transversality conditions (11a), (11b),

$$\lim_{i\to\infty} \theta^i \eta_{t+i} R_{t+i} = 0, \tag{17a}$$

$$\lim_{i\to\infty} \theta^i \upsilon_{t+i} E_{t+i} = 0. \tag{17b}$$

By using (15a), (15b) and (15c) to eliminate μ_t, η_t and υ_t one can rewrite (6), (16), (7a), (8), (10c), (15d), (15e) and (15f) as (12b),

$$R_{t+1} - R_t = rR_t(1 - V_t R_t M_t), \; M_t \equiv \frac{K_t}{E_t}, \tag{18a}$$

$$(1+\omega_t)D_{t+1} - D_t = \beta D_t N_t, \tag{18b}$$

$$\frac{1+\omega_t}{M_{t+1}} = \frac{1+\gamma(1 - L_t - N_t)}{M_t}, \tag{18c}$$

$$(1+\omega_t)S_t = S_{t+1}\theta[(1-\alpha)(D_{t+1}L_{t+1})^{\alpha} + 1 - \delta], \; S_t \equiv \lambda_t K_t, \tag{18d}$$

$$\frac{S_{t+1}(D_{t+1}L_{t+1})^{\alpha-1}}{\beta}\theta(\beta N_{t+1} + 1) + S_{t+1}\theta D_{t+1}^{\alpha-1} L_{t+1}^{\alpha} = \frac{S_t(D_t L_t)^{\alpha-1}(1+\omega_t)}{\beta}, \tag{18e}$$

$$\frac{(1-V_tS_t)}{rV_tM_tR_t^2}=\frac{\theta(1-V_{t+1}S_{t+1})}{rV_{t+1}M_{t+1}R_{t+1}^2}\left(1+r-2rM_{t+1}V_{t+1}R_{t+1}\right)+\frac{\theta}{R_{t+1}}, \qquad (18f)$$

$$\frac{\alpha M_tS_tL_t^{\alpha-1}D_t^{\alpha}}{\gamma}=\frac{\theta M_{t+1}(1-V_{t+1}S_{t+1})}{1+\omega_t}+\frac{\theta\alpha M_{t+1}S_{t+1}L_{t+1}^{\alpha-1}D_{t+1}^{\alpha}}{\gamma(1+\omega_t)}[1+\gamma(1-L_{t+1}-N_{t+1})]. \qquad (18g)$$

Thus, (12b) and (18a)-(18g) constitutes a system of eight equations in M_t, ω_t, V_t, D_t, S_t, R_t, N_t and L_t which governs the Pareto-optimal path of the economy when the labor-augmenting technical progress is intentional. Again, a BGP can be characterized by setting $M_{t+1}=M_t=M$, $\omega_t=\omega$, $V_{t+1}=V_t=V$, $D_{t+1}=D_t=D$, $S_{t+1}=S_t=S$, $R_{t+1}=R_t=R$, $N_{t+1}=N_t=N$ and $L_{t+1}=L_t=L$ in (12b) and (18a)-(18f). In particular, one can easily check that the growth rate of the output is lower along such a BGP than along the BGP emerging under laissez-faire:

$$0<\rho^{**}=\pi^{**}=\omega^{**}=\frac{\gamma[\theta(1+\beta)-1]}{\gamma+\theta\beta}<\rho^{*}=\pi^{*}=\omega^{*}=\theta(1+\beta)-1, \qquad (19)$$

where "**" denotes the BGP value of a variable consistent with the Pareto-optimal solution.

We summarize this result in the following proposition:

Proposition 1. As the appropriability of the labor-augmenting technical knowledge is perfect (since this knowledge is household specific), the internalization of the negative externalities generated by the consumer activities on the renewable resource reduces the steady-state rate of labor-augmenting technical progress and the steady-state rate of output growth.

Proof: See (19).

The content of Proposition 1 is a consequence of the fact that if the institutional setup creates adequate incentives to invest in resource-saving technical progress (for example, by introducing a pollution tax), less effort is devoted to boost labor productivity and the economy grows more slowly.

Furthermore, along a BGP consistent with the Pareto-optimal solution, the renewable resource is not asymptotically depleted because of the implementation of resource-saving technical progress, although this BGP is characterized by a strictly positive rate of economic growth. Hence, the well-being of the representative household grows forever along the Pareto-optimal BGP, since

$$\vartheta^{**}=\rho^{**}>0,\ \vartheta_t\equiv\frac{x_{t+1}-x_t}{x_t}. \qquad (20)$$

In other words:

Proposition 2. As the appropriability of the labor-augmenting technical knowledge is perfect (since this knowledge is household specific), the internalization of the negative externalities generated by the consumer activities on the renewable resource allows to avoid the asymptotic depletion of the open-access resource and the stagnancy of the individual well-being which take place under laissez faire in the long run.

Proof: Consider that under laissez-faire a BGP is characterized by Z*>0 and ω*>0, thus entailing $\lim_{i\to\infty} R_{t+i} = 0$, while the BGP consistent with the Pareto-optimal solution displays R**>=0. Moreover, to see that the steady-state individual well being is stagnant under laissez faire and grows forever under a benevolent planner, consider (1), (14) and (20).

4. The laissez-faire BGP and the Pareto-optimal BGP when the labor-augmenting technical progress is unintentional

In this section we compare the laissez-faire BGP to the Pareto-optimal BGP when the labor-augmenting technical progress is the unintentional result of the aggregate capital accumulation. As in the previous section, resource-saving technical progress occurs only if private agents devote purposive efforts to develop specific new technologies.

Laissez-faire

Under laissez-faire, the households have no interest in taking into account the externalities that they generate by investing in capital. Moreover—as in the previous section—the do not have any interest in investing in resource-saving technical progress. Thus, $E_t=E_0$ $\forall$t, and the problem of the representative household in period t can be solved by maximizing

$H_t = \sum_{i=0}^{\infty} \theta^i \left\{U_{t+i} - \lambda_{t+i}\left[K_{t+i+1} - K_{t+i}^{1-\alpha} A_{t+i}^{\alpha} - (1-\delta)K_{t+i} + C_{t+i}\right]\right\}$ with respect to C_t and K_{t+1}, where λ_{t+i} is a Lagrange multiplier.[9] Hence, one obtains the conditions that each household must satisfy for optimality:

$$C_t^{-1} = \lambda_t, \tag{21a}$$

$$\lambda_t = \lambda_{t+1}\theta[(1-\alpha)K_{t+1}^{-\alpha} A_{t+1}^{\alpha} + 1 - \delta], \tag{21b}$$

A path maximizing (9) must also satisfy the laws of motion (3), (6) and (7b), and the transversality

[9] Since under laissez-faire households do not invest in resource-saving technical progress, they devote all their time to production. Hence, $L_{t+i}=1$ $\forall$i.

condition:

$$\lim_{i\to\infty} \theta^{i} \lambda_{t+i} K_{t+i} = 0 . \tag{22}$$

By using (21a) to eliminate λ_t, one can rewrite (3), (6) and (21b) as:

$$\frac{Z_{t+1}}{1+\omega_t} - Z_t = rZ_t\left(1-\frac{Z_t V_t}{E_0}\right), \tag{23a}$$

$$1+\omega_t = 2-\delta-V_t, \tag{23b}$$

$$(1+\omega_t)V_{t+1} = V_t\theta(2-\alpha-\delta) . \tag{23c}$$

Thus, (23) constitutes a system of three equations in Z_t, ω_t and V_t which governs the equilibrium path of the economy under laissez-faire when labor-augmenting technical progress is unintentional. Along a BGP, one must have $Z_{t+1}=Z_t=Z$, $\omega_t=\omega$ and $V_{t+1}=V_t=V$ (23). In particular, the steady-state rate of growth of the output is

$$\rho^* = \pi^* = \omega^* = \theta(2-\alpha-\delta)-1 . \tag{24}$$

As in the case in which labor-augmenting technical progress is the result of purposive R&D efforts, also in this case the steady-state utility level of the representative household is constant:

$$U^*=\ln(Z^*V^*)= \ln\left\{1+\frac{[\theta(2-\alpha-\delta)-1]}{r\theta(2-\alpha-\delta)}\right\} +\ln(E_0). \tag{25}$$

Pareto-optimality

In the presence of a regulatory authority that has the instruments to induce the economic agents to internalize both the technological spillovers generated by their investment in capital and the externalities caused by their consumer activities, the economy can move along its Pareto-optimal path. This path can be characterized by maximizing

$$H_t = \sum_{i=0}^{\infty}\theta^{i}\Big\{U_{t+i} - \lambda_{t+i}\left[K_{t+i+1} - K_{t+i}L_{t+i}^{\alpha} - (1-\delta)K_{t+i} + C_{t+i}\right] - \eta_{t+i}\left[R_{t+i+1} - rR_{t+i}\left(1-\frac{C_{t+i}R_{t+i}}{E_{t+i}}\right) - R_{t+i}\right]$$

$- \upsilon_{t+i}\left[E_{t+i+1} - \gamma E_{t+i}(1-L_{t+i}) - E_{t+i}\right]\Big\}$ with respect to C_t, L_t, K_{t+1}, R_{t+1}, E_{t+1} where λ_{t+i}, η_{t+i} and υ_{t+i} are Lagrange multipliers. Hence, a Pareto-optimal path in the presence of resource-saving technical progress must satisfy

$$C_t^{-1} = \lambda_t + \frac{\eta_t r R_t^2}{E_t}, \tag{26a}$$

$$\lambda_t \alpha K_t L_t^{\alpha-1} = \upsilon_t \gamma E_t, \tag{26b}$$

$$\lambda_t = \lambda_{t+1}\theta[L_{t+1}^{\alpha} + 1 - \delta], \tag{26c}$$

$$\eta_t = \eta_{t+1}\theta r\left(1 - \frac{2C_{t+1}R_{t+1}}{E_{t+1}}\right) + \eta_{t+1}\theta + \frac{\theta}{R_{t+1}}, \tag{26d}$$

$$\upsilon_t = \eta_{t+1}\theta r\frac{C_{t+1}R_{t+1}^2}{E_{t+1}^2} + \upsilon_{t+1}\theta[\gamma(1 - L_{t+1}) + 1], \tag{26e}$$

the laws of motion (6),

$$R_{t+1} - R_t = rR_t\left(1 - \frac{C_t R_t}{E_t}\right), \quad R_0 \text{ given}, \tag{27a}$$

$$E_{t+1} - E_t = \gamma E_t(1 - L_t), \quad E_0 \text{ given}, \tag{27b}$$

and the transversality conditions (22),

$$\lim_{i\to\infty} \theta^i \eta_{t+i} R_{t+i} = 0, \tag{28a}$$

$$\lim_{i\to\infty} \theta^i \upsilon_{t+i} E_{t+i} = 0. \tag{28b}$$

By using (26a) and (26b) to eliminate η_t and υ_t, one can rewrite (26c)-(26f), (6) and (27a)-(27b) as

$$(1 + \omega_t)S_t = S_{t+1}\theta(L_{t+1}^{\alpha} + 1 - \delta), \tag{29a}$$

$$\frac{(1 - V_t S_t)}{rV_t M_t R_t^2} = \frac{\theta(1 - V_{t+1}S_{t+1})}{rV_{t+1}M_{t+1}R_{t+1}^2}\left(1 + r - 2rM_{t+1}V_{t+1}R_{t+1}\right) + \frac{\theta}{R_{t+1}}, \tag{29b}$$

$$\frac{\alpha M_t S_t L_t^{\alpha-1}}{\gamma} = \frac{\theta M_{t+1}(1 - V_{t+1}S_{t+1})}{1 + \omega_t} + \frac{\theta\alpha M_{t+1}S_{t+1}L_{t+1}^{\alpha-1}}{\gamma(1 + \omega_t)}[1 + \gamma(1 - L_{t+1})]. \tag{29c}$$

$$1 + \omega_t = L_t^{\alpha} + 1 - \delta - V_t, \tag{29d}$$

$$R_{t+1} - R_t = rR_t\left(1 - V_t R_t M_t\right), \tag{29e}$$

$$\frac{1 + \omega_t}{M_{t+1}} = \frac{1 + \gamma(1 - L_t)}{M_t}. \tag{29f}$$

Thus, (29) constitutes a system of six equations in M_t, ω_t, V_t, S_t, R_t and L_t which governs the Pareto-optimal path of the economy when the labor-augmenting technical progress is unintentional. By setting $M_{t+1}=M_t=M$,

$\omega_t=\omega$, $V_{t+1}=V_t=V$, $S_{t+1}=S_t=S$, $R_{t+1}=R_t=R$ and $L_{t+1}=L_t=L$ in (29), one can check that

$$\rho^{**}=\pi^{**}=\omega^{**}>0 \text{.}^{10} \tag{30}$$

Moreover, one has

$$\rho^{**}=\pi^{**}=\omega^{**}\begin{Bmatrix}>\\=\\<\end{Bmatrix}\rho^{*}=\pi^{*}=\omega^{*} \text{ whenever } L^{**}\begin{Bmatrix}>\\=\\<\end{Bmatrix}(1-\alpha)^{\frac{1}{\alpha}} \tag{31}$$

(the steady-state rate of economic growth is higher under a benevolent social planner than under laissez-faire whenever the steady-state amount of time devoted to production by the social planner is higher than the threshold $(1-\alpha)^{\frac{1}{\alpha}}$). In its turn,

$$L^{**}\begin{Bmatrix}>\\=\\<\end{Bmatrix}(1-\alpha)^{\frac{1}{\alpha}} \text{ whenever } 1+\gamma-\theta(1-\delta)\begin{Bmatrix}>\\=\\<\end{Bmatrix}\theta(1-\alpha)+\gamma(1-\alpha)^{\frac{1}{\alpha}}. \tag{32}$$

In other words, L** tends to be higher than $(1-\alpha)^{\frac{1}{\alpha}}$ when α (the labor elasticity of output), γ (the efficiency of labor in accumulating the resource-saving knowledge) and δ (the capital-depreciation parameter) are large, and when agents discount the future more heavily (small θ). In particular, note that the internalization of externalities tends to generate a higher rate of perpetual growth when the spillovers caused by individual capital accumulation on the labor-augmenting technical progress are relevant (large α) and when the labor allocated to increase the resource-saving knowledge is highly productive (large γ). Under these circumstances, indeed, the boosting effect on long-run growth due to the internalization of the positive externalities caused by the individual investment activities tends to dominate the depressing effect on long-run growth due to the internalization of the negative externalities caused by the individual consumer activities.

We summarize this result in the following proposition:

Proposition 3. As the increase of the labor-augmenting technical knowledge is the result of positive externalities produced by individual investment activities, the internalization of all the externalities generated

[10] We impose $\theta(2-\delta)>1$, which is necessary to have an interior solution to the benevolent planner's problem.

by the private agents has an ambiguous effect on the steady-state rate of labor-augmenting technical progress and the steady-state rate of output growth. The sign of this effect depends on whether the boosting effect on long-run growth due to the internalization of the positive externalities caused by the individual investment activities aimed at accumulating capital dominates the depressing effect on long-run growth due to the internalization of the negative externalities caused by the individual consumer activities.

Proof: See (31) and (32).

An important implication of Proposition 3 is that the definition and the enforcement of property rights over the labor-augmenting technical progress generated by private agents do not necessarily lead to a higher rate of technical progress and to faster economic growth if also the negative externalities caused by individual consumer activities are internalized.

Finally, also when the labor-augmenting technical progress is not the result of purposive R&D efforts, along the BGP consistent with Pareto optimality the renewable resource is not asymptotically depleted and the well-being of the representative household grows forever:

$$\vartheta^{**} = \rho^{**} > 0 \,. \tag{33}$$

Therefore:

Proposition 4. As the increase of the labor-augmenting technical knowledge is the result of positive externalities produced by individual investment activities, the internalization of all the externalities generated by the private agents allows to avoid the asymptotic depletion of the open-access resource and the stagnancy of the individual well-being which take place under laissez faire in the long run.

Proof: Consider that under laissez-faire a BGP is characterized by Z*>0 and ω*>0, thus entailing $\lim_{i\to\infty} R_{t+i} = 0$, while the BGP consistent with the Pareto-optimal solution displays R**>=0. Moreover, to see that the steady-state individual well being is stagnant under laissez faire and grows forever under a benevolent planner, consider (1), (25) and (33).

5. Conclusion

In the endogenous growth literature, markets are incomplete (given that there are positive externalities) and growth is sub-optimally low under laissez faire. This implies that a regulatory intervention leading to the internalization of the externalities raises long-run growth. In our model, by contrast, the internalization of the externalities lowers the steady-state rate of economic growth (except when the positive externalities generated by individual investment activities aimed at accumulating capital dominate the negative externalities produced by individual consumer activities). In any case, however, our model predicts that the laissez-faire regime leads in the long run to the stagnancy of individual well-being in spite of the unbounded output growth and the unceasing labor-augmenting technical progress. Our viewpoint is that the combination of excessive depletion of commonly owned assets and stagnant long-run welfare calls for some collective action (e.g. pollution taxes, creation of authorities managing environmental resources…). This call for collective action is consistent with the hypothesis that "even for those dimensions of environmental quality where growth seems to have been associated with improving conditions, there is no reason to believe that the process is an automatic one", since "the strongest link between income and pollution in fact is via an induced policy response" (Grossman and Krueger, 1995: pp.371-372). In its turn, this policy response is driven by citizen demand.[11]

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[11] In the debate on the so-called 'environmental Kutznets curve', i.e., on the hypothesis that the relationship between per capita income and environmental degradation takes an inverted U-shaped form, also Arrow et al. (1995) claim that economic growth is no substitute for environmental policy. Moreover, they note that "reductions in one pollutant in one country may involve increases in other pollutants in the same country or transfers of pollutants to other countries" (Arrow et al., 1995: p. 92). Estimating a dynamic model, De Bruyn et al. (1998) show that economic growth has a direct positive effect on the levels of emissions, thus supporting the radical standpoint, according to which the idea that economic growth can be good for the environment is 'false and pernicious nonsense' (see Ayres, 1995). However, it should be emphasized that sustainability is not simply a function of the levels of emissions and resource depletion, since it depends on the capacity of natural systems to absorb wastes and renew resources (see Kaufmann and Cleveland, 1995).

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