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Short communication

Ethanol learning curve—the Brazilian experience

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Abstract

Economic competitiveness is a very frequent argument against renewable energy (RE). This paper demonstrates, through the Brazilian experience with ethanol, that economies of scale and technological advances lead to increased competitiveness of this renewable alternative, reducing the gap with conventional fossil fuels.

Keywords: Ethanol; Learning curve; Brazil

The discussions at the Johannesburg 2002 World Summit made clear that policies for renewable energy (RE) are essential to achieve sustainable development in a broad sense. Environmental protection, job creation, alleviation of external debts in developing countries, and security of supply are some of the key issues to mention.

A very common argument against RE is their economic competitiveness against mainly fossil fuels. The answer to this argument is exactly the objective of the Brazilian Energy Initiative (BEI), which proposed a minimum global target of 10% of energy from renewable sources, with the possibility of trading RE certificates amongst countries [1]. The initiative aims at pushing governments to introduce renewables, even if they cost more at present. A mandatory target on RE acts on the demand side of large markets in developed countries, lowering costs through the "learning curve effect". This approach is complementary to Type II Initiatives proposed at Johannesburg: partnerships that will create the grassroots for the RE movement.

For many products and services, unit costs decrease with increasing experience. This effect is often referred to as learning by doing, progress curve, experience curve or learning curve [2–4]. McDonald and Schrattenholzer [5] provide a good overview on the subject, stressing that for most products and services it is not the passage of time that leads to cost reductions, but the accumulation of experience. Leaving a technology on the shelf, unlike a fine wine, will not make it better. Interruptions in production and use can cause a "forgetting by not doing" effect. The learning curve represents graphically how market experience reduces prices for various energy technologies and how these

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reductions influence the dynamic competition among technologies. It is a long-range strategic rather than a short-term tactical concept [6].

Learning curves are empirical, with several benchmarks throughout the world. One of the most important examples—if not the most important—is the one provided by Brazilian Alcohol Program (PROALCOOL), established in 1975 with the purpose of reducing oil imports by producing ethanol from sugarcane. The program has positive environmental, economic and social aspects, and has become the most important biomass energy program in the world [7].

In 1975, 91 Mt of sugarcane was produced, yielding 6 Mt of sugar and 555 km^3 of ethyl alcohol (ethanol). In 2002, sugarcane production reached 320 Mt, yielding 22.3 Mt of sugar and 12.6 Mm^3 of ethanol. In 2002, the total land area covered by sugarcane plantations in Brazil was approximately 4.9 Mha (60% in the State of São Paulo). The average productivity of sugarcane crops in Brazil is 65 t ha^{-1}, but in Sáo Paulo State there are mills with yields of up to 100 t ha^{-1}.

In Brazil, ethanol is used in one of two ways: as an octane enhancer and oxygenated additive to gasoline, blended in the proportion of 20–26% in volume of anhydrous ethanol (99.6 Gay-Lussac (GL) and 0.4% water) to gasoline, a mixture called gasohol or in neat-ethanol engines, in the form of hydrated ethanol with 95.5 GL.

Since the creation of PROALCOOL in 1997, prices received by ethanol producers were determined by the federal government, as were the prices of fuels in general. In May 1997, the price of anhydrated ethanol was liberalized, and the same occurred with the price of hydrated ethanol in February 1999.

Ethanol production costs were close to 100 US dollars a barrel in the initial stages of the Program in 1980. Until 1985, as production increased, prices paid to producers reflected average costs of production, which were surveyed by a government mandate through the Getúlio Vargas Foundation. During this initial phase, prices fell slowly reflecting the gains in agroindustrial yield and economies of scale captured by producers, and transferred to consumers through the pricing regulation scheme. After 1985, however, prices were set at levels below the average costs of production, while the federal government tried to curb inflation by controlling the average costs of production, while the federal government tried to curb inflation by controlling

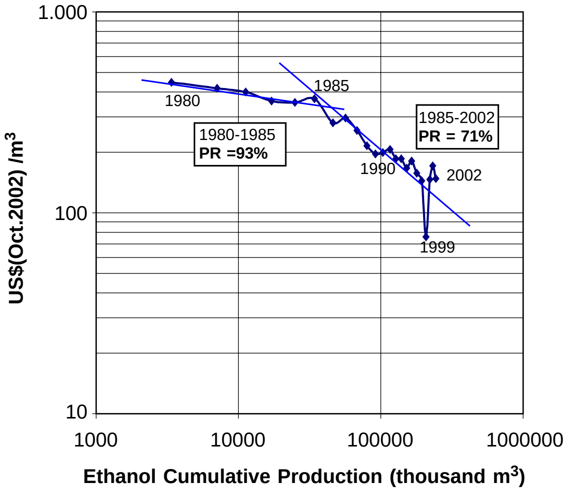

Fig. 1. Ethanol learning curve: prices, trends and progress ratios.

public prices, inclusive of fuels. Due to this factor, together with economies of scale, the price fell much more rapidly, as shown in Fig. 1. Prices paid to producers (made in terms of the internal currency, Real) are proxies for costs. However, in the medium and long term, the high competition in the ethanol activity has caused the prices to move towards production costs.

The Progress ratio of the technology is the variation of prices according to the cumulative sales. The lower the progress ratio, the more the drop in prices. Thus, an efficient technology penetration is one that has achieved low PRs. In US dollars, sugarcane ethanol produced in Brazil has shown progress ratios of 93% (1980–1985) and 71% (1985–2002). For comparison, there are European figures [8] calculated for wind (PR=99% between 1981–1985 and PR=88% in 1985 –2000), solar photovoltaics (PR= 77% in 1981–2000) and combined cycle gas turbines (PR=104%, i.e. cost increases between 1981–1989 and PR=81% in the 1985–2002 period). Fig. 2 shows the price paid to alcohol producers compared to Rotterdam gasoline prices. For an easier comprehension of the end-use utility, prices were converted to US$ per GJ of each fuel, assuming the low heating value of each.

In the early stages of the alcohol program, ethanol use became viable to consumers due to the pricing policy applied to fuels in Brazil. As the efficiency and cost competitiveness of ethanol production evolved

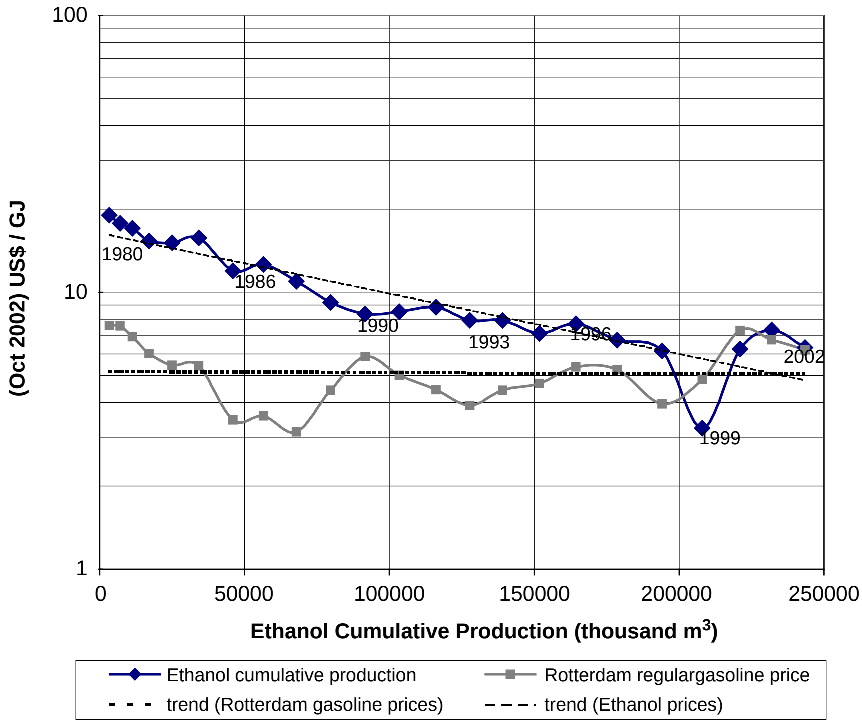

Fig. 2. Ethanol and gasoline prices.

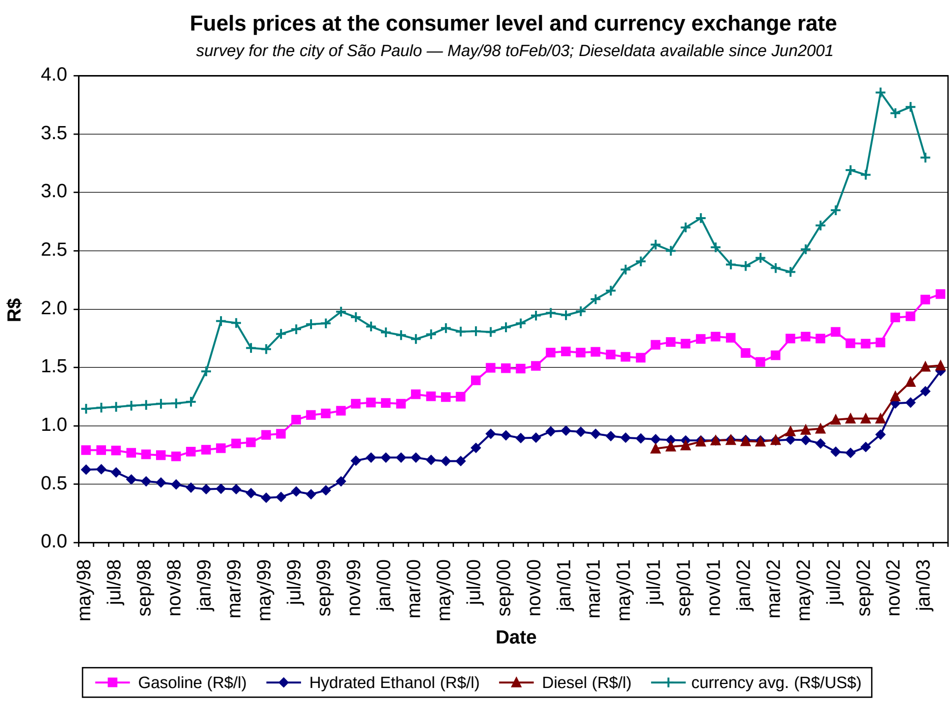

Fig. 3. Fuel prices in Brazil and currency rates.

over time, and fuel prices were liberalized, this support was no longer needed and was not applied. Of great significance is the fact that the total amount of investments in the agricultural and industrial sectors for the production of ethanol for automotive use in the period 1975–1989 reached a total of US$4.92 billion (US$ of 2001) directly invested in the program. On the other hand, savings with foregone imports evaluated at international prices, have amounted to US$52.1 billion (Jan 2003 US$) from 1975 to 2002 [9,10].

Presently, there are no subsidies for anhydrous or hydrated ethanol production. Hydrated ethanol is sold for 60–70% of the price of gasohol at the pump station, due to significant reductions in production costs. These results show the economic competitiveness of ethanol when compared to gasoline. Considering the higher consumption rates of neat-ethanol cars, the consumer is indifferent between hydrated ethanol for a price at the station of up to 80.67% of that from gasohol. Fig. 3 shows a comparison for the main transportation fuels used in Brazil in terms of the price paid in local currency (Real) and the exchange rates to the North American dollar. It demonstrates the long-term competitiveness of the ethanol fuel.

References

[1] Goldemberg J. The Brazilian energy initiative. Presented at the Johannesburg World Summit on Sustainable Development; 2002.

[2] Dutton JM, Thomas A. Treating progress function as a managerial opportunity. Academy of Management Review 1984;9:235.

[3] Argote L, Epple D. Learning curves in manufacturing. Science 1990;247:920–4.

[4] Argote L. Organizational learning: creating, retaining and transferring knowledge. Dordrecht, Netherlands: Kluwer; 1999.

[5] McDonald A, Schrattenholzer L. Learning rates for energy technologies. Energy Policy 2001;29(4):255–61.

[6] International Energy Agency—IEA. Experience curves for energy technology policy. Organisation for Economic Co-operation and Development, Paris: 2000.

[7] Goldemberg J, Moreira JR. The alcohol program. Energy Policy 1999;27(4):229–45.

[8] Goldemberg J, Coelho ST, Lucon O. How adequate policies can push renewables. Energy Policy, 22 February 2003, doi:10.1016/S0301-4215(03)00077-6, in press.

[9] Datagro. Costs of fuels and cumulative sales in Brazil and Rotterdam. São Paulo: Datagro; 2003.

[10] Nastari PM. Poupança de divisas com o uso do álcool combustível no Brasil (Savings by the use of ethanol fuel in Brazil). São Paulo: Informativo Datagro; January 2003.