The Threat of Competition Enhances Productivity*

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Abstract

State-owned enterprises tend to perform worse than privately owned firms. However, the reason for the poor results is unsettled, with some emphasizing ownership itself and others the market environment. We examine this issue by studying productivity at Brazil's state-owned oil company Petrobras after it lost its legal monopoly. After losing its monopoly rights Petrobras's total factor productivity increased sharply, more than doubling the growth rate of labor productivity. This gain was obtained by shedding excess inputs and reallocating capital and labor towards more productive wells. These large gains occurred despite the fact that Petrobras faced little immediate *de facto* competition. Indicators of market concentration changed very little. The *threat* of competition was sufficient to generate large productivity gains. These findings suggest that changing the competitive environment can be a powerful force for improving productivity at state-owned firms and indicators of market concentration can be poor proxies of market competitiveness.

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1 Introduction

State-owned enterprises (SOEs) tend to perform worse than privately owned firms. (See Megginson and Netter [29] for a survey.) However, the reason for the poor results from SOEs is unsettled. Some have emphasized ownership itself. For example, public firms may be used to accomplish non-economic goals such as providing patronage to the government's political supporters (World Bank [40]). The government may be less able to solve agency problems (Hart, Shleifer, and Vishny [21]). Others have emphasized the market environment that SOEs face. They are often given preferential market access, up to outright monopoly, and protected by trade and entry barriers (Vickers and Yarrow [39]).

We study a reform that shows the importance of the competitive environment for productivity. In 1995, Brazil ended the legal monopoly rights of its state-owned oil company, Petrobras, over production, refining, import and export of oil. Petrobras was not privatized or broken up and there are no plans to do so. We evaluate the productivity performance of the company's oil extraction division before and after the loss of monopoly. Immediately after this change, both labor productivity and Total Factor Productivity (TFP) growth sharply increased.

There are a number of advantages to studying this reform over the existing literature. First, we do not have to rely on imperfect proxies for competitive pressure such as market share or import penetration. We have a clear change in the competitive environment: Prior to the reform, competition was illegal while afterward it was allowed. In fact, market concentration indicators changed very little after the reform. So they miss this significant shift in the competitive environment.[1]

Second, the change brought about by the reform is free of a number of confounding effects that other studies encounter. In most cases, reforms are typically part of a comprehensive package, making it difficult to identify how each change affects productivity. For instance, a firm may be privatized at the same time as its markets are liberalized and trade barriers are reduced. Therefore, it is difficult to disentangle

[1]There is a literature suggesting that competition over a field (that is, more than one company exploring the same field at the same time) can generate inefficient allocation (Libecap and Wiggins [28]). As shown below, this did not happen in the Brazilian oil industry. By competition we mean here more than one company exploring different oil fields in Brazil at the same time.

the effects of ownership change from those of market changes. We do not have to disentangle the effects of multiple policy changes since the Petrobras reform was simply the removal of a legal monopoly and was not accompanied by any other changes. For example, Petrobras's performance can not be accounted for by the anticipation of future privatization (Brown, Earle, and Telegdy [7]). Therefore, any changes in productivity cannot be attributed to other direct policy changes.

The main finding is the reform led to a significant increase in Petrobras's productivity growth. Between 1976 and 1993 labor productivity grew at an annual average of 4.6 percent whereas between 1994 and 2001 it grew at an annual average of 13.6 percent. Not only did growth more than double, the sources of the growth changed. Labor productivity growth prior to 1995 was due to capital accumulation and materials use with little TFP growth. After 1994 TFP grew rapidly, accounting for almost all the increase in the labor productivity growth rate.

To accomplish these results, Petrobras slashed its use of inputs while maintaining output growth. It also began to shift its portfolio of oil wells to more productive regions and changed its corporate structure. The speed with which the changes were implemented indicate that they were feasible prior to reform (physically, if not politically).

What makes this case particularly compelling is that labor productivity growth immediately doubled despite the fact that the reform put little immediate pressure on Petrobras. Petrobras maintains a dominant position, still extracting 97 percent of Brazil's oil. Its advantages as a large incumbent made it difficult for competitors to enter the market. The *threat* of competition was sufficient to generate significant productivity gains.

These results have some policy implications. When privatization is not politically viable, increasing competition in the markets of state-owned firms can provide an avenue for improving performance. Also, indicators of market outcomes can be poor proxies of market competitiveness. The prospect of competition resulted in major changes in Petrobras's management strategy and productivity. However, commonly used market outcome proxies such as concentration indices changed very little with the reform. As a proxy for competition, they would have missed a important shift in the competitive environment.

Our findings are in line with that of Goolsbee and Syverson [20] and Bartel and Harrison [3]. The first shows that the threat of entry in the U.S. airline industry led to price cuts by incumbents before the entry occurred. The second provides evidence from Indonesia that the competitive environment is an important determinant of productivity, regardless of ownership. Our findings are also consistent with contestable markets theory, which argues that a monopolist's behavior is affected by the threat of new entrants, not just actual entrants (Tirole [38]). Similar to Bresnahan and Reiss [5], adding an entrant to a market with few incumbents has a large effect. Though only one company entered the oil extraction market in the first ten years of the reform, the productivity growth rate more than doubled.

Our paper is part of a growing literature examining the productivity effects of discrete changes in competitive pressure. Galdon-Sanchez and Schmitz [16] and Schmitz [23] find that productivity increased sharply in response to increased competitive pressure in the 1980s. Schmitz and Teixeira [24] find that private firms' productivity increased when public firms in the Brazilian iron ore industry were privatized. Cole, et al. [12] examine a number of these studies for Latin America. The closest work to ours is Garcia, Knight and Tilton's [17, 18] study of Chilean copper mining. Industry labor productivity increased after other firms were allowed to compete with the state-owned monopoly Codelco. In contrast to our findings, most of the increase came from high productivity entrants rather than improved productivity at Codelco.

It is closely related to the "barriers to riches" literature. Parente and Prescott [32] build a model where a monopolist sets price above marginal cost and does not use the most productive technology. Our empirical results match their theoretical predictions. After the end of monopoly rights of Petrobras, output and technological progress (as measured by TFP growth) increased sharply.

The causes of the post-reform productivity gains are similar to those found in Olley and Pakes [30]. They study the effects of deregulation and entry on productivity at the plant level in the U.S. telecommunication industry. They find that productivity increased mainly due to reallocation of inputs (capital) toward more productive plants. Productivity growth increased in a similar way at Petrobras, as it shifted production to more productive wells after the loss of its monopoly.

Laitner [26] separates the costs of imperfect competition in two parts: a static and dynamic effect. The static effect is the well-known deadweight loss caused by setting price above marginal cost (Harberger Triangles). The dynamic effect is due to underinvestment, reducing the capital stock and production. While Petrobras's production grew rapidly after the reform, to the point that Brazil is a zero net importer of oil, investment did not. Production was increased by using capital and other inputs more efficiently. In fact, it was during the monopoly period that Petrobras invested heavily, due in part to a national policy designed to encourage investment (Bugarin et al [10]).

Our work is largely consistent with the literature on the effects of competition. However, in contrast to much of this work, we study a public company. We find that public companies react to competition in the same ways as private ones. However, the nature of the inefficiency of monopoly may be different, since public firms may pursue political goals that privately held companies do not.

2 Petrobras and the Brazilian Oil Industry

Petrobras is an integrated state-owned oil company that extracts, imports and exports, and refines crude oil and distributes gasoline[2]. It is a major player in the world oil industry and was ranked 125th in the 2005 Global Fortune 500. It is also very important in Brazil. Its sales are 6 percent of Brazil's GDP.

While its sheer size makes it economically important in Brazil, Petrobras is also politically important. It is one of the "Crown Jewels," a set of politically sensitive state-owned companies that figure prominently in the nationalist movement. Taxes on oil extraction are an important source of revenue for Federal, state, and city governments. There are also indirect benefits. It employs skilled, high-wage workers and is a source of local supply contracts.

Petrobras was created in 1954 and given a monopoly over oil exploration, extraction and refining. (Existing private refining companies were allowed to continue operating but could not expand.) This policy was part of a larger import substitution

[2]The government holds a majority of the voting stock. Non-voting shares and a minority of voting shares have been held by the public since the creation of Petrobras.

policy to develop the industrial sector (Kingstone [25]).

From its creation until the 1990s, Petrobras's control of the Brazilian oil market steadily increased.[3] The monopoly power of Petrobras was extended to the import and export of oil in the 1963. Between the creation of Petrobras and 1970s, domestic prices were essentially equal to the international price plus a Federal tax. In an attempt to shield the domestic economy from the oil shocks, domestic prices became disconnected from international prices in 1977 and based on a measure of domestic production cost. In 1988, Petrobras's monopoly rights were guaranteed in the new Brazilian constitution.

The policy to remove the monopoly originated with President Fernando Henrique Cardoso. The first time that he publicly mentioned his intention of ending Petrobras's monopoly rights was in December of 1993 while he was still the Finance Minister (Prado [34, page 178]). He was elected with a majority in the first round of presidential voting in October 1994 and took office in January 1995. The election also provided him with strong legislative support, which his reformist predecessors did not have. In February 1995, he sent the amendment to the Congress eliminating Petrobras's monopoly.

Congressional resistance to the reform was strong. Members from both the left and right opposed it on ideological grounds; the left was opposed to private involvement and the right opposed weakening a nationalist symbol. The reform also threatened patronage opportunities. The reform likely would have failed without a strike by Petrobras's employees that generated a shortage of natural gas, which is used widely for cooking. Public opinion turned sharply against the strikers, which coupled with his personal popularity as the architect of currency stabilizing *Real* Plan, allowed Cardoso to push the reform through the Congress. Cardoso's congressional allies extracted a concession in the form of a clause prohibiting privatization in the law regulating the oil sector[4]. (This Petroleum Law was approved in 1997, as seen below). To end the monopoly, Cardoso had to give up the idea of privatizing Petrobras (Kingstone [25]).

The amendment was approved in November 1995. The Federal government re-

[3]See Campos [11] and Barreto [2].

[4]The law requires that at least 51 percent of the voting shares be held by the Federal government.

tained the ownership of hydrocarbon reserves but opened the sector to private firms, ending 40 years of monopoly. We argue that the reform began in 1994 since Petrobras's managers would have anticipated Cardoso's likely ability to pass reform upon his election in that year.

Market opening was phased in. The amendment called for new legislation regulating the oil market. This law, called the Petroleum Law, was approved by the Congress in August 1997. It created the National Petroleum Agency (ANP henceforth), which took over regulation of the oil market from Petrobras. The Petroleum Law set out the process of liberalization for all sectors related to production of oil products. In this paper, we focus on the extraction sector. (For a description of the deregulation of other sectors, see Serour [37]).

The Petroleum Law allowed Petrobras to keep its rights of extraction of oil in areas where it could prove that it had done investment. In August 1998, Petrobras signed 397 contracts with ANP, 282 of which covered areas already under development. These contracts, called "Round Zero," gave the rights for 450 thousand square kilometers to Petrobras without payment. After that, new areas for exploration were offered in auctions where any company from any country could participate. By 2003, 41 companies, besides Petrobras, had bought some areas. In that year, Shell was the first private company to produce oil in Brazil, though Petrobras's share of Brazilian production is still almost 100 percent.

In 2001, exports and imports of oil and its derivatives were opened to companies besides Petrobras (through its subsidiary Transpetro).

In what follows, we date the beginning of the reform in the oil industry as 1994. Even though the change in Petrobras's monopoly status occurred in 1995, as noted above, discussion of the policy change began earlier. When dating the beginning of a reform, the date of the legal change may not be the most relevant date. Managers in the reformed industry may have anticipated the reform and introduced changes prior to the reform becoming official. For example, in a study of the impact of privatization in the Brazilian iron ore sector, Schmitz and Teixeira [24] argue that the reform began in 1990, when a new President was elected promising to privatize and deregulate the economy, rather than the official announcement in 1995.

We argue that the threat of competition changed managers' behavior at Petro-

bras. A competing interpretation is that Petrobras's managers reacted to the threat of privatization rather than competition. Brazil's political environment made privatizing Petrobras very difficult, so it is unlikely that its managers thought that this was a serious threat. Even when public support for privatization was at its highest and for Petrobras was low, congressional supporters of reform demanded that privatization be taken off the table. Petrobras may be the only company in Brazil that is legally obligated to be state owned. It is always possible for the Congress to change this law, but there is little political will to do so. As noted above, both the socialist left and nationalist right have ideological reasons to oppose privatization. Privatization would remove entirely a valuable source of patronage. Whatever support there was for privatization lessened over time while the threat of competition has intensified. Therefore, we believe that it is reasonable to attribute the ongoing TFP growth to competition.

3 Production Process in the Oil Industry

This paper examines oil and gas extraction productivity. This section discusses the techniques employed to extract oil and gas from the soil and preparing it for refining, with particular attention to the attributes of wells that affect extraction productivity.[5]

Once a field with oil and gas is discovered, the first step is to install the wells: holes where pipes are inserted to extract oil and gas from the rock. Recent advances in satellite seismic imaging have improved exploration and the siting of wells. In the 1990s, seismic imaging shifted from two to three dimensional geological images. In the beginning of the 21st century, a fourth dimension, time, was added. These techniques are available in the international market and any company in the sector can use it.

Every well produces both oil and natural gas simultaneously.[6] Extraction may

[5]This section draws heavily on discussions with Petrobras engineers Sergio Barros da Cunha, Demetrius Casteloes, and Marcelo Duque.

[6]Generally the separation of oil from gas is automatically done through the change of pressure. That is, inside the field there is high pressure. Once the oil and gas comes to the surface, the reduced pressure allows an automatic separation. See Worley and Laurence [41] and Rondeon [36].

or may not use energy. Some wells have natural pressure that forces oil out without additional inputs. Other wells do not have enough natural pressure, so it must be built up artificially. This can be done by either pumping water into the reservoir or compressing gas into the well.[7] Adding pressure requires energy which comes from the gas produced by the wells themselves, reducing net output. The consumption of gas can reach 30 percent of the total produced by a well.

The existence of natural pressure in the well is not related to any geographic characteristics of the field or the well. Both deep sea and land based wells may or may not have natural pressure. For example, wells in the Middle East have natural pressure, making it a low cost producer.

Natural pressure is related to the age of the well since removing oil from a field reduces its pressure. It is possible to reduce the amount of energy spent to produce oil and gas by shifting production to new wells, even when the new wells are much bigger than the old ones. As discussed below, this happened in the Brazil when Petrobras abandoned older, smaller wells in the states of Alagoas, Sergipe, and Bahia and concentrated its production in the state of Rio de Janeiro.

The oil and gas extracted from wells comes mixed with water which must be separated out. The oil and gas are separated from water using chemicals. The amount of chemicals required may not increase in the same proportion to the liquid extracted from the well. Chemical use depends on the temperature of the liquid once it has reached the platform, with colder liquid using more chemicals.

Larger and newer wells may use fewer chemical inputs. First, the amount of water coming out of a well together with oil depends on the age of the well. The older the well, the more water it produces. Second, equipment specialized in the separation of oil from water can be attached to a platform. It uses gas to produce energy that is use to separate oil from water through a electrostatic treater[8]. This reduces transportation costs, since less water is transported to the refinery. This technology is only economical for wells that produce a high daily volume. This technology is used in Rio, where wells are large, but is rare in the states where wells were closed.

We conclude that a shift to newer and larger wells used in production likely re-

[7] See Bennion et al [4] and Patton [33].

[8] See Cummings and Engelman [13] and Bromley, Gaffney and Jackson [6].

duced materials usage per well. Newer wells tend to have higher pressure, so they consume less energy than older wells, and produce less water, so they use fewer chemicals inputs. The move to larger and newer wells also allowed the use of separating technology based in gas that reduces chemical use and reduce transportation cost.

4 Productivity at Petrobras

In this section, we analyze Petrobras's domestic oil extraction unit's labor productivity and TFP performance in response to the loss of its legal monopoly. We argue that the end of Petrobras's monopoly and the threat of new competitors had an impact on its productivity performance. We examine Petrobras's TFP which is computed using a Cobb-Douglas production function given by

$$Y_t = A_t K_t^{\theta} M_t^{\alpha} N_t^{(1-\theta-\alpha)} \tag{1}$$

where K_t is the aggregate capital stock, M_t is the amount of material, N_t is the number of employees, θ is the capital share, α is the labor share and A_t is TFP.

The data is drawn from balance sheets of Petrobras and the ANP. Output Y_t is the total physical quantity of oil produced. Natural gas produced, a joint product of oil, is converted into oil equivalents as described in the Appendix. Labor input N_t is the number of employees for each year, adjusted for contracting out as described in the Appendix.

The capital stock is calculated using perpetual inventory on capital expenditures.[9] Data extends back to the establishment of Petrobras, so we directly observe the initial stock. (Further details are available in the Appendix). Since the data reported on an annual basis, Brazil's history of very high inflation rates complicates the measurement

[9]Our measure of capital includes capital formation in two sectors: well exploration and development. But we do not include development as part of our output. Well development is fairly constant aside from a spike in the years 1979 to 1983. This should not affect our main results although our estimate of TFP may be biased downward during the early 1980s. The data cannot be extended beyond 2001 since the Exploration and Production unit was consolidated with other units in 2002, making the data non-comparable.

of capital. The same nominal expenditure will buy much less real capital if it occurs in December rather than January. Brazilian accounting rules required indexation of financial reports during the high inflation years, which mitigates this problem. If the capital stock is mismeasured in the high inflation years, it will tend to be underestimated. The Brazilian currency total was converted into U.S. Dollars using the December monthly exchange rate. When inflation is high, this conversion will tend to underestimate the real capital stock. The Brazilian currency was pegged to the dollar. The peg would be periodically adjusted (daily during hyperinflation), depreciating the Brazilian currency. Therefore, the currency would be at its most depreciated level at the end of the year. This factor will lead us to understate the impact of the reform on TFP growth. In high inflation years, capital expenditures are converted using the exchange rate when the Brazilian currency buys the fewest dollars during the year, which will tend to understate investment. In turn, TFP will tend to be biased upward. This systematic bias is not present in low inflation years. Since the oil sector reform occurred after high inflation ended in Brazil (the *Real* Plan that ending high inflation was implemented in July 1994), the upward bias will only be present before the reform.

Another concern with the deflation of the capital expenditure data is that the U.S. price series we use does not reflect price changes in Brazil. In particular, the relative price of structures in Brazil nearly doubled in the mid-1980s (Bugarin, et al. [8]). This mismeasurement would also tend to overstate TFP since real investment in structures would be understated after the mid-1980s. However, the quantitative impact is likely to be tiny. Structures make up very little of Petrobras's capital, less than 2 percent of the value of net property, plant and equipment 2005.

The average labor share in the period 1976 and 2001 is 0.2. Since we do not have data on Petrobras's materials expenditures, we cannot calculate the capital and materials shares directly. Instead, we use the U.S. data. The fact that the labor share in Brazil is similar to that of the United States is an indicator that factor shares are similar in the two countries. We use a capital share of 0.45 and material share of 0.35 [10].

[10] We use the KLEM data set for Oil and Gas Extraction (Industry Group 4) described in Jorgenson and Stiroh [22]. See the Appendix for details on the data.

We did not have data for material use in Brazil so we use wells in production as a proxy. This assumes average material use per well is constant over the period considered. As a check of the validity of this assumption, we examine materials per producing well in the United States. Figure 1 shows real materials for the U.S. oil and gas extraction industry from the KLEM database (Jorgenson and Stiroh [22]). U.S. materials per producing well are relatively stable except for a spike from 1978 to 1984. This spike may be due to the fact that this industry does not just produce oil and gas products, but is also engaged in exploration, drilling and equipping oil and gas wells. A substantial share of materials use is for well development. The largest categories of expenditures in the U.S. Census of Mineral Industries are "Purchased machinery installed" and "Steel mill shapes and forms." The spike coincides with a big increase in well development, as can be seen in Figure 1. Figure 2 compares the TFP calculations for the United States using real materials and wells. The two estimates are very similar, though they do not match exactly due to the spike in well development during the oil crisis years.

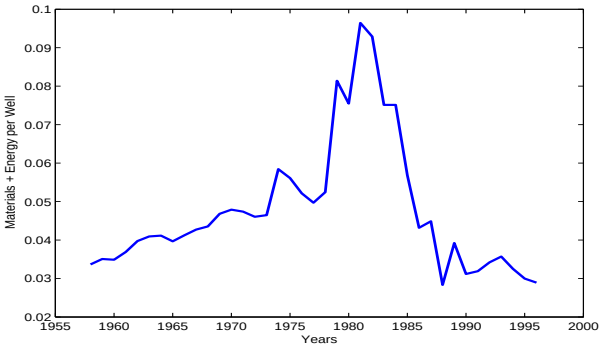
In fact, Brazilian material use per producing well may have fallen during the 1990s. As discussed above, material usage is largely driven by well attributes and Petrobras shifted production to newer and larger wells that tend to use fewer material inputs. If this is the case, our measure of TFP is biased downward since we overestimate material input.

On the other hand, if material use per well increased, we overestimate TFP growth. However, it is unlikely that our results would be overturned. As shown below, material usage would have to have exploded to account for the large post-reform increase in TFP we find. Petrobras engineers we spoke with did not believe that this was the case.

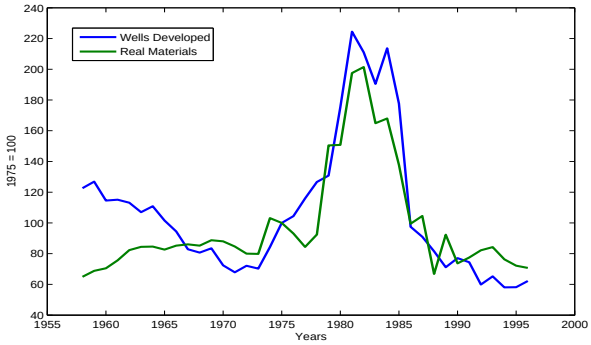
Using equation 1 and the Brazilian data we computed Petrobras TFP shown in Figure 3. During the time that Petrobras was a legal monopolist, there in very little sustained growth in TFP. There is a deep and abrupt fall in TFP in the second half of the 1970s with a recovery in the early 1980s. From 1984 until 1993, TFP shows no sustained gains. On the other hand, during the post-reform era from 1994 until 2001 TFP almost doubled, growing 95 percent[11].

[11]Note that material usage per well would have to have increased by a factor of nearly 7 to

Figure 1: Real Materials Expenditure and Wells, USA



(a) Real Materials Expenditure per Producing Well, 1958-1996

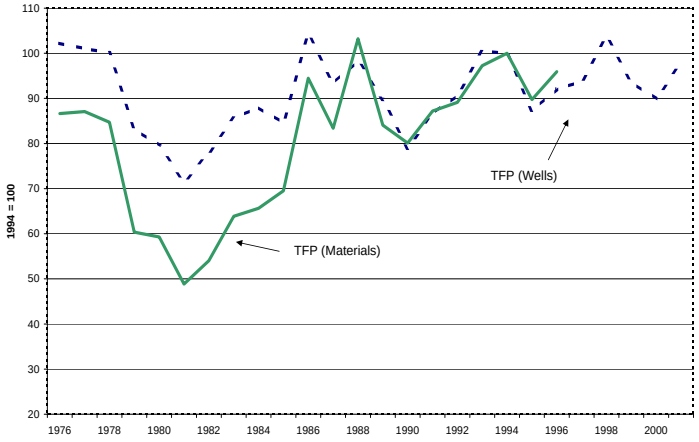


(b) Wells Developed and Real Materials Expenditure, 1958-1996

This calculation allows us to decompose the sources of growth of labor productivity (henceforth productivity). Dividing Equation 1 by N_t, then taking logs yields:

account for the post-reform increase in productivity. TFP (A in Equation 1) grew by a factor of 1.95. Given an input share of 0.35, material usage per well would need to increase by a factor of 6.74 ($1.95 = (6.74)^{0.35}$).

Figure 2: Alternative TFP Measures, 1976-2001

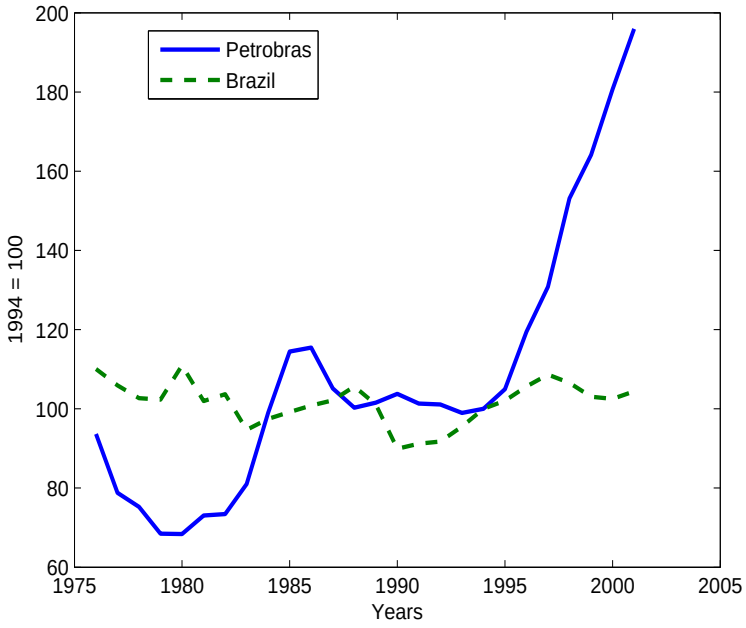


$$\left[\log\left(\frac{Y_{t+s}}{N_{t+s}}\right) - \log\left(\frac{Y_t}{N_t}\right)\right]/s = \left[\log A_{t+s} - \log A_t\right]/s + \tag{2}$$
$$\theta\left[\log\left(\frac{K_{t+s}}{N_{t+s}}\right) - \log\left(\frac{K_t}{N_t}\right)\right]/s\alpha\left[\log\left(\frac{M_{t+s}}{N_{t+s}}\right) - \log\left(\frac{M_t}{N_t}\right)\right]/s$$

Table 1 reports a growth accounting for the pre- and post-reform periods. The growth rate of productivity more than doubled after the end of monopoly. The sources of growth in the two subperiods also changed. In the first subperiod, productivity grew almost completely due to an increases in K/N and M/N while TFP was nearly constant. In the second, TFP became the major source of growth.

Table 1 - Growth Accounting of Petrobras's Labor Productivity (%)

Figure 3: Total Factor Productivity of Petrobras and Brazil, 1976-2001



Period	change in Y/N	due to TFP	due to K/N	due to M/N
1977-1993	4.6	0.3	2.1	2.2
1994-2001	13.6	8.5	2.6	2.4

This result is similar to the the findings of Bugarin, et al. [9] for the aggregate Brazilian economy. They find that the government encouraged capital accumulation to keep the economy growing after the oil shocks of the 1970s, despite the lack of technological progress. The government subsidized private companies and had SOEs, like Petrobras, increase investment.

5 Sources of Productivity Growth

Since TFP growth increased so dramatically, it is natural to ask what the sources of that growth were. In this section, we argue that TFP accelerated due to the change in competitive environment. Though the increase in TFP coincides with the policy change (Figure 3), it could have resulted from some other unrelated sources. We first show that the increase did not result from a number of plausible candidates: improvements in the aggregate Brazilian economy, technological progress in oil extraction and maturation of previous investments. We then show that inputs were used inefficiently prior to the policy change. With the loss of its monopoly, Petrobras quickly reduced its use of inputs while continuing to expand output. (Output grew at similar rates before and after the policy change). The company reorganized its structure in an effort to appeal to outside investors. The evidence is consistent with non-economic goals becoming less important relative to the economic goal of improving efficiency.

One potential source of the improvement in productivity is the expansion of the Brazilian economy in the 1990s. It began recovering from its depression of the 1980s when many reforms such trade liberalization, currency stabilization, deregulation, and privatization took place. After these reforms, Brazilian labor productivity and TFP began growing (Bugarin, et al. [10]). This raises the possibility that it was the aggregate environment that caused the increase in productivity at Petrobras.

The evidence is not consistent with this explanation. We computed the TFP of Brazil using the methodology used in Bugarin et al [10]. Figure 3 plots TFP for Brazil and Petrobras[12]. The two series have very different patterns. Brazilian TFP started increasing earlier than Petrobras's. While Petrobras's TFP shows sustained growth after 1994, Brazil's begins to decline after 1998. We conclude that Petrobras's experience is not due to the movements of the aggregate Brazilian economy.

It is also possible the increase was the result of significant improvements in oil extraction technology after 1994. The evidence does not support this explanation. We compare the Brazilian industry to those of the United States, United Kingdom

[12]Brazil's TFP is calculated using a value added measure while Petrobras's uses a gross output measure. Data constraints prevent us from calculating a value added measure of Petrobras's TFP. We use a capital share of 0.37 for Brazil.

and Norway. If technology advanced faster after 1994 the relative productivity should not change. We would expect the oil industries in other countries to implement the new technology and experience similar growth in the labor productivity.

Most of Brazil's oil comes from offshore wells, accounting for over 85 percent of production in 2004. Norway's and UK's oil industries resemble Brazil's since they extract oil (exclusively) from deep water wells. The United States also extracts some oil from deep water but much comes from land-based sources. Therefore, the comparison should control for both general technological change in extraction that would affect all countries and specific change that would only affect offshore extraction.

We do not have enough data to compute TFP for the Norwegian and UK oil industries or the U.S. industry beyond 1996, so we examine labor productivity.

Figure 4: Oil Extraction Labor Productivity - Brazil, Norway, UK and the United States (Index 1994=100), 1976-2001

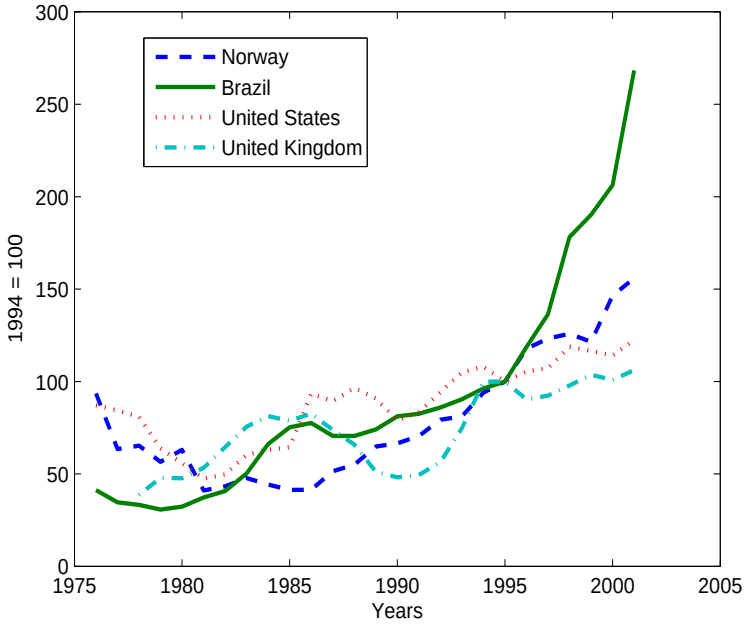


Figure 4 plots labor productivity (indices set to 100 in 1994) for the four countries. While there are clearly differences in the year to year movements of productivity, the overall pattern is similar prior to 1994. Productivity falls in the late 1970s and begins to grow in the 1980s. The magnitude to the growth from the 1980s to 1994 is similar for all four countries. After 1994, Brazil begins to strongly outperform the other three.

Another possible candidate to explain Petrobras rapid productivity growth after 1994 could be the maturation of previous investments. There is a lag between exploration and production. In our case, Petrobras could have increased its investment in exploration for new and more productive fields during the 1980s and the increased in productivity could be due to the beginning production in these fields.

Figure 5: Brazil Wells Exploration and Real Crude Oil Price, 1976-2001

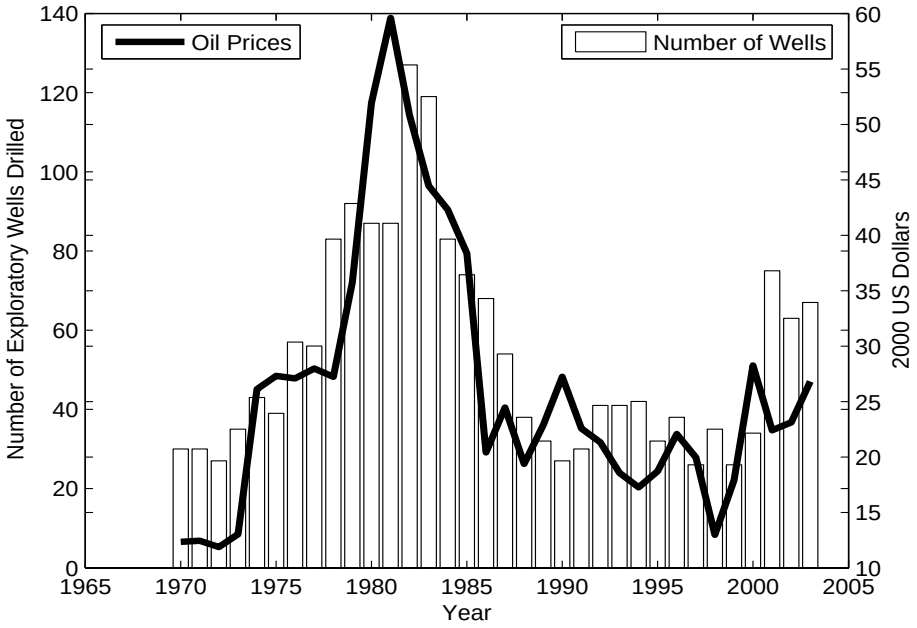


Figure 5 plots the number of exploratory wells drilled and real crude oil prices from 1970 until 2001. Until 1999, the number for the whole industry corresponds to

those drilled by Petrobras. From the late 1980s through the 1990s, there relatively little exploration activity. The number of wells drilled is strongly correlated with the oil prices, which were low during this period. Therefore, there is little evidence of the increase in TFP being caused by previous exploration coming online.

While the evidence does not support the idea that the acceleration in TFP growth was due these sources, it is consistent with a shift in management priorities that resulted from the threat of competition. Inputs were used more efficiently with the reform. Overstaffing was reduced and production was shifted to more productive wells. The inefficient use of inputs likely reflected non-economic goals such as maximizing employment that became less important after the reform.

Company managers explicitly state that prior to the reform, Petrobras pursued a number of non-economic goals such as encouraging Brazilian economic development by building infrastructure in remote areas and purchasing domestically produced inputs (2003 Annual Report). During the 1970s, the company restricted its foreign purchases to conserve the government's foreign currency reserves (1977 Annual Report).

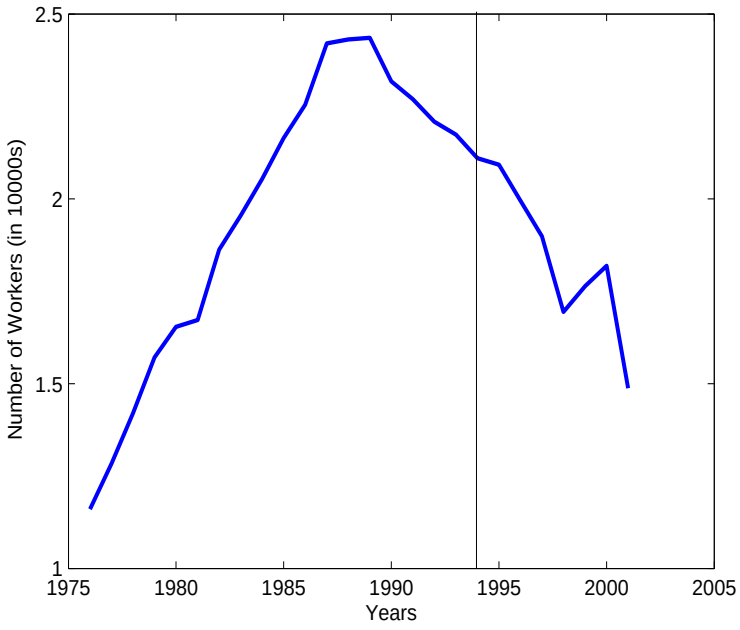
After the reform, the company made a number of changes in an effort to become more internationally competitive. Anticipating a loss of market share in Brazil, it changed its corporate and financial structure so the the company would be able to expand overseas. A major goal was to be able to raise capital "at a cost that was at least compatible with that of its competitors" (2003 Annual Report). It issued a minority of its voting stock as American Depository Receipts on the New York Stock Exchange in 2000, which requires the company maintain U.S. accounting, disclosure and corporate governance standards.[13]

The data are consistent with this change in priorities. Employment fell rapidly after the reform, suggesting there was overstaffing before. Figure 6 shows the number of employees. While employment was declining prior to the loss of monopoly status, the rate of decline increases sharply in 1994. The data are consistent with Petrobras employing more workers than required to produce its output, either for

[13]This offering was not part of a privatization program. In this offering, the Federal government reduced its holdings from 82 to 56 percent of voting shares. Recall that it is legally obligated to hold 51 percent of voting shares.

specific patronage reasons or to increase employment generally.

Figure 6: Number of Workers (in 10,000s), 1976-2001

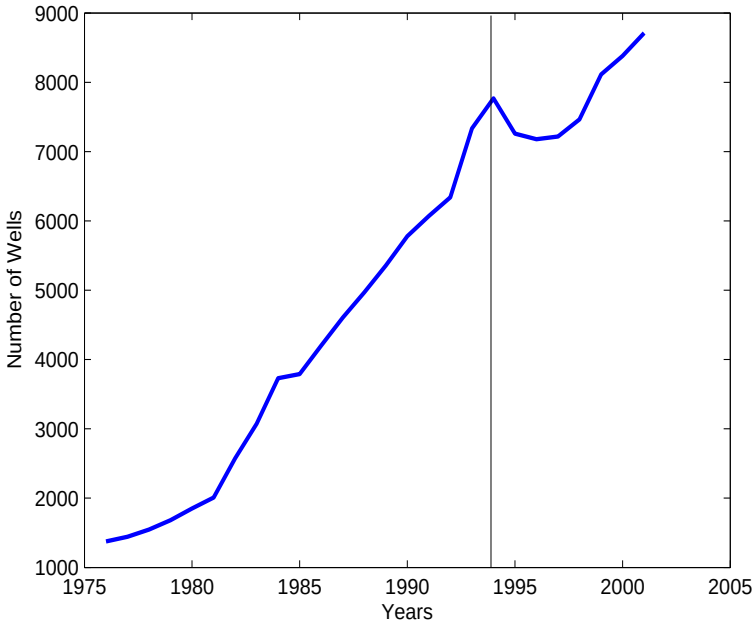


A number of authors have argued that political considerations led to overstaffing. Some overstaffing was due to patronage. Geddes [19] argues that Petrobras began to be used for political purposes in the 1960s, while it had been relatively unpoliticized before. Management power was given to the oil workers' union to garner political support of the employees. Randall [35] estimates that that the company was overstaffed by 20 percent. Up to 10 percent of the workforce were political patrons, hired at the behest of the government. Political pressure also forced the rehiring of fired employees, so both the replacement and original employees were on the payroll. Petrobras was also expected to assist in economic development which may have encouraged excess employment in an attempt to build up the Brazilian economy.

Oil wells were also used inefficiently, with low quality wells kept in production prior to the policy change. Figure 7 shows the number of wells in production. Prior

to 1994, the number of wells increased steadily. In 1994, wells in production decline (sharply) for the first time in the period covered.

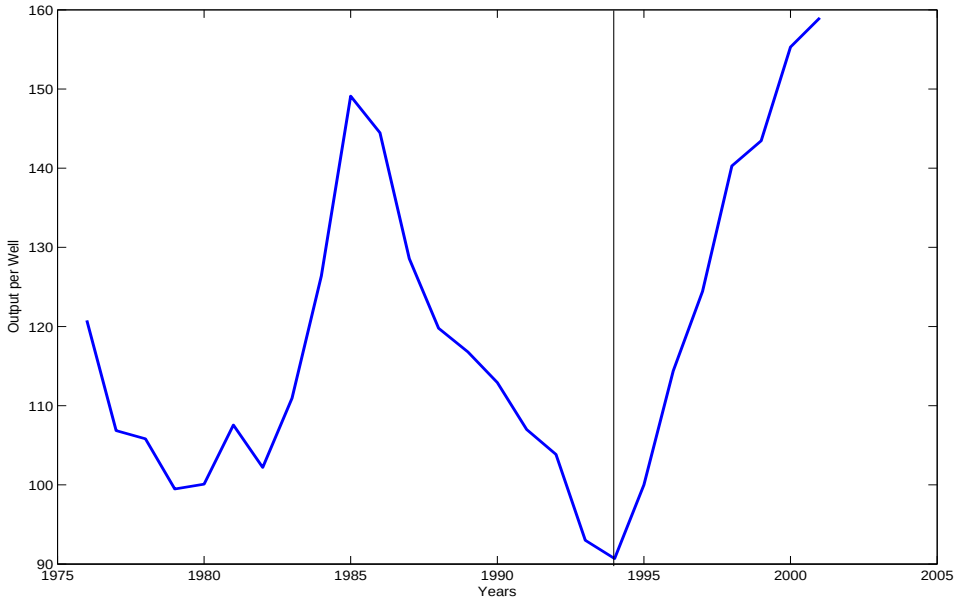
Figure 7: Number of Wells in Production, 1975-2001



The decline in wells coincides with a large increase in well productivity. Figure 8 shows output per well. Petrobras seems to have removed poor wells from production and concentrated its efforts on the best wells. These marginal wells may have remained in use to spread production and the associated employment, tax revenue and other advantages of local production over a wider geographical area.

The geographical distribution of wells does change after the reform, with the number of wells in less productive areas declining. The number of wells in the States of Alagoas, Sergipe, and especially Bahia, states with some of the least productive wells, fell sharply while production has largely shifted to more productive areas. In 1994, wells in Bahia produced an average of 9,300 barrels a year while wells in the State of Rio de Janeiro produced an average of 402,000 barrels a year. The State

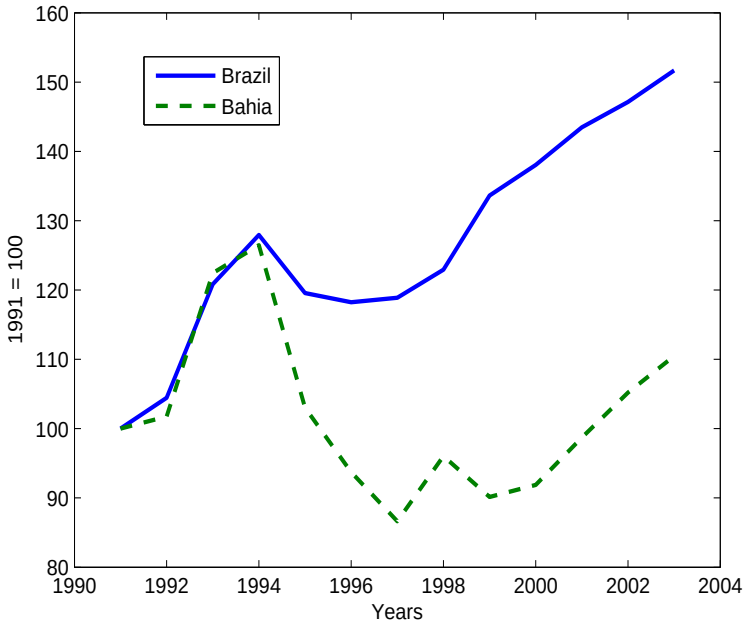
Figure 8: Output Per Well in Production



of Rio de Janeiro is where the high quality Campos reserves are located and is a large source of increased production since the reform. Figure 9 shows the number of wells in Brazil and the state of Bahia. Prior to the reform, the number of wells in both were growing at the same rate. After the reform, the number of wells declined with much of the decline coming in Bahia: From 1994 to 1995, total wells declined by 509 while Bahia's wells declined by 419. Bahia is a politically important state so maintaining production there may have been politically motivated.

The rapid change in the use of inputs in the absence of major technical change suggests that the goals of Petrobras's managers changed with the loss of monopoly rights. The evidence is consistent with non-economic goals, such as spreading tax revenue across a wider base, becoming less important relative to the economic goals of reducing costs and increasing productivity.

Figure 9: Number of Wells in Production, Brazil and Bahia 1991-2004



6 Competition and Productivity

The reform brought about a remarkable increase in productivity. What makes it all the more remarkable was how little competition Petrobras faced over the period we study. Even though Petrobras lost its *de jure* monopoly, *de facto* Petrobras is still a monopolist[14] (Palacios [31] and Lewis [27]). The results show that the threat of competition, even absent actual competition, can increase productivity. We discuss the implications of this finding for studying competition and designing reforms.

Petrobras potentially faces two sources of competition in oil extraction: domestic production and imports. There was little competition from either source.

Recall that the reform was slowly phased in. The Petroleum Law was not passed

[14]There is still barriers to entry and the sector is quite risky due to government intervention. For example, recently the Brazilian government blocked a price increase in the domestic market in response to the high prices of oil in the international market.

until two years after Amendment 9 was adopted. The Petroleum Law laid out a process of gradual opening. It took nearly a decade from the proposal to actual market opening.

There was very little entry into the oil extraction market. Table 2 shows the number of fields that Petrobras and other companies bought in each round that took place since 1998. The last column shows that share of all fields purchased over the period. Petrobras has at least an interest in nearly three quarters of new concessions. Even though the number of areas bought by other companies has increased, they have had little success discovering oil. As can be seen in Table 3, it was not until 2003 that a company aside from Petrobras (Shell) extracted oil in Brazil. In the last line of Table 3 we show the Herfindhal-Hirschman Index (HHI) (HHI is the sum of the square of the market share of all companies in a given industry). It takes values between zero and one, with higher numbers indicating more concentration in the industry). The HHI has not changed much since the end of monopoly. According to Kingstone [25], this has been used as evidence that Petrobras kept all the most promising areas in Round Zero.

Table 2 - Purchase of Rights of Exploitation 1998-2004

Measuring Entry – Number of Fields								
	1998	1999	2000	2001	2002	2003	2004	*Share 98-04 (%)*
Petrobras	96	1	0	7	3	85	57	*54.5*
Petrobras with others	0	6	11	7	5	0	50	*17.3*
Others	19	5	10	19	13	16	47	*28.2*
Total	115	12	21	33	21	101	154	*100*

Source: ANP

There was also very little import penetration. The market was not liberalized until 2001. Petrobras has enormous advantages as the incumbent that cushion it

from foreign competition. It owns all oil terminal facilities in Brazilian ports, though competing facilities are currently being built.

Table 3 - Petrobras's Share of Oil Extraction 2001-2004 (%)

Period	2001	2002	2003	2004
Extraction	100.0	100.0	99.2	96.6
HHI	1.00	1.00	0.98	0.93

Source: Anuario Estatistico (ANP) and Petrobras.

Petrobras dominates most aspects of the Brazilian oil market. (Lewis [27] and Ellsworth and Gibbs [15]). It controls nearly all the refining market. Table 4 shows the percentage of Petrobras in the total refining capacity between 1997 and 2003. Petrobras has 98% of the Brazilian installed capacity to refine oil during the entire period. The end of the monopoly did not affect Petrobras's share in the industry[15]. Maintaining control of exploration and refining gives Petrobras control of the gasoline market. There is little international trade in gasoline since it must be formulated to local standards, which prevents taking full advantage of economies of scale in transportation.

Table 4 - Share of the Installed Refining Capacity 1997-2003 (%)

Period	1997	1998	1999	2000	2001	2002	2003
Petrobras	98.7	98.7	98.5	98.6	98.6	98.3	98.4
Other Companies	1.3	1.3	1.5	1.4	1.4	1.7	1.6
HHI	0.97	0.97	0.97	0.97	0.97	0.97	0.97

Source: Anuario Estatistico (ANP).

[15]Since 1954, four private companies have operated in the refining sector. They were allowed to operate since they were operating prior to the creation of Petrobras (Serour [37])

6.1 Policy Implications

The results have a number of policy implications.

First, economists should be cautious when using market shares as a indicator of competitiveness. Using the HHI, one might conclude that the reform was a failure since Petrobras did not cede its market share. However, it was successful in increasing productivity. Studies using market share data will miss threats of competition, which can have real effects.

Another implication is that if privatization is not possible, reducing barriers to competition can increase productivity. There are no plans to privatize Petrobras and it is unlikely to occur in the future (Kingstone [25]). The removal of the monopoly guarantee alone generated significant political conflict.

The results lend support to the view that the competitive environment is an important determinant of productivity, regardless of ownership. In fact, many instances when only ownership was changed have not resulted in an improvement in performance (Bartel and Harrison [3]). When privatization is not politically viable, increasing competition in the markets of state-owned firms can provide an avenue for improving performance.

7 Conclusion

We show that competition can be a strong spur to productivity growth. The threat of competition alone led to a large and swift increase in Petrobras's productivity.

The results provide support for the idea that closing off competition in the 1970s contributed to Brazil's poor economic performance in the 1980s. Petrobras is a microcosm of the aggregate Brazilian economy. As documented in Bugarin, et al. [10, 9], Brazilian TFP began to fall after the government expanded state-owned enterprises (including Petrobras) and raised trade barriers during the 1970s as a strategy to keep the economy growing despite the worldwide recession. While from 1968 to 1974 the economy grew rapidly due to surging TFP growth, after 1974 TFP began to fall. Bugarin, et al. [10, 9] argue that Brazil's falling TFP in the 1970s was due to the closing off of competition. The findings give support to this argument. While the

study of a single industry, even a large one like oil, cannot definitely answer whether restricting competition reduced TFP, it suggests that this is a fruitful avenue of inquiry.

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A Data

The main source for Brazilian data is the Oil Report ('Relatório do Petróleo') from Ministry of Mines and Energy.

Oil production – thousands barrels per day:

1. Brazil: Oil Report, several years (1954-1990). Anuário Estatístico Brasileiro do Petróleo e do Gás Natural, Agência Nacional do Petróleo, several years (1990-2003).
2. United States: Energy Information Administration, Annual Energy Review, 2001, p. 129.
3. United Kingdom: BP Statistical Review of World Energy, June 2003.
4. Norway: Statistics Norway, Oil and Gas Activity, 4th Quarter 2002, Tables 23 and 24.
5. World production, includes crude oil, shale oil, oil sands and NGLs (natural gas liquids - the liquid content of natural gas where this is recovered separately): BP Statistical Review of World Energy, June 2002.

Employment – oil and gas extraction, and oil and gas extraction services:

1. Brazil: Oil Report and RAIS. Employment has been adjusted for contracting out. Employment by other firms in the oil extraction industry are added to Petrobras's exploration and production employment. Prior to the reform, all these firms were contractors for Petrobras. Beginning in the late 1990s when other firms could begin oil exploration, employment will include employees of some firms that are not Petrobras contractors. For details about RAIS see De Castro, Gomes and Muendler [14].
2. United States: Production and Service Jobs and Wells Drilled. U.S. Department of Labor, Bureau of Labor Statistics, National Employment, Hours, and Earnings (*www.bls.gov*). Oil and gas production (eeu10131001), and oil and gas services (eeu10138001).

3. United Kingdom: Employees extraction of mineral oil and natural gas: SIC 92 CA 11. Department of Trade and Industry, UK.[16]

4. Norway: Statistics Norway, Oil and Gas Activity, 4th Quarter 2002, Table 45.

Oil Prices – prices for oil: Dubai, oil spot crude price. US dollars per barrel. 1972-1985: Arabian Light; 1986-2001: Dubai. Sources: Brazilian Oil Report and BP Statistical Review of World Energy, June 2002.

Natural Gas Prices – prices for natural gas: U.S. Natural Gas Wellhead Price (Dollars per Thousand Cubic Feet). Source: Energy Information Administration, Historical Natural Gas Annual.

Investment – For investment series, in U.S. dollars, we use the number from the Oil Report (several years). The nominal series is converted to 1994 dollars by deflated by the producer prices *Oil and gas field machinery and equipment manufacturing. U.S. Department of Labor, Bureau of Labor Statistics* (pcu333132333132). This series begins in 1965. For 1954 to 1964, we use the U.S. Consumer Price Index.

Wages – U.S.: Average weekly earnings of production workers, oil and gas extraction. U.S. Department of Labor, Bureau of Labor Statistics (ceu1021100004).

A.1 Capital Stock

We constructed the capital stock of Petrobras using the perpetual inventory method on investment (x). The law of motion for capital stock is:

$$k_{t+1} = (1 - \delta)k_t + x_t \tag{3}$$

where k is the capital stock and δ is a constant depreciation rate. We assume a depreciation rate (δ) of 4% per year. Since we start accumulating investment in

[16]Thanks to Philip Beckett and Mike Earp, Department of Trade and Industry, UK.

1954, the year Petrobras was established, the initial capital stock comes from the data.

A.2 Total Output: Oil and Gas

Typically, petroleum exploration and development yields a joint product: oil and natural gas. The typical way to aggregate oil and gas output has been to convert natural gas to 'oil equivalent' at a fixed ratio based on physical thermal content or on some thermal value content implied by relative wellhead prices at a given point in time. There is a major problem with fixed coefficient. Relative values of oil and gas change over time and this affects the problem of firm (see Aldeman and Watkins [1]).

To adjust our data to this possibility, we transform the amount of gas produced into oil using the price of gas relative to oil in the U.S. spot market. Data constraints prevent us from producing country specific series. Though the relative prices can differ across countries, the variances are very similar. The intuition behind these procedure is that in equilibrium the marginal rate of transformation of gas in oil is equal to the relative price. Therefore the total amount of oil produced is given by:

$$y_t = o_t + \frac{p_{gt}}{p_{ot}} g_t \tag{4}$$

Where o_t is the production of oil in period t (thousand barrels day), g_t is the production of gas in period t (million cubic feet day), p_{ot} is the price of oil (Dubai – barrel price), p_{gt} is the price of natural gas (U.S. natural gas wellhead price – dollars per thousand cubic feet).