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Latin America: incorporating environmental factors into the measurement of production efficiency and technical change

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This paper examines growth in a set of Latin American countries from 1980 to 2004 by analysing total factor productivity (TFP) from a twofold perspective: maximization of output (GDP) and minimization of the CO_2 emissions generated in the production process. Malmquist productivity indices are constructed for this purpose. In addition, kernel density functions are employed to analyse convergence (or divergence) in the efficiency estimated. The results obtained indicate that incorporating environmental factors into the measurement of efficiency and productive change significantly improves the estimates for certain countries in the region by comparison with those obtained by more traditional methods.

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I
Introduction

The purpose of this article is to consider and empirically analyse economic growth, convergence in efficiency levels and the environmental implications of these by studying and measuring changes in total factor productivity (TFP) in the countries of Latin America.

The main idea of the study is to see how technical efficiency in the use of resources can combine with the concept of environmental sustainability. This is done by estimating TFP growth in the Latin American economies between 1980 and 2004 and breaking this down into efficiency improvements and technological change by calculating Malmquist indices.

Non-parametric techniques such as data envelopment analysis (DEA) are used to measure productivity so that disaggregated country-by-country results can be arrived at for efficiency improvements and technical change, taking a number of externalities in the production function into account. Another aim is to detect possible convergent (or divergent) growth patterns in the Latin American countries during the 1980-2004 period.

We believe the subject to be important because growth in Latin America over the past 25 years has been modest; at the same time, it is not just the pace of growth that matters but its quality and stability too. It is in consideration of this that an effort is needed to analyse the causes of growth in a way that distinguishes the internal effects of technical efficiency change (catching-up) as opposed to just an aggregate index.

The environmental factor, among others, has become part of the debate about growth quality, and the quantitative analysis and methodologies used in this study provide a way of constructing a measure of growth that incorporates this variable with a view to analysing its influence when TFP is modified and being able to compare growth situations.

In pursuit of these goals, this paper is structured as follows. Section II analyses the major known facts about the relationship between growth, convergence and the environment. Section III provides an overview of the methodology used for decomposing TFP and analysing convergence. Section IV describes the data employed and presents the findings. Lastly, section V contains the conclusions of the study.

II
Some background

1. Total factor productivity (TFP), growth and efficiency convergence

Ever since the pioneering work of Solow (1957) on growth accounting (residual factor), TFP changes have routinely been measured as a way of identifying the causes of growth and thereby reducing what Solow called "the measure of our ignorance".

Progress in this field has been significant. Efforts were initially oriented towards distinguishing the determinants of factor accumulation by seeking to observe the quality of both labour and capital. The idea was essentially to answer the following questions: why did economies grow, and what were the prospects for convergence?

A second stage in growth theory began with the publication of an article by Romer (1986) proposing a production function with increasing returns external to the firm. In those years, in an attempt to provide answers to the same questions as before, so-called endogenous growth models made their appearance while work began on decomposing technical progress and efficiency as two distinct measures affecting TFP.

Work on the convergence hypothesis had taken an important new turn, meanwhile, and the empirical studies of Abramovitz (1986), Baumol (1986) and

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Maddison (1987) found evidence of convergence between developed countries, but this hypothesis did not hold up when the sample was extended to developing countries. Barro (1991), Barro and Sala-i-Martin (1992) and Mankiw, Romer and Weil (1992) also demonstrated the existence of convergence conditional upon the characteristics of the steady state.

As well as defining absolute and conditional β-convergence, Quah (1993) defines a third measure termed σ-convergence.[1] For the case of Latin America, Elías (2001) analyses the σ-convergence of seven countries in the 1960-1994 period and finds some degree of convergence between countries, but when the United States is integrated into the sample the situation is clearly divergent.

This paper introduces the idea of σ-convergence from the efficiency standpoint only and thus does not go thoroughly into the subject, since the important thing is to complement the idea of efficiency in Latin America from this perspective.[2]

The evidence shows growth in Latin America to have been modest and unstable over the last 40 years, with particular volatility in the 1980-2000 period. An initial guide to the analysis of growth in Latin America can be found in Hofman (2001), which undertakes a detailed analysis of the region's growth process in the twentieth century, convergence trends, and productivity and efficiency. Among other characteristics, the study takes an innovative approach to analysis of the growth process by distinguishing and relating what are considered to be the "proximate causes" (traditional analysis of the sources of growth and β-convergence) with so-called "ultimate causes" (institutions, income distribution and macroeconomic stability).

The conclusions are in line with those of other studies and are to the effect that there are clear convergence tendencies within the region and that the role of TFP has held steady over time at about 40%, a reflection of the fact that capital and labour are the variables which alter over time (Hofman, 2001, p. 12).

Where the 1980-2000 period is concerned, the study incorporates an explanation of the region's structural weaknesses and the way these affect the growth process, although this proves hard to quantify.

Along similar lines, Solimano and Soto (2005) seek to identify in significant detail the economic development process of Latin America and its relationship with development cycles in the closing decades of the last century. To this end, they first formulate some stylized facts concerning the region's economic performance: (i) the existence of heterogeneity and volatility in long-term growth, (ii) the deterioration of economic development after 1980 and (iii) major shifts in economic development between countries.

Secondly, the article focuses on analysing the sources of growth, concluding that the deterioration of gross domestic product (GDP) in the closing decades of the last century was essentially due to a drop in TFP. The study identifies TFP determinants that may be behind the fall-off in growth, including the business cycle, the quality of the workforce, external shocks and macroeconomic instability (Solimano and Soto, 2005, pp. 35-36).

Certain studies have proceeded along similar lines to our own work by estimating TFP using DEA and Malmquist indices, as these provide a way of distinguishing between technical progress and technical efficiency changes at the country level:

— For the 1970-2001 period, Lanteri (2002) estimates measures of change in TFP and its components for nine countries, including the United States and a number of Latin American and South-East Asian countries. Given the importance of measuring efficiency in TFP changes, it should be mentioned that Argentina presents an annual decrease of 0.5% over the period (the United States is the frontier), but when TFP is decomposed it transpires that efficiency increased at a rate of 0.3% annually over the period, the fundamental cause of the decline in TFP being an annual 0.7% reduction in technological change.

— Taskin and Zaim (1997) conducted a study on TFP changes for 23 high- and low-income countries in the 1975-1990 period, seeking to test the technical efficiency change hypothesis by measuring this change and assessing the rate at which methodology spreads. Overall, the countries saw a very small loss in productivity, but high-income countries gained 0.37% a year while low-income ones lost 0.38% a year.

— In the case of Organisation for Economic Cooperation and Development (OECD) countries, studies by Dowrick and Nguyen (1989) and Färe, Grosskopf and Norris (1994) show marked

[1] Sigma (σ) convergence measures the dispersion of income by taking the standard deviation of income (Y_{it}) in each country (i) over time (t) (Barro and Sala-i-Martin, 1992).

[2] See ECLAC (2008, pp. 17-51) for an analysis of convergence in Latin America.

convergence in efficiency changes, whereas the same is not found to be true of changes in TFP relative to the frontier.

— Ching-Cheng and Yir-Hueih (1999) study the sources of factor productivity growth in the Asian countries. Using distance functions based on the Malmquist productivity index, they reveal some interesting findings from a sample including 19 countries of the Asia-Pacific Economic Cooperation Forum (APEC), dividing productivity between technical efficiency changes and technical progress (innovation). The data indicate that the United States (included in the sample) is not the only innovator in the region; in the 1980s, both Hong Kong Special Administrative Region and Singapore proved able to adjust the country frontier, meaning that they are good not only at adaptation but at innovation too.
— Employing non-parametric techniques, and with a view to avoiding the efficiency biases that come with the use of production frontiers, Maudos, Serrano and Pastor (1999) consider the possibility of inefficient behaviour, as do Färe, Grosskopf and Norris (1994), who signal the importance of efficiency gains as a source of convergence in labour productivity for the OECD countries.

2. Total factor productivity, growth and the environment

The recent literature has incorporated the issue of the environment into the analysis, seeking to justify TFP changes and differentiating them into efficiency and technical progress.

Although the link between economic growth and the environment is not a new topic of research, it is not of very long standing either. It was in the 1970s that the idea of environmental problems being somehow necessarily related to economic development became well-established.

The history of the subject starts with *Silent Spring* (Carlson, 1962), a book which detailed the problems caused to the environment by the indiscriminate use of pesticides and insecticides. A few years later, Boulding (1966), in his essay "The Economics of the Coming Spaceship Earth", sought to show the dangers of unrestricted economic growth from the standpoint of resources and pollution.

The report by Meadows and others (1972) gave an early intimation of the existence of limits to economic growth, with the main hypothesis concerning non-renewable resources as a constraint. The debate focused on three points: the rate of change in technical progress, future changes in the composition of output, and the scope for substitution (Ekins, 1993, p. 271).

The debate is basically the same today; however, empirical studies on the existence of the environmental Kuznets curve (growth and the environment), scale decomposition of emissions and the composition effect have clarified the discussion somewhat. It has been argued that economic growth does not necessarily have to be associated with environmental deterioration but, on the contrary, can coexist with an improving environment (Cole, 2007).

In the 1980s, the Brundtland Commission report (WCED, 1987) consolidated the use of the term "sustainable development" (WCED, 1987).[3] Economically, the aim was to reconcile the social benefits of access to goods and services with the environmental costs deriving from their production.

Studies of the environmental Kuznets curve became widespread in the 1990s, not least because more data were available. Grossman and Krueger (1995) and Shafik (1994) found evidence for the environmental Kuznets curve (in terms of scale, composition and technical effects). There are reservations about the turning point, however, depending on the economic, cultural, political and social characteristics of each economy (Cole, Elliot and Shimamoto, 2005; Stern, 2002).[4]

Since then, much of the economic literature on changes in TFP, efficiency and convergence has included environmental topics, and the relationship between growth and the environment is accepted:

— Kumar (2006) analyses TFP change by considering goods and services output and the generation of negative environmental externalities, while others treat it as a pollution abatement cost. The traditional productivity measure ignores reductions in unwanted emissions because of abatement activity, as there is no price on the production of unwanted emissions unless a tradable goods market exists.
— The study calculates an adjusted Malmquist productivity index for 41 more- and less-developed countries in the 1971-1992 period and analyses the

[3] Although the central idea of sustainable development is to preserve equity between generations, this concept ignores concerns about income equity and poverty levels (intragenerational equity) (Markandya, 1992).

[4] Cole (2007, p. 245) analyses the results of estimating turning points in the environmental Kuznets curve.

components of TFP, dividing technical progress and efficiency (the null hypothesis of the indices being equal when emissions are ignored is not accepted), as a result of which it is found that just six countries (all developed) are innovators while lower-income countries are not.

— Färe, Grosskopf and Hernández-Sancho (2004, p. 349) propose an indicator to measure environmental behaviour using the data envelopment analysis (DEA) technique, consisting in the quotient between the index for the quantity of goods produced and the environmental externalities index. This indicator shows the extent to which a sector, firm or country can succeed by producing goods while simultaneously accounting for the negative environmental effects. To apply the index, they use data from a sample of 17 OECD countries for 1990, comparing GDP data with data on environmental emissions (carbon dioxide, nitrogen oxide and sulphur oxide) and energy consumption. The findings show France and Sweden to have the best quotients and Greece the worst.

— Ball and others (2005) consider the relationship between productivity growth and the adverse effects on the environment. To this end they consider a number of studies indicating that factor productivity growth is overestimated in the presence of rising negative externalities of an environmental nature (Denison, 1979 and Robinson, 1995). The authors set out by constructing an index they call the Malmquist cost productivity (MCP) index, the purpose of which is to establish a measure of higher productivity that takes account of externalities. Using panel data, they show how the productivity measure rises when negative environmental externalities are ignored. When the risks associated with production diminish, conversely, productivity increases (Ball and others, 2005, pp. 382-386).

— Starting from this basis, Färe, Grosskopf and Pasurka (2007) consider the possibility of generating a productivity measure taking into account the absence of data on inputs used in environmental externalities. For this they propose the traditional measure of productivity in a different context termed a "joint production perspective".[5] They use electricity plant data for the 1985-1995 period with one output, net electricity generation, and two externalities, carbon dioxide (CO_2) and nitrogen oxide (NO_x). The findings show that pollution abatement activities are associated with reductions in traditional productivity and technical change, although these differences are not statistically significant (Färe, Grosskopf and Pasurka 2007, p. 680).

— Schuschny (2007) analyses the energy performance of 37 countries in Latin America and the Caribbean by employing indicators of economic activity, CO_2 emissions intensity and energy consumption based on the use of fossil fuels or clean alternative sources. The findings show that there are countries which have made an effort to increase the level of activity in their economies while seeking to meet their energy consumption needs from clean technologies.

In contrast to the study by Schuschny (2007), this article treats pollutants (CO_2 emissions in this case) not as a factor to be minimized but as an undesirable output or externality. This different approach is taken because the main goal of this paper is to carry out an economic growth accounting exercise (whence the choice of traditional production factors such as capital and labour and of an output, GDP, that is also standard in this type of literature) from a broader perspective that also considers negative environmental effects associated with this economic growth.

To conclude this section, we should emphasize how important it has been for the present analyses to be set within the context of a region like Latin America and a very significant time period encompassing the "lost decade", the Washington Consensus and the recovery.

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[5] This approach has some advantages: (i) no information on the cost of abatement technologies is required, (ii) there is no need to investigate actual abatement strategies and (iii) the measure captures the abatement effect for more than one pollution problem.

III

The efficiency analysis methodology

1. Measuring production efficiency and technical change: the Malmquist index

The analysis proposed in this investigation has required estimation of Malmquist TFP indices, and the methodology followed has been that proposed by Färe and others (1994) whereby the change in TFP between two time periods is measured by calculating the quotient of the distances of each data point in relation to a common technology. Given a technology in period t, the change in the (output-oriented) Malmquist TFP index between period s (the base period) and period t can be expressed as:

$$m_0^t\left(q_s, x_s, q_t, x_t\right) = \frac{d_0^t\left(q_t, x_t\right)}{d_0^t\left(q_s, x_s\right)} \quad (1)$$

Or alternatively, using the technology of reference in period s, the index can be defined as:

$$m_0^s\left(q_s, x_s, q_t, x_t\right) = \frac{d_0^s\left(q_t, x_t\right)}{d_0^s\left(q_s, x_s\right)} \quad (2)$$

In equations (1) and (2), the notation $d_0^s\left(q_t, x_t\right)$ represents the distance from the period t observation to the period s technology, in the terms already defined. Thus, a value for (m_0) that is greater than 1 indicates positive growth in TFP from period s to period t, while a value below one indicates a drop in TFP.

As Färe, Grosskopf and Roos (1998) have argued, these two indices are only equivalent if the technology is Hicks-neutral, i.e., if the distance functions of output can be represented as $d_0^t\left(q_t, x_t\right) = A\left(t\right) d_0\left(q_t, x_t\right)$ for any t.

To avoid imposing this constraint or arbitrarily choosing one of the two technologies, the Malmquist TFP index is often defined as the geometric mean of these two indices, in the sense of Fisher (1992) and Caves, Christensen and Diewert (1982). In other words:

$$m_0^s\left(q_s, x_s, q_t, x_t\right) = \left[\frac{d_0^s\left(q_t, x_t\right)}{d_0^s\left(q_s, x_s\right)} \text{x} \frac{d_0^t\left(q_t, x_t\right)}{d_0^t\left(q_s, x_s\right)}\right]^{\frac{1}{2}} \quad (3)$$

The distance functions in this productivity index can be reorganized to show that the above is equivalent to the product of the technical efficiency change index and the technical change index:

$$m_0^s\left(q_s, x_s, q_t, x_t\right) = \frac{d_0^t\left(q_t, x_t\right)}{d_0^s\left(q_s, x_s\right)} \left[\frac{d_0^s\left(q_t, x_t\right)}{d_0^t\left(q_t, x_t\right)} \text{x} \frac{d_0^s\left(q_s, x_s\right)}{d_0^t\left(q_s, x_s\right)}\right]^{\frac{1}{2}} \quad (4)$$

In the above equation, the quotient outside the brackets measures the change in the Farrell output-oriented technical efficiency measure between period s and period t. The remainder of the index in equation (4) is a technical change measure, i.e., the geometric mean of the technology change between the two periods, evaluated at (x_t) and also at (x_s).

Färe, Grosskopf and Roos (1994) suggest that technical efficiency change be broken down into two components represented by "scale efficiency and pure technical efficiency".[6] This decomposition involves adopting the efficiency change measure in the first term of equation (4)[7] and separating it into a pure efficiency change component and a scale efficiency change component, as expressed respectively by the following equations:

$$\text{Pure efficiency change} = \frac{d_{0v}^t\left(q_t, x_t\right)}{d_{0v}^s\left(q_s, x_s\right)} \quad (5)$$

Scale efficiency change =

$$\left[\frac{d_{0v}^t\left(q_t, x_t\right) / d_{0c}^t\left(q_t, x_t\right)}{d_{0v}^t\left(q_t, x_t\right) / d_{0c}^t\left(q_s, x_s\right)} \text{x} \frac{d_{0v}^s\left(q_t, x_t\right) / d_{0c}^s\left(q_t, x_t\right)}{d_{0v}^s\left(q_t, x_t\right) / d_{0c}^s\left(q_s, x_s\right)}\right]^{\frac{1}{2}} \quad (6)$$

[6] This is only possible when the distance functions of the equations taken are estimated for a technology with constant returns to scale.
[7] In this case, it means assuming a quotient of two distance functions with constant returns to scale.

The scale efficiency change component of equation (6) is actually the geometric mean of two scale efficiency change measures, the first relating to the technology of period t and the second to the technology of period s.

Data envelopment analysis (DEA) will be used to estimate the above components.[8] The essence of this technique lies in the definition of an efficient frontier as a point of reference for evaluating the variations observed in the performance of different production units (countries in this case).[9] The DEA method does not create assumptions about functional forms, being a non-parametric performance evaluation approach; however, it does allow different inputs and outputs to be incorporated, something that is essential to the aims of the present study and the principal justification for its employment.

One of the major advantages of DEA is that it can be used to work with multiple inputs and outputs that have different units, while it does not create a need to consider full employment of production factors or require explicit functional forms. As for the drawbacks, the method is sensitive to measurement errors (the reference points are highly productive) and does not permit easy application of statistical tests, and relative rather than absolute inefficiencies are identified (Schuschny, 2007, pp. 22-23).

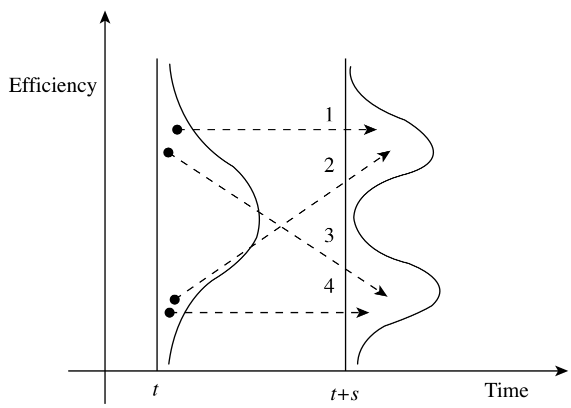
2. The efficiency distribution dynamic

To understand the dynamic of the whole efficiency distribution, the intention is to use stochastic kernel estimators in much the same way as Birchenal and Murcia (1997) employed them to analyse convergence.

Figure 1 illustrates this approach, showing a possible distribution of efficiency in two time periods, t and $t+s$. The distribution in period t indicates that there is an average efficiency level shared by most of the economies considered and that there are few with extremely high or low efficiency. By contrast, $t+s$ has grouped the most and least efficient economies to create two clearly differentiated groups, while the medium-efficiency groups have disappeared.

FIGURE 1

Change in the efficiency distribution



Source: prepared on the basis of J.A. Birchenal and G.E. Murcia, "Convergencia regional: una revisión del caso colombiano", Archivos de macroeconomía, No. 69, Bogotá, D.C., National Planning Department, 1997.

The arrows in figure 1 show the internal dynamic of the distribution. For example, arrows 2 and 3 indicate the "mobility" of the economies within the distribution and arrows 1 and 4 the "persistence" of the economies that keep their original position between periods t and $t+s$.

To analyse this dynamic without distorting it, the idea is to divide the efficiency space into an infinite number of regions or continuum. In this case, the corresponding transition probability matrix will tend towards a continuum of rows and columns, becoming a stochastic kernel.

[8] Schuschny (2007) gives a detailed presentation of this technique and an excellent review of the concepts of productivity and efficiency.

[9] In other words, the starting assumption when applying this technique in the case before us is that all the countries in the sample ought to be able to function at an optimal level of efficiency, determined by the efficient countries included therein. In the specialist literature, these efficient countries are called "peer countries" and are the ones that determine the efficiency frontier, so that the distance to the efficient frontier represents the measure of efficiency or the lack thereof.

IV

Empirical data and findings

To apply this methodology to the analysis of productivity (TFP) growth in a set of Latin American countries between 1980 and 2004, use has been made of data on GDP (expressed in constant 2000 dollars) and CO_2 emissions (kt) as the main externality.[10] As for inputs, these are represented by the total workforce and gross capital formation (expressed in constant 2000 dollars). The data concerned were generated by the World Bank in collaboration with other international agencies.[11]

Table I of the statistical appendix presents a descriptive analysis of the basic statistics of the variables used for the 18 Latin American countries in the sample.

These variables have been used to estimate the change in TFP and its decomposition (efficiency change, technological change, pure efficiency change and scale efficiency change) for the set of countries considered in the sample. This estimate has been produced by a traditional approach (which we shall call normal), in which the only output considered is GDP, plus an alternative approach (which we shall call environmental) incorporating an undesirable additional output, represented by CO_2 emissions, which accompany this growth.

1. TFP and efficiency analysis

The analysis starts by considering the decomposition of annual TFP growth summarized in table 1. It first presents the results of the change experienced over the period (1980-2004), while also producing estimates of change in different subperiods with a view to providing greater information on the behaviour of these variables.[12]

Broadly speaking, there are no great differences in the magnitudes estimated using the two indices, with mean TFP falling slightly over the whole period in both cases (when TFP is decomposed and the normal index is used, this reduction is apparently explained by the decline in technical efficiency, pure technical efficiency and scale efficiency; when the environmental index is used, conversely, technological change is what accounts for this diminution of TFP). Although the final results are not disparate, the preliminary conclusions and thence policy and incentive recommendations may be different depending on what TFP measure is used.

When the full period is analysed, the 1981-1982 and 1982-1983 subperiods prove to be times of TFP growth (about 10%) in both scenarios, although growth is higher for the environmental index, especially in the 1981-1982 subperiod. The 1986-1987 subperiod is the time of greatest decline in TFP (about 7%) for both indices, apparently indicating a negative evolution in the main macroeconomic indicators during what has come to be called the "lost decade". In the 1990s, TFP declined substantially during the 1996-1997 subperiod and recovered in the 1998-1999 subperiod. This seems to coincide with the financial and banking crises and the recovery from them in Latin America and worldwide.

During subperiods of both rising and falling productivity, the greatest influence comes from technological change or, what comes to the same thing, the variation of technological change is much more pronounced than the variation of efficiency change.

For a more thorough analysis, table 2 shows the decomposition of TFP growth for each of the countries considered and for all of them as a group. It transpires that there are no great differences in the magnitudes estimated with the two indices employed much as with the data of table 1. There are some countries whose performance calls for comment, however. TFP in the Plurinational State of Bolivia shows a small mean increase when the normal index is used but declines when the environmental index is used.

In the case of Ecuador and the Bolivarian Republic of Venezuela, the situation is as follows. In Ecuador, TFP rises in both scenarios, but the environmental index shows a clear upward trend with a mean |rate of 2.3% for the whole period, well in excess of the GDP measure, apparently indicating a major efficiency effort by Ecuador when environmental externalities

[10] CO_2 emissions derive from fossil fuel use and cement production. We include CO_2 produced during the consumption of fuels in a solid, liquid or gaseous state.

[11] The authors especially wish to thank these institutions for their generosity in providing access to the World Bank World Development Indicators and Global Development Finance databases.

[12] A simple interpretation of the results is to consider values over 1 as representing improved growth and values under 1 as a deterioration in growth.

TABLE 1

Decomposition of TFP growth: mean annual increase, 1980-2004

Period	Malmquist index summary (normal index)					Malmquist index summary (environmental index)				
	EFFCH	TECHCH	PECH	SECH	TFPCH	EFFCH	TECHCH	PECH	SECH	TFPCH
1980-1981	1.032	0.958	0.983	1.05	0.989	1.023	0.972	1.007	1.016	0.995
1981-1982	0.959	1.141	0.96	0.999	1.093	0.961	1.157	0.977	0.983	1.112
1982-1983	0.942	1.169	0.958	0.983	1.101	0.918	1.207	0.911	1.008	1.108
1983-1984	1.038	0.938	1.061	0.978	0.974	1.117	0.871	1.097	1.018	0.973
1984-1985	0.955	1.05	0.977	0.978	1.003	0.99	1.006	1.02	0.971	0.997
1985-1986	1.028	0.951	1.037	0.991	0.977	0.986	0.971	0.977	1.009	0.957
1986-1987	0.965	0.956	0.986	0.979	0.923	0.986	0.943	1	0.986	0.93
1987-1988	0.861	1.179	0.922	0.934	1.016	0.906	1.141	0.945	0.959	1.035
1988-1989	0.916	1.123	0.836	1.095	1.029	0.807	1.287	0.789	1.022	1.038
1989-1990	1.081	0.895	1.182	0.914	0.967	1.03	0.947	1.146	0.899	0.975
1990-1991	1.332	0.713	1.153	1.155	0.95	1.348	0.705	1.164	1.158	0.95
1991-1992	0.976	0.958	0.998	0.978	0.935	1.068	0.884	1.043	1.024	0.944
1992-1993	0.992	0.98	0.97	1.023	0.971	0.911	1.076	0.932	0.977	0.981
1993-1994	0.77	1.255	0.888	0.868	0.966	0.759	1.274	0.873	0.869	0.966
1994-1995	1.189	0.823	1.096	1.085	0.978	1.188	0.818	1.103	1.076	0.971
1995-1996	0.962	1.086	1.01	0.952	1.044	0.963	1.09	1.019	0.945	1.049
1996-1997	1.078	0.855	1.029	1.047	0.922	1.214	0.76	1.09	1.113	0.922
1997-1998	1.047	0.909	1.019	1.028	0.952	1.058	0.908	1.035	1.022	0.96
1998-1999	0.957	1.155	1.035	0.925	1.105	0.91	1.207	0.998	0.912	1.098
1999-2000	1.002	1.014	0.955	1.05	1.016	1.041	0.963	1.002	1.039	1.002
2000-2001	0.98	1.028	0.954	1.027	1.008	1.014	0.994	0.968	1.047	1.008
2001-2002	0.843	1.205	0.874	0.964	1.016	0.87	1.164	0.935	0.93	1.012
2002-2003	1.12	0.911	1.127	0.994	1.02	0.988	1.043	0.966	1.023	1.031
2003-2004	1.035	0.945	0.999	1.036	0.978	1.126	0.862	1.082	1.041	0.971
Mean	0.996	1	0.997	0.999	0.996	1	0.998	1	1	0.998

Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

TFP: total factor productivity.
EFFCH: technical efficiency change.
TECHCH: technological change.
PECH: pure technical efficiency change.
SECH: scale efficiency change.
TFPCH: total factor productivity change.

are taken into account. In the Bolivarian Republic of Venezuela, meanwhile, although TFP declines in both scenarios, the trend is much better when emissions are included, as TFP falls by 2.8% when measured by GDP alone but by just 0.7% when the environmental index is included.

The TFP breakdown shows a behaviour pattern different to that discussed in table 1. In the case of Ecuador, some of the improvement can be seen to be due especially to the efficiency change, which in turn is mainly accounted for by the pure technical efficiency change in the case of the environmental index, whereas when the normal index is taken it is essentially technical progress that accounts for the (much smaller) positive change. In the case of the Bolivarian Republic of Venezuela, the conclusion is the same: the decline in the normal index is explained by both efficiency and technology, whereas when the environmental index is used, efficiency (pure efficiency) compensates for a decline in technical change.

In the case of the Dominican Republic, the situation is also fairly clear: in the environmental index, the good performance of (pure) technical efficiency helps to offset the decline in technical change, whereas in the normal index the two perform very much alike.

In summary, it can be said that the results obtained for the whole of the period considered are generally quite consistent when the two measures are compared (with the exception already mentioned of the Plurinational State of Bolivia). The countries where TFP increases most are Uruguay (which scores 1.015 on both indices) and Ecuador (1.006 on the normal index and 1.023 on the environmental index); TFP declines

TABLE 2

Decomposition of TFP growth by country: mean annual increase, 1980-2004

Country	Malmquist index summary (normal index)					Malmquist index summary (environmental index)				
	EFFCH	TECHCH	PECH	SECH	TFPCH	EFFCH	TECHCH	PECH	SECH	TFPCH
Argentina	1	0.997	1	1	0.997	1	0.998	1	1	0.998
Bolivia (Plur. St. of)	1.007	0.995	1	1.007	1.001	1	0.996	1	1	0.996
Brazil	0.994	1.009	1	0.994	1.003	0.999	1.001	1	0.999	1
Chile	0.999	1.004	0.999	1	1.002	0.997	1.002	1	0.997	1
Colombia	0.997	1	0.996	1.001	0.997	0.995	1.001	0.995	1	0.996
Costa Rica	0.985	1.004	0.989	0.996	0.989	0.985	1.002	0.99	0.995	0.986
Dominican Republic	0.998	0.997	1	0.998	0.996	1.005	0.992	1.004	1.001	0.997
Ecuador	1.001	1.006	1.005	0.996	1.006	1.013	1.009	1.012	1.001	1.023
El Salvador	0.987	0.998	0.987	1	0.986	0.99	0.997	0.99	1	0.987
Guatemala	0.991	0.998	0.991	1	0.989	0.997	0.995	0.995	1.002	0.992
Honduras	0.99	0.998	0.982	1.009	0.988	1	0.994	0.994	1.006	0.994
Mexico	1.006	0.99	1	1.006	0.995	1.004	0.984	1	1.004	0.989
Nicaragua	0.997	0.991	1	0.997	0.988	1	0.995	1	1	0.994
Panama	0.994	1.009	1	0.994	1.003	0.995	1.006	1	0.995	1.001
Paraguay	1.009	1.002	1.012	0.996	1.011	1.011	1.003	1.014	0.997	1.014
Peru	0.994	0.997	0.999	0.995	0.991	0.998	0.993	1	0.999	0.991
Uruguay	1.006	1.009	1.002	1.004	1.015	1.006	1.01	1.002	1.004	1.015
Venezuela (Bol. Rep. of)	0.984	0.989	0.986	0.997	0.972	1	0.993	1	1	0.993
Mean	0.996	1	0.997	0.999	0.996	1	0.998	1	1	0.998

Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

TFP: total factor productivity.
EFFCH: technical efficiency change.
TECHCH: technological change.
PECH: pure technical efficiency change.
SECH: scale efficiency change.
TFPCH: total factor productivity change.

in the Bolivarian Republic of Venezuela, meanwhile, with a score of 0.972 on the normal index and a more moderate 0.993 on the environmental index.

In conclusion, it can be said that the performance of the region has been rather weak as regards TFP growth over the years observed, from the standpoint of both technological change and technical efficiency, although the latter plays a far more important role when the environmental index is used. This comes out particularly clearly in the case of countries further from the mean.

2. Aggregate analysis of technical efficiency in Latin America

The use of non-parametric techniques to analyse TFP growth yields information on the past evolution of technical efficiency in Latin America (see figure 2). Comparing the magnitudes obtained with the two indices reveals a very similar trend over time, although on the whole the environmental index yields somewhat higher figures than the normal index.

Figure 2 shows a number of stages in the trend of this variable, with the two measures coinciding in 1989 and 1994 following large declines in TFP. Without setting out to perform a detailed analysis, it is possible to say that the first change of trend coincides with the end of the decade and the application of Washington Consensus policies, while the change of trend in 1994 might be explained by expansionary policies culminating in the 1995 financial crisis. Another change of trend occurs in 2002, when the performance of Latin America coincides with stable macroeconomic indicators in most of the region. Another point is that the difference between the environmental index and the normal one is greater in the 1990s than in the 1980s, suggesting that the emissions efficiency effort became much more substantial as a result of certain regulations, coinciding with a greater concern to improve environmental standards, although it should be borne in mind that this improvement (or lesser deterioration) was due more to technical efficiency (especially pure technical efficiency) than to technical progress.

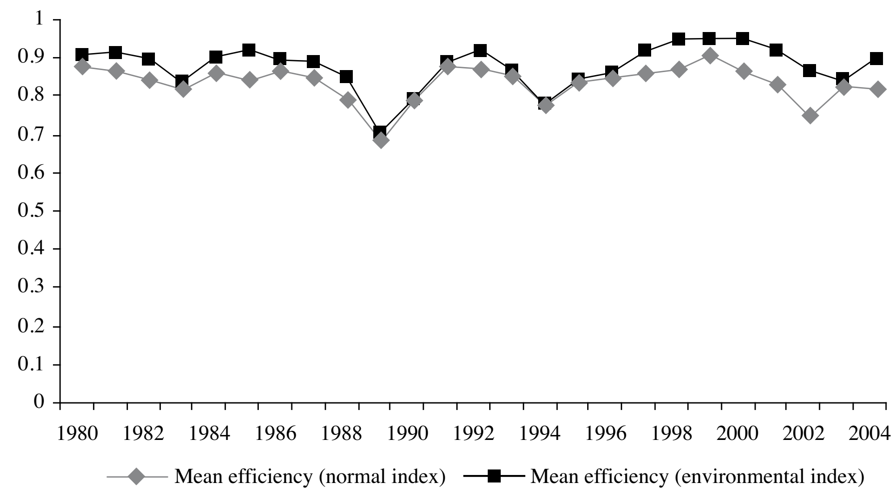
With the evolution of technical efficiency analysed, it is interesting to consider whether this has favoured the assimilation of technology that already exists in the countries closest to the frontier (convergence) and thence efficiency convergence.

To ascertain the degree of dispersion, figure 3 shows σ-convergence calculated from the standard deviation of the efficiency indicator logarithm.

Figure 3 shows that there were marked changes of trend in the evolution of technical efficiency during those years. When the magnitudes obtained with the two indices are compared, the trends once again prove very similar over time, although in terms of convergence the environmental index yields slightly higher figures than the normal index. This trend reflects stages of improving efficiency in 1983-1987, 1989-1992 and 1994-1998 that tended to reduce the differences between countries. Between those periods, efficiency improvements in the countries closest to the frontier widened the inequalities again.

FIGURE 2

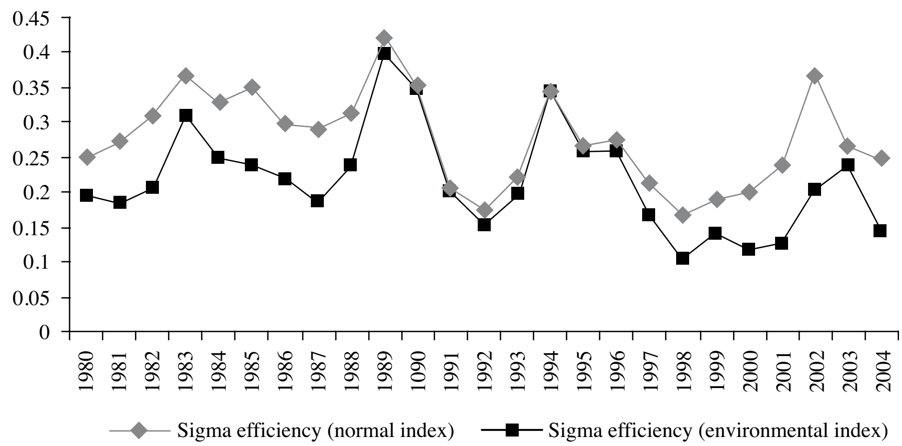
Annual change in the mean efficiency index, 1980-2004



Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

FIGURE 3

Annual change in σ-convergence of the mean efficiency index, 1980-2004



Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

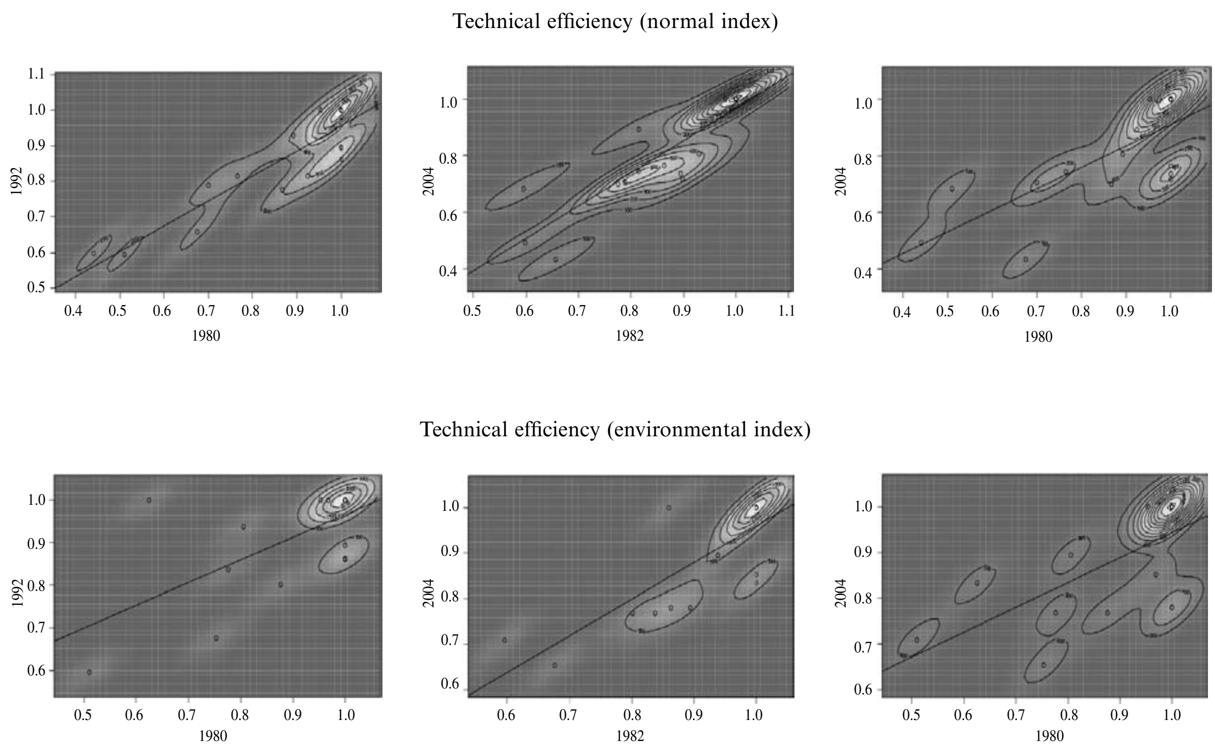
An important point is that convergence is greater on the environmental index than on the normal index over the whole period and that in the periods of greatest convergence (1987, 1992, 1998), if an interval of five years is taken (two years before and two after), the difference between environmental and normal convergence widens. Consequently, the greater the level of convergence, the greater the difference between the indices, apparently indicating that convergence takes place more easily on the environmental convergence index than on the normal convergence index.

Considering not just the convergence measures but also the distribution of technical efficiency (change in the form of the distribution and distributional dynamic within that distribution) (Quah, 1993 and 1997),[13] the dynamic of the technical efficiency distribution, based on estimation of kernel density functions as proposed by Lucy, Aykroyd and Pollard (2002), will now be presented. With the specifications noted, figure 4 shows convergence (divergence) and persistence (mobility) in the level of technical efficiency attained by the Latin American countries during the partial periods 1980-1992, 1992-2004 and 1980-2004.

[13] Quah (1997) argues that convergence coalitions or clubs can form endogenously across all countries, and the different convergence dynamics will depend on the initial distribution of country characteristics.

FIGURE 4

Efficiency distribution dynamic: kernel density functions



Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

To aid interpretation of this chart, one strategy is to illustrate the extreme cases in which the whole distribution variously presents mobility, persistence and convergence. In this situation, persistence would be reflected in the whole distribution maintaining its characteristics between periods t and $t+s$, with efficient countries remaining efficient and inefficient ones remaining inefficient. In the case of mobility, we would have a complete reversal of the countries' starting conditions, so that those deemed inefficient in period t would become efficient in period $t+s$, while those deemed efficient would become inefficient.[14] Lastly, if the distribution clusters around a plane parallel to the t axis over time, whereas efficiency was distributed normally in the whole of the cross-section to begin with (i.e., with grouping around the value $t+s=1$), the distribution is said to be converging on equality in the countries' efficiency levels.

While it is hard to generalize, given that the behaviour of the set of countries is quite heterogeneous over the period considered, what seems to come out is a pattern of mobility as regards the efficiency level attained over the years, with a degree of convergence upon higher efficiency levels (this is reflected in the increasing proximity of the dots marking out the different level curves to the axis drawn across the graphs).

When we consider the normal technical efficiency index over the whole period, we detect a pattern of convergence with a degree of polarization towards higher technical efficiency values. Distinguishing between subperiods, we observe mobility in the distribution, especially in the 1992-2004 period.

When considering the environmental technical efficiency index over the whole period, meanwhile, we find a pattern of convergence with polarization towards higher technical efficiency values although, by contrast with the previous case, this polarization is not strongly marked. Distinguishing between periods, we also observe greater mobility in the distribution in the 1992-2004 period. To conclude, it is interesting to observe how the countries in the upper part of the distribution do not clearly converge upon equality in efficiency levels, especially if the environmental technical efficiency index is used.

3. Disaggregated analysis of technical efficiency in Latin America at the country level

To obtain individual information on the technical efficiency of each of the 18 Latin American countries analysed, tables II and III of the statistical appendix give the normal and environmental indices, respectively, for each of the 25 years considered in the period from 1980 to 2004. From these tables it can be seen that Argentina is the country at the efficiency frontier throughout the period, so that movement towards the frontier in the remaining countries is going to be related to the technological development of Argentina.

From the efficiency estimates arrived at by year and by country for the indices considered, it is possible to determine whether the two proposed measures actually present significant differences at the country level. The Wilcoxon comparison is proposed as a non-parametric approach for paired samples.[15]

The results of the Wilcoxon comparison presented in table 3 allow us to infer that in the cases of the Plurinational State of Bolivia, the Dominican Republic and Ecuador the hypothesis of both indices producing the same technical efficiency estimates during the years considered is rejected.

[14] According to Birchenal and Murcia (1997), a simple way of appreciating these things is to observe whether the outlines of the distribution are concentrated on the 45 degree line marked on the t–$t+s$ plane (in this case, the distribution persists during the periods). If the outlines of the distribution are concentrated on a line perpendicular to the 45 degree line, there is total mobility within the distribution.

[15] In the present case, there are n pairs of values (x_i, y_i) that can be taken as a variable measured in each subject by two different methods. This is done by taking all the differences between the sample pairs, ordering their absolute values from lowest to highest and ranking them. Lastly, each rank is associated with the sign of the corresponding difference and the W statistic is the lower of the sum of positive ranks and the sum of negative ranks (H_o being rejected if W is too small).

TABLE 3

Wilcoxon comparison of differences between normal and environmental technical efficiency (TE) measures by country, 1980-2004

	Normal TE	Environmental TE	Normal TE	Environmental TE	Wilcoxon statistical comparison	P value
Argentina	-	-	-	-	-	-
Bolivia (Plur. St. of)	1.0	1.0	20.9	30.1	427.5	0.00613147[a]
Brazil	-	-	-	-	-	-
Chile	0.833	0.938	22.4	28.6	390.0	0.133593
Colombia	0.78	0.852	23.44	27.56	364.0	0.321335
Costa Rica	0.869	0.882	24.54	26.46	336.5	0.640475
Dominican Republic	0.704	0.847	18.62	32.38	484.5	0.000874616[a]
Ecuador	0.481	0.735	17.38	33.62	515.5	0.0000851074[a]
El Salvador	0.968	0.968	25.08	25.92	323.0	0.836961
Guatemala	0.814	0.832	24.36	26.64	341.0	0.586772
Honduras	0.566	0.679	22.76	28.24	381.0	0.182123
Mexico	-	-	-	-	-	-
Nicaragua	1.0	1.0	24.5	26.5	337.5	0.580007
Panama	-	-	-	-	-	-
Paraguay	0.56	0.564	24.94	26.06	326.5	0.793175
Peru	0.719	0.722	25.02	25.98	324.5	0.823365
Uruguay	-	-	-	-	-	-
Venezuela (Bol. Rep. of)	-	-	-	-	-	-

Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

[a] 95.0% confidence level.

V

Conclusions

This study has set out to provide evidence to determine whether consideration of efficiency and productivity measures incorporating environmental elements produces significant differences in the assessment of the region's economies. It began with a discussion of the importance of using these measures in the analysis of economic growth and supplementing this analysis with measures that take account of environmental externalities in pursuit of the goals of efficiency and convergence.

Accordingly, TFP growth in a set of Latin American countries between 1980 and 2004 was analysed, with the construction of Malmquist productivity indices incorporating environmental factors calculated using non-parametric linear programming techniques.

This approach has enabled us to obtain information on the behaviour of each of the Latin American economies in the light of the goal not just of maximizing a desirable output like GDP, but also of minimizing externalities such as environmental pollution associated with this growth process.

Specifically, it has been observed that the incorporation of environmental factors in the measurement of efficiency and productive change means that estimates for some countries in the region improve significantly when compared with those obtained by more traditional methods that only measure the magnitude of growth in terms of GDP generated.

It is also important to highlight the difference between "pure technical efficiency" and "technical progress" when considering modifications in TFP calculated with and without the environmental variable.

We believe that this new perspective incorporates an element of sustainability which it is important to consider when the region's efficiency and productivity growth are assessed and the relevant policies decided upon.

These measures are supplemented by a σ-convergence analysis, allowing the behaviour of the two measures (environmental and normal indices) to be analysed in a way that reflects the evolution of efficiency convergence. The additional inclusion of stochastic kernel analyses has made it possible to conclude that convergence patterns are different in the two cases.

Lastly, we conclude with a reflection on the concept of environmental sensitivity, using some earlier ideas set forth in studies such as those of Prieto and Zofío (1996), which model the effects of environmental regulation as technological frontiers constructed using non-parametric production functions estimated by DEA, permitting the development of what could be called an environmental efficiency sensitivity index (EESI):

$$EESI = \frac{E_A}{E_N} \qquad (7)$$

In this index, environmental efficiency E_A is measured as the capacity to increase desired outputs such as gross national product (GNP) and reduced unwanted ones (CO_2), and normal efficiency E_N as the capacity to increase desired outputs (GNP) while ignoring unwanted ones.

The EESI shows the effect on the efficiency level when unwanted outputs are ignored. Table IV of the statistical appendix reveals that the index often takes a value of 1, indicating that normal and environmental efficiency are the same, so that ignoring the impact of negative externalities has not affected the measurement of efficiency using the two approaches suggested.

A value over 1 for the index, however, indicates that ignoring negative externalities leads to very different normal and environmental efficiency results (and the higher the value, the greater the difference). An example of a large disparity between the two proposed efficiency measures is provided by Ecuador, where the EESI takes values in excess of 2 in 1982, 1984 and 2002.

(Original: Spanish)

STATISTICAL APPENDIX

TABLE I

Basic output and input statistics by country, 1980-2004

Country	GDP (in constant 2000 dollars)				CO_2 emissions (kt)				Gross capital formation (constant 2000 dollars)				Workforce, total			
	Mean	Standard deviation	Maximum	Minimum	Mean	Standard deviation	Maximum	Minimum	Mean	Standard deviation	Maximum	Minimum	Mean	Standard deviation	Maximum	Minimum
Argentina	$2.33x10^{10}$	$3.85x10^{10}$	$2.97x10^{11}$	$1.82x10^{11}$	117 898.1	13 100.74	141 659.2	97 582.32	$3.79x10^{10}$	$9.46x10^{9}$	$5.65x10^{10}$	$2.14x10^{10}$	13 669 895	2 429 348	17 935 785	9 994 149
Bolivia (Plur. St. of)	$6.72x10^{9}$	$1.41x10^{9}$	$9.36x10^{9}$	$5.07x10^{9}$	6 413.327	2 175.794	10 315.01	3 772.89	$1.03x10^{9}$	$3.93x10^{8}$	$2.02x10^{9}$	$4.98x10^{9}$	2 790 266	662 825.5	4 030 275	1 904 508
Brazil	$5.44x10^{11}$	$9.22x10^{10}$	$7.17x10^{11}$	$4.02x10^{11}$	245 350.2	58 048.56	331 856.8	170 399.1	$8.97x10^{10}$	$1.83x10^{10}$	$1.18x10^{11}$	$5.22x10^{10}$	68 240 356	14 048 140	90 112 347	46 383 610
Chile	$5.19x10^{10}$	$2.12x10^{10}$	$8.82x10^{10}$	$2.54x10^{10}$	39 921.13	15 394.37	63 311.29	21 322.32	$1.05x10^{10}$	$5.99x10^{9}$	$2.02x10^{10}$	$2.25x10^{9}$	5 199 154	881 040.1	6 440 791	3 764 594
Colombia	$6.9x10^{10}$	$1.58x10^{10}$	$9.44x10^{10}$	$4.6x10^{10}$	54 977.97	7 340.267	67 882.72	39 816.81	$1.26x10^{10}$	$3.55x10^{9}$	$2.03x10^{10}$	$8.87x10^{9}$	15 005 980	3 938 424	21 624 471	8 767 824
Costa Rica	$1.14x10^{10}$	$3.74x10^{9}$	$1.84x10^{10}$	$6.77x10^{9}$	3 943	1 506.379	6 468.858	1 999.998	$2.11x10^{9}$	$1.02x10^{9}$	$4.12x10^{9}$	$7.12x10^{8}$	1 270 419	324 250.8	1 890 374	803 514
Dominican Republic	$1.37x10^{10}$	$4.34x10^{9}$	$2.14x10^{10}$	$8.77x10^{9}$	13 064.6	5 457.289	21 476.17	6 080.58	$2.59x10^{9}$	$1.26x10^{9}$	$4.91x10^{9}$	$1.18x10^{9}$	2 912 533	598 930.2	3 922 804	1 970 477
Ecuador	$1.42x10^{10}$	$2.48x10^{9}$	$1.96x10^{10}$	$1.09x10^{10}$	20 042.91	3 980	29 241.73	13 428.56	$3.95x10^{9}$	$7.24x10^{8}$	$5.65x10^{9}$	$2.49x10^{9}$	4 141 844	1 154 034	6 094 389	2 481 790
El Salvador	$1.01x10^{10}$	$2.48x10^{9}$	$1.42x10^{10}$	$7.3x10^{9}$	3 835.894	1 748.742	6 373.62	1 582.416	$1.51x10^{9}$	$6.41x10^{8}$	$2.45x10^{9}$	$7.01x10^{8}$	2 054 709	347 329.5	2 652 950	1 573 128
Guatemala	$1.5x10^{10}$	$3.57x10^{9}$	$2.17x10^{10}$	$1.12x10^{10}$	6 415.232	2 821.467	12 208.78	3 146.517	$2.39x10^{9}$	$9.12x10^{8}$	$4.08x10^{9}$	$1.24x10^{9}$	3 037 231	514 338.6	4 007 775	2 294 138
Honduras	$5.72x10^{9}$	1.33E+09	$8.41x10^{9}$	$4.05x10^{9}$	3 501.681	1 661.561	7 608.051	1 761.903	$1.36x10^{9}$	$5.85x10^{8}$	$2.36x10^{9}$	$5.22x10^{8}$	1 804 894	478 641.7	2 780 670	1 151 767
Mexico	$4.55x10^{11}$	8.76E+10	$6.18x10^{11}$	$3.46x10^{11}$	38 6262.6	4 4395.27	437 629.6	305 871.5	$9.52x10^{10}$	$2.66x10^{10}$	$1.39x10^{11}$	$5.8x10^{10}$	31 956 418	6 875 134	41 947 700	20 949 972
Nicaragua	$3.38x10^{9}$	$4.73x10^{8}$	$4.41x10^{9}$	$2.81x10^{9}$	2 719.997	769.3747	4 003.659	1 542.123	8.96E+08	$2.46x10^{8}$	$1.43x10^{9}$	$4.89x10^{8}$	1 473 547	297 830.1	2 005 893	1 048 795
Panama	$8.91x10^{9}$	$2.19x10^{9}$	$1.34x10^{10}$	$6.19x10^{9}$	4 202.047	1 389.2	6 996.33	2 457.873	$1.75x10^{9}$	$8.13x10^{8}$	$3.09x10^{9}$	$3.13x10^{8}$	1 010 102	240 724.1	1 429 199	650 672.8
Paraguay	$6.17x10^{9}$	$1.13x10^{9}$	7.8E+09	$4.51x10^{9}$	2 851.133	1 138.477	4 498.164	1 373.625	$1.41x10^{9}$	$3.01x10^{8}$	$2x10^{9}$	$9.55x10^{8}$	1 841 108	482 349.4	2 710 230	1 122 132
Peru	$4.54x10^{10}$	$7.53x10^{9}$	$6.13x10^{10}$	$3.61x10^{10}$	24 014.04	3 109.941	31 465.17	19 113.53	$9.13x10^{9}$	$2.44x10^{9}$	$1.31x10^{10}$	$5.02x10^{9}$	9 061 440	2 179 845	12 711 846	5 574 149
Uruguay	$1.7x10^{10}$	$2.84x10^{9}$	$2.16x10^{10}$	$1.25x10^{10}$	4 585.343	789.5953	6 161.166	3 139.191	$2.39x10^{9}$	$7.42x10^{8}$	$3.68x10^{9}$	$1.23x10^{9}$	1 422 088	166 220.8	1 658 579	1 145 160
Venezuela (Bol. Rep. of)	$1.02x10^{11}$	$1.36x10^{10}$	$1.21x10^{11}$	$8.25x10^{10}$	133 977.7	33 705.71	182 325.8	87 681.23	$1.8x10^{10}$	$6.95x10^{9}$	$3.22x10^{10}$	$7.87x10^{9}$	8 100 614	2 181 901	12 389 620	4 995 009

Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

TABLE II

Technical efficiency estimates by year and country: normal index, 1980-2004

Country	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Argentina	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Bolivia (Plur. St. of)	1	1	1	1	1	0.558	1	1	0.626	0.566	0.988	0.943	0.98	0.994	1	1	1	0.86	0.768	0.93	0.962	1	0.663	1	1
Brazil	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Chile	0.924	0.886	1	1	0.997	0.966	1	0.939	0.917	0.608	0.606	0.774	0.815	0.677	0.68	0.673	0.687	0.721	0.749	0.833	0.748	0.816	0.947	0.912	0.893
Colombia	0.892	0.85	0.696	0.554	0.613	0.755	0.775	0.87	0.827	0.61	0.59	0.939	0.93	0.683	0.504	0.557	0.604	0.843	0.918	1	1	1	0.685	0.78	0.806
Costa Rica	1	1	1	1	1	1	0.829	0.753	0.81	0.847	0.848	0.83	0.863	0.869	0.895	1	1	0.994	0.807	1	0.889	0.749	0.855	0.858	0.764
Dominican Republic	0.7	0.85	0.801	0.649	0.86	0.787	0.701	0.681	0.726	0.487	0.553	0.862	0.789	0.799	0.651	0.814	0.719	0.778	0.745	0.622	0.604	0.582	0.449	0.591	0.704
Ecuador	0.441	0.481	0.4	0.348	0.416	0.424	0.45	0.438	0.5	0.316	0.326	0.525	0.598	0.541	0.373	0.499	0.503	0.6	0.584	0.974	0.692	0.487	0.311	0.459	0.493
El Salvador	1	1	1	0.968	1	1	1	1	0.794	0.511	0.901	1	0.894	0.893	0.714	0.803	1	1	1	1	0.884	0.76	0.589	0.653	0.736
Guatemala	0.867	0.815	0.728	0.71	0.814	0.874	0.949	0.802	0.84	0.63	0.77	0.875	0.776	0.89	0.706	0.934	1	1	0.915	0.85	0.779	0.72	0.515	0.641	0.699
Honduras	0.675	1	1	1	1	1	1	1	0.489	0.398	0.596	0.663	0.657	0.536	0.467	0.549	0.56	0.566	0.703	0.559	0.547	0.53	0.399	0.466	0.434
Mexico	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Nicaragua	1	0.463	0.447	0.367	0.365	0.33	0.395	0.426	0.353	0.304	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Panama	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Paraguay	0.51	0.51	0.504	0.478	0.51	0.482	0.528	0.53	0.493	0.361	0.451	0.56	0.595	0.633	0.507	0.622	0.581	0.578	0.913	1	1	0.794	0.779	0.767	0.683
Peru	0.765	0.693	0.621	0.637	0.801	1	0.862	0.816	0.821	0.612	0.476	0.748	0.815	0.742	0.454	0.537	0.516	0.692	0.719	0.688	0.722	0.745	0.541	0.674	0.743
Uruguay	0.953	0.997	0.948	0.923	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Venezuela (Bol. Rep. of)	1	0.989	0.894	1	0.979	0.907	0.949	0.943	0.903	1	1	0.995	0.898	1	1	1	1	0.773	0.762	0.721	0.665	0.698	0.704	0.948	0.716
Mean	0.874	0.863	0.836	0.813	0.853	0.838	0.858	0.844	0.783	0.681	0.784	0.873	0.867	0.848	0.775	0.833	0.843	0.856	0.866	0.899	0.861	0.827	0.746	0.819	0.815

Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

TABLE III

Technical efficiency estimates by year and country: environmental index, 1980-2004

Country	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Argentina	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Bolivia (Plur. St. of)	1	1	1	1	1	1	1	1	0.902	0.764	0.988	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Brazil	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Chile	1	0.938	1	1	1	1	1	0.95	0.981	0.608	0.619	0.776	0.86	0.677	0.68	0.731	0.771	0.809	0.835	0.952	0.901	0.922	0.988	0.965	1
Colombia	0.968	0.94	0.88	0.554	0.716	0.809	0.802	0.888	0.897	0.61	0.59	0.941	1	0.683	0.504	0.557	0.604	0.926	1	1	1	1	0.804	0.787	0.852
Costa Rica	1	1	1	1	1	1	0.85	0.753	0.81	0.847	0.848	0.83	0.863	0.873	0.916	1	1	0.995	0.871	1	0.99	0.787	0.867	0.882	0.78
Dominican Republic	0.805	0.939	0.81	0.683	0.967	1	0.872	0.847	0.856	0.487	0.553	0.931	0.938	0.801	0.651	0.814	0.759	1	0.986	0.8	0.868	0.885	0.752	0.614	0.895
Ecuador	0.625	0.779	0.888	0.625	0.917	0.783	0.576	0.588	0.752	0.437	0.341	0.554	1	0.735	0.373	0.531	0.559	0.758	0.824	1	1	0.966	0.699	0.496	0.834
El Salvador	1	1	1	0.968	1	1	1	1	0.794	0.511	0.901	1	0.894	0.894	0.714	0.803	1	1	1	1	0.902	0.818	0.686	0.659	0.78
Guatemala	0.876	0.815	0.728	0.71	0.814	0.9	0.97	0.832	0.845	0.63	0.77	0.883	0.801	0.891	0.706	0.934	1	1	0.969	0.851	0.844	0.784	0.599	0.646	0.768
Honduras	0.753	1	1	1	1	1	1	1	0.507	0.398	0.596	0.679	0.676	0.536	0.467	0.549	0.568	0.639	0.764	0.639	0.689	0.696	0.697	0.574	0.654
Mexico	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Nicaragua	1	0.744	0.669	0.375	0.43	0.457	0.549	0.722	0.53	0.304	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Panama	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Paraguay	0.51	0.51	0.504	0.478	0.511	0.503	0.547	0.558	0.501	0.361	0.451	0.564	0.596	0.633	0.507	0.622	0.586	0.638	0.925	1	1	0.794	0.861	0.767	0.709
Peru	0.776	0.695	0.621	0.637	0.801	1	0.862	0.816	0.831	0.612	0.476	0.749	0.837	0.742	0.454	0.537	0.516	0.7	0.735	0.688	0.722	0.745	0.542	0.675	0.768
Uruguay	0.953	0.997	0.948	0.923	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Venezuela (Bol. Rep. of)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mean	0.904	0.909	0.892	0.831	0.898	0.914	0.89	0.886	0.845	0.698	0.785	0.884	0.915	0.859	0.776	0.838	0.854	0.915	0.939	0.941	0.94	0.911	0.861	0.837	0.891

Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

TABLE IV

Environmental efficiency sensitivity index (EESI) estimates by year and country: quotient between normal and environmental indices, 1980-2004

Country	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Argentina	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Bolivia (Plur. St. of)	1	1	1	1	1	1.792	1	1	1.441	1.350	1	1.060	1.020	1.006	1	1	1	1.163	1.302	1.075	1.040	1	1.508	1	1
Brazil	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Chile	1.082	1.059	1	1	1.003	1.035	1	1.012	1.070	1	1.021	1.003	1.055	1	1	1.086	1.122	1.122	1.115	1.143	1.205	1.130	1.043	1.058	1.120
Colombia	1.085	1.106	1.264	1	1.168	1.072	1.035	1.021	1.085	1	1	1.002	1.075	1	1	1	1	1.098	1.089	1	1	1	1.174	1.009	1.057
Costa Rica	1	1	1	1	1	1	1.025	1	1	1	1	1	1	1.005	1.023	1	1	1.001	1.079	1	1.114	1.051	1.014	1.028	1.021
Dominican Republic	1.150	1.105	1.011	1.052	1.124	1.271	1.244	1.244	1.179	1	1	1.080	1.189	1.003	1	1	1.056	1.285	1.323	1.286	1.437	1.521	1.675	1.039	1.271
Ecuador	1.417	1.620	2.220	1.796	2.204	1.847	1.280	1.342	1.504	1.383	1.046	1.055	1.672	1.359	1	1.064	1.111	1.263	1.411	1.027	1.445	1.984	2.248	1.081	1.692
El Salvador	1	1	1	1	1	1	1	1	1	1	1	1	1	1.001	1	1	1	1	1	1	1.020	1.076	1.165	1.009	1.060
Guatemala	1.010	1	1	1	1	1.030	1.022	1.037	1.006	1	1	1.009	1.032	1.001	1	1	1	1	1.059	1.001	1.083	1.089	1.163	1.008	1.099
Honduras	1.116	1	1	1	1	1	1	1	1.037	1	1	1.024	1.029	1	1	1	1.014	1.129	1.087	1.143	1.260	1.313	1.747	1.232	1.507
Mexico	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Nicaragua	1	1.607	1.497	1.022	1.178	1.385	1.390	1.695	1.501	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Panama	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.	1
Paraguay	1	1	1	1	1.002	1.044	1.036	1.053	1.016	1	1	1.007	1.002	1	1	1	1.009	1.104	1.013	1	1	1	1.105	1	1.038
Peru	1.014	1.003	1	1	1	1	1	1	1.012	1	1	1.001	1.027	1	1	1	1	1.012	1.022	1	1	1	1.002	1.001	1.034
Uruguay	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Venezuela (Bol. Rep. of)	1	1.011	1.119	1	1.021	1.103	1.054	1.060	1.107	1	1	1.005	1.114	1	1	1	1	1.294	1.312	1.387	1.504	1.433	1.420	1.055	1.397
Mean	1.034	1.053	1.067	1.022	1.053	1.091	1.037	1.050	1.079	1.025	1.001	1.013	1.055	1.013	1.001	1.006	1.013	1.069	1.084	1.047	1.092	1.102	1.154	1.022	1.093

Source: prepared by the authors on the basis of data from the World Development Indicators (WDI) and Global Development Finance (GDF) databases of the World Bank.

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