Inter-American Development Bank
Banco Interamericano de Desarrollo (BID)
Research Department
Departamento de Investigación
Working Paper #525

Innovation and Technology Adoption in Central America

by

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Inter-American Development Bank

July 2005

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Rodríguez-Clare, Andrés.

Innovation and technology adoption in Central America / by Andrés Rodríguez-Clare.

p. cm.
(Research Department working paper series ; 525)
Includes bibliographical references.

1. Technological innovations--Central America. 2. Educational technology—Central America. 3. Intellectual property—Central America. I. Inter-American Development Bank. Research Dept. II. Title. III. Series.

338.064 R398--------dc22

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Abstract

In spite of deep structural reforms, Central American countries have failed to experience rapid and stable growth in recent years. This paper explores whether and to what extent we can consider lack of innovation and technology adoption as a main reason for this disappointing experience. The paper starts by documenting that technology adoption and innovation are indeed very low, and then turns to a more qualitative and eclectic analysis drawing on interviews and case studies to try to understand the reasons for this. Four hypotheses are explored: weak intellectual property rights, low competition, lack of finance and low levels of education. The conclusion that emerges is that the last two of these four hypotheses may be especially relevant for the region. The paper concludes with several policy recommendations.

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1. Introduction

Growth has been disappointing in the countries of Central America in the last 50 years. In fact, the region as a whole has grown at a slower pace than Sub-Saharan Africa from 1950 to the late 1990s (Esquivel, 2001). From Klenow and Rodríguez-Clare (1997) and Easterly and Levine (2001), we know that this slow growth is due to a low rate of total factor productivity (TFP) growth. The key question then becomes: how can Central American countries increase their TFP growth rate?

Although at different speeds, and with different degrees of success, all Central American countries conducted significant structural reforms in the 1990s. The results have been favorable in terms of lowering inflation and fiscal deficits, allowing these countries to achieve higher levels of macroeconomic stability. The reforms have also succeeded in increasing inflows of Foreign Direct Investment (FDI) to the region. Unfortunately, the results have not been as positive in terms of increasing economic growth, and TFP growth remains low.

Presumably, low TFP growth is due to low rates of innovation and technology adoption. To explore this issue, in Section 2 we will look at different measures of innovation and technology adoption to get an idea about the amount invested in these activities in the region. The robust and not surprising conclusion that emerges is that technological efforts in the region are low. Section 2 analyzes different explanations for this, focusing on the impact of low education levels and weak intellectual property rights (IPR) protection.

The analysis in Section 2 is quantitative, seeking to learn as much as possible from the available aggregate data. The sections that follow are more qualitative in nature and are based mostly on interviews: the goal is to learn more about innovation and technology adoption by looking in depth at particular firms, sectors and institutions in the region. Section 3 discusses the findings from interviews with innovative firms in the Central American countries, while Sections 4 and 5 present case studies of the software and food sectors, respectively, in Costa Rica. These sectors were chosen because they appear to have enjoyed a rapid rate of technological progress in recent years. Hopefully, they may provide clues about the elements that favor such a positive phenomenon. Section 6 presents the third and last case study centered in Costa Rica: the role of the two major public universities (Universidad de Costa Rica, UCR, and Instituto Tecnológico de Costa Rica, ITCR) in research efforts in the country.

The three case studies presented in Sections 4, 5 and 6 point to the importance of higher education systems for research. Hence, Section 7 is devoted to an analysis of higher education systems in the region. The main goals here are the identification of market failures and the derivation of policy recommendations to strengthen these systems and improve their contribution to research efforts in the private sector. Finally, Section 8 concludes with a summary and overall policy recommendations for the Central American countries.

2. Innovation and Technology Adoption in Central America: A Quantitative Analysis

This section explores different ways to measure innovation and technology adoption. We will see that, with the exception of Costa Rica, investment in these activities is low in Central America. The section ends with an analysis of the different explanations that exist for this phenomenon.

A. Innovation in Central America

A large literature exists on alternative ways to measure innovation. Here we follow conventional practice and use both output and input measures. As output measures of innovation, we use patents granted in the United States to agents in Central American countries as well as domestic patents. We will also examine data on research published in academic journals in order to measure the research output of universities, which is more closely associated with basic research than commercial research and innovation. As input measures, we use total investment in research and development (R&D), as well as the number of scientists and engineers engaged in R&D.

1. U. S. Patents

The benefits of using U.S. patents as a measure of innovation are well known (Griliches, 1991). This measure is comparable across countries and across time. Moreover, since the cost of obtaining a U.S. patent is not negligible (around $20,000, according to Salazar, 2002), these patents must reflect a high average value.

Table 1 presents patents granted in the United States per 100,000 people for each country in the region, together with the regional average, and the data for a group of reference countries (Mexico, United States, Brazil, Chile, Singapore, South Korea and Taiwan). As the table shows, U.S. patenting is negligible for all the Central American countries except Costa Rica. This, of

course, is not surprising given the income level of these countries. In fact, according to Loayza, Fajnzylber and Calderón (2002), U. S. patenting per capita (subsequently referred to as the patenting ratio) in the region is not low when countries' income level is taken into account.

Table 1 also shows that Costa Rica had the highest patenting ratio in Latin America from 1993 to 1997. In the Central American region, Honduras came in second place, but its patenting ratio was only one third of the Costa Rican level. In term of the temporal dimension, patenting has stagnated in recent decades, except again for Costa Rica and Honduras, both of which tripled their patenting ratio from 1988-1992 to 1993-1997. This rate of growth is higher than in Brazil, Chile and Mexico, all of which only doubled their patenting ratio. For the other countries in the region, patenting in the period 1993-1997 is even lower than it was in 1970-1972.

For the case of Costa Rica and Honduras, it becomes important to understand who is patenting and in what areas. As to the first question—who is patenting?—the data show that in Honduras it is U.S. corporations that are registering the patents, whereas this is not the case for Costa Rica. In Honduras, out of the total 12 U. S. patents obtained in the period 1988-1997, nine were assigned to U.S. corporations. In the case of Costa Rica, out of the total 20 U.S. patents assigned, only five were assigned to U. S. corporations.

As to the second question, the areas in which patents are issued, the data reveal that the main area of patenting is in "mechanical" for Costa Rica and "agriculture, husbandry and food" for Honduras. Out of the 20 patents obtained by Costa Rica in the period 1988-1997, five were in "miscellaneous-mechanical," four in "miscellaneous-others" and three in "furniture, house fixtures." Out of the 12 patents obtained by Honduras in the period 1988-1997, the only significant grouping is in "agriculture, husbandry, food" with six patents, half of the total.

To summarize, patenting in the region is very low and has stagnated in recent decades. This is not surprising given the low income levels prevailing in the region. Deviating slightly from this general observation, Costa Rica's patenting ratio tripled from 1988-1992 to 1993-1997, reaching levels above those of Mexico, Chile and Brazil in that period. But even for Costa Rica, an analysis of the areas where the country has patented suggest that there is no strong area of innovation; on the contrary, the data suggest that patenting is still an isolated activity of a few individuals rather than the outcome of an advanced innovation system.

2. Domestic Patents

The data on domestic patenting are not as useful as the data on U.S. patenting because differences in national requirements make it impossible to draw comparisons across countries. Moreover, there are constant changes in laws and in the definitions and procedures followed by the national patent offices, so that the data do not permit clear inferences along the time dimension either. Still, domestic patenting data can be useful for determining who is patenting in each country.

Salazar (2002) obtained data directly from the National Patent Offices of Honduras, El Salvador and Nicaragua. For Costa Rica and Guatemala I only have the data published by RICYT (2002). With the exception of Costa Rica, in Central American countries most patents are granted to foreigners. As shown in Table 2, this pattern is common in small countries. Even in the case of Canada, patents granted to nationals are less than 8 percent of the total patents granted. This is common in other countries of the OECD: according to data from Eaton and Kortum (1996), the share of patents granted to nationals in Italy, Netherlands, Portugal and Spain, to cite just four cases, was 5.5 percent, 5.7 percent, 2.2 percent and 7.5 percent, respectively.

This comparison with more developed countries implies that we should not think of the low share of patents granted domestically to nationals as a sign of weakness. This is what should be expected for small countries, even advanced ones.

As mentioned above, domestic patenting data is not strictly comparable across countries. Still, it is hard to resist making a few additional remarks based on Table 2. First, it is clear that innovation is extremely low in all the Central American countries when we measure innovation by domestic patenting by nationals. This is in accord with data reviewed above for U.S. patenting. Second, it is also the case that domestic patenting *by foreigners* is much lower in Central American countries than in comparator countries such as Mexico, Chile, and Canada.

This second observation merits some consideration. We should start from a basic question: why do agents choose to patent in a particular country? It is not only that they want to protect their intellectual property; the relevant point is that they also want to *exploit* that intellectual property in that particular country. Since patenting entails a fixed cost, the decision hinges on the comparison between this cost and the benefit of patenting, which is determined by the expected profits associated with exploiting the patent in that country. This immediately

implies that agents will not want to patent in a country with a small market for the good in question, since this would limit the possible profits that can be generated and hence make it hard to justify the fixed cost associated with patenting. There are two additional reasons why agents may not want to patent in a particular country: first, agents do not trust the patent system in the country; and second, agents think that there is a negligible risk of somebody copying their design, given the low technology level of the country. The first point is certainly relevant for the Central American region, given the low marks these countries get for the strength of their IPR system. As to the second point, it must be qualified because it is always possible for foreign companies to copy the design (see Table 7.7 of De Ferranti et al., 2002). This may be a valid issue in large and poor countries, such as China and India: a company may want to patent there, even if there are no domestic companies with the technological capacity to copy their product, because they would want to prevent other foreign companies from doing so.

3. Academic Publications

This project is mostly concerned with commercial innovation and technology adoption, so it is not obvious why we would want to look at data related to academic research in universities. The reason is that these data provide a good indication of the quality of universities, which in turn determines the quality of their graduates and their possible role in joint R&D with the productive sector.

Table 3 provides basic data on publications by country in academic journals. Several comments are in order. First, it is clear that Costa Rica has a much more developed academic environment than the rest of the Central American countries. The research output of other countries appears extremely low, especially in El Salvador, but also in Honduras and Nicaragua.

Second, all countries except Guatemala have been increasing their academic research levels. Nicaragua stands out in this regard, with an increase from a yearly average of only 2.4 academic publications in the 1981-1985 period (the lowest in the region) to 23.8 publications in the second half of the 1990s, surpassing Honduras and El Salvador. El Salvador barely manages to increase its research output from the first half of the 1980s to the second half of the 1990s, but it is notable that most of this stagnation is due to the 1980s; in the 1990s there is a strong increase, from 5.2 academic publications per year in the first half of the decade to 9.4 in the second half.

4. R&D Data

We now turn to data on R&D. Figure 1 shows what we already know, namely that R&D spending as a percentage of GDP is very low in the region, something entirely expected given countries' low levels of GDP per capita. Figure 2 further illustrates the well-known fact that, at low levels of development, private (for-profit) R&D spending is a small part of total R&D. Most R&D spending in Central America is paid for by governments or by (mostly foreign) NGOs and performed by universities. This is a potential problem to the extent that the research performed by universities is not in accord with the needs of the productive sector.

One interesting aspect to note is that Costa Rica spends less on R&D than Chile or Mexico and yet generates more patents than either. This is the case even if we restrict our attention to privately financed R&D. This could be interpreted as a higher efficiency of R&D, but only if we reduce R&D to patent generation. It is clear, however, that this is not the only purpose of R&D. Another problem with this conclusion is that—particularly for LDCs with low levels of R&D spending—R&D data are very noisy. Thus, it is difficult to draw strong conclusions from small variations in R&D data among LDCs.

As a way to explore this issue further, we now turn to the survey conducted for the *World Competitiveness Report* 2001-2002. This survey asked about the opinion regarding the level of R&D spending in each country. As Table 4 shows, the perception is not entirely consistent with the R&D data, since respondents view R&D spending in Costa Rica as being higher than in Mexico and Chile. But the differences are small, and these surveys also have high margins of error. The tentative conclusion we can draw is that differences in R&D spending are not significant among these three countries.

Another useful way to shed light on R&D spending in the region is by reviewing data on the number of people engaged in research. According to the data from RYCIT (2002), shown in Figure 3, the relative number of people devoted to research is extremely low in Central America, as well as in Mexico and Chile. These data again show significantly higher levels for Costa Rica than for the Central American countries (although we only have data for El Salvador and Nicaragua). Moreover, the data show a higher level for Costa Rica than Mexico and Chile, although the difference with Chile is negligible.[1]

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[1] It is interesting to compare the data on the number of people engaged in R&D with the data on R&D spending as a proportion of GDP. If the production function for research were the same as for output, then these two ratios would

Is low R&D spending in the Central American region related to its low income levels? Using data on R&D spending from Lederman and Sáenz (2003) and GDP per capita from Heston, Summers and Bettina (2002), I ran a simple regression of R&D/GDP on GDP per capita and year dummies. The estimated coefficient for GDP per capita (in thousands) is 0.00097, with a t- statistic of 29.11 (the R squared of the regression is 0.44). Figure 4 shows the partial correlation between these two variables (adjusting for the year dummies). A difference of $10,000 in income per capita would imply a difference of almost 1 percentage point in R&D/GDP between two countries.

Table 5 shows the predicted R&D/GDP for the Central American countries, together with Chile, Mexico and the United States. It is clear that the low R&D spending in the Central American countries is generally consistent with their low income levels. For example, according to the regression, Nicaragua should be spending 0.09 percent of GDP on R&D, and it is actually spending 0.13 percent. More generally, their low income levels lead to an expectation of R&D/GDP below one percent in all the countries listed in the table except, of course, the United States. Beyond this general consistency, however, there are also some interesting discrepancies between actual and predicted levels. In particular, if we believe the data, El Salvador spends about three times as much on R&D as would be expected given its income level. On the other hand, Chile, Costa Rica, Guatemala and Mexico all have R&D spending levels below the levels that would be expected for their income levels. Still, I would not make much of these insufficiencies given the high measurement error that is likely to prevail here.

5. Summary

Central American countries in general have low indicators of innovation: low U.S. patenting, low domestic patenting, low spending on R&D as a share of GDP and a small number of researchers in relation to the workforce. Moreover, all the countries in the region have a small fraction of R&D financed by the private sector. These low indicators of innovation are, of course, not surprising given the region's low income levels.

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be the same. This, of course, is a very restrictive condition, but it is interesting nevertheless to see how much the two ratios differ. In the case of Costa Rica, to focus on just one case, R&D spending is equivalent to 0.27 percent of GDP, whereas only 0.15 percent of the workforce is engaged in research. A simple explanation of this divergence is that the average wage of researchers is higher than the national average wage.

Costa Rica is significantly ahead of the rest of the Central American countries, again something that is not surprising given Costa Rica's higher income per capita relative to the rest of the countries. The comparison of Costa Rica with Mexico and Chile leads to the conclusion that the data may be underestimating Costa Rica's R&D spending. Indeed, except in this variable, Costa Rica comes out ahead in everything in comparison with these two countries: it comes out ahead in U.S. patenting per capita, in researchers per capita and in the *World Competitiveness Report* survey on R&D spending.

The question then is: if the Central American countries are engaged in as much innovation as should be expected given their income levels, why worry about this? There are two reasons. First, we know that innovation is lower than the optimal level given the positive externalities associated with it. In other words, the social rate of return is higher than the private return to R&D (Griliches, 1992). Thus, it is always important to understand the determinants of innovation and to think about policies that could increase innovation. Second, and more importantly, countries that embark on phases of fast growth are likely to see their innovation numbers increasing ahead of their income level. Surely this is not causal, but it masks something more important going on at the same time, namely higher adoption rates, which I posit would indeed be causing higher growth rates.

B. Technology Adoption in Central America

In the previous section we reviewed different ways to measure innovation. We saw that it can be measured by its results (domestic and foreign patents, academic publications), and by its inputs (R&D spending, scientists and engineers engaged in R&D). Unfortunately, there are no such indicators for technology adoption, which is an even more diffuse and abstract notion than innovation.

In the technology adoption models proposed by Parente and Prescott (1994) and Howitt (2000), countries must invest in technology adoption to benefit from the technologies developed elsewhere. In both of these models, the level of technology adoption effort determines the country's relative productivity, but not its growth rate, which in steady state is given by the rate of growth of the world's technology frontier. This feature arises because of what is commonly referred to as the "benefits of backwardness," whereby countries with a lower relative productivity level have to invest less in order to maintain that relative productivity level than

countries with a higher level. This arises for different reasons in these two models: in Parente and Prescott's model, technology adoption is less costly for more backward countries (presumably because these technologies have been standardized and so are easier to adopt, or because countries have more available technological options from which to choose); in Howitt's model, more backward countries benefit more from any given technology adoption effort, because every time they are successful they jump all the way to the frontier.[2]

In the context of this type of model, technology adoption efforts could be indirectly measured by each country's relative productivity level. Table 6 presents relative TFP levels of the countries of Central America and the comparator countries we have been considering (Chile and Mexico), together with Panama. These data are taken from Klenow and Rodríguez-Clare (2003) and are calculated with the new Penn World Table (Heston, Summers and Bettina, 2003), together with Barro and Lee schooling data in a similar way as in Klenow and Rodríguez-Clare (1997). These levels are relative to the United States, the country that is assumed to be marking the technology "frontier."

The table shows Central American countries' with relative TFP levels ranging between 31 percent for Honduras to 67 percent for Guatemala, all below Chile's level of 68.9 percent. These numbers may not seem that low at first glance, but one should recall that a low TFP level also leads to low investment in physical and perhaps even in human capital. As argued in Klenow and Rodríguez-Clare, if we assume that the production function is $Y = K^{\alpha}(AH)^{1-\alpha}$, then $TFP = A^{1-\alpha}$ and hence the full effect of a low TFP level is $A = TFP^{1/(1-\alpha)}$. The relative A level, shown in the third column of Table 6, provides figures ranging from 17.4 percent for Honduras to 55 percent for Guatemala. To see how low these numbers are, consider that the historic rate of growth of TFP in the United States is around 1.5 percent per year. Thus, a country with a relative TFP level of 31 percent has the TFP level that the U. S. had 79 years ago (fourth column in Table 6).

Table 6 also shows that all the countries except Chile and El Salvador experienced a decline in their relative TFP levels, although El Salvador basically remained at the same level. This shows that the Central American countries are not even adopting technology at the rate required to maintain their relative technological levels. The counterpart of this is, of course, the

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[2] See Klenow and Rodríguez-Clare (2003) for a more general treatment of this type of models, the reason why they

average annual TFP growth rate during the 1990s, which is shown in the last column. Only Chile achieved a decent growth rate of 1.9 percent. Honduras actually had a significantly negative TFP growth rate of –2.5 percent.

It is surprising to see such a high relative TFP level for Guatemala, which is almost as high as Chile's corresponding level. It is also surprising that both El Salvador and Guatemala have higher relative TFP levels than Costa Rica, which is the Central American country with the highest innovation indicators. To a large extent, this all comes from the fact that the relative labor productivity levels are very similar for Costa Rica, Guatemala and El Salvador. In the Penn World Tables (Mark 6.1), Costa Rica's income per capita is almost 50 percent and 30 percent higher than the corresponding levels for Guatemala and El Salvador, respectively. But its participation rate (workforce relative to total population) is also significantly higher: it is 40 percent in Costa Rica, whereas it is only 29 percent in Guatemala and 33 percent in El Salvador.

Table 7 may help us to understand this situation. In the first column we see, again, that Costa Rica, Guatemala and El Salvador have very similar relative labor productivity levels. However, both Guatemala and El Salvador have significantly lower relative capital-labor ratios, and slightly lower relative human capital per worker levels. Hence, these two countries must have higher relative TFP levels than Costa Rica.

To check the accuracy of these numbers from the Penn World Tables (PWT), I obtained PPP and GDP data for the year 2000 from the *World Development Indicators* (WDI) dataset. I adjusted the capital stocks calculated by Klenow and Rodríguez-Clare with the ratio of the WDI and PWT GDP levels, and then recalculated TFP numbers. The results of this exercise are shown in Table 8. It is apparent that, for some reason, Costa Rica's GDP level in the PWT is significantly lower than in the WDI dataset. The WDI seems much more accurate than that of the PWT. We can see that once we use the WDI adjusted numbers, Costa Rica's relative TFP level becomes even higher than Chile's, although the most important point is that now Chile, Costa Rica, Guatemala, and El Salvador all come out with very similar relative TFP levels.

It is important to compare these TFP numbers with those calculated by Loayza, Fajnzylber and Calderón (2002) using better data sources for the Latin American countries (especially for the number of employed workers). Unfortunately, I do not have these data in levels, but I do have the growth rates, which are presented in Table 9. In the type of model

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are appealing, and an analysis of their features.

discussed above, a TFP growth rate higher than the growth rate of the world's technology frontier (which can be approximated by the rate of growth of rich-mature economies, such as the United States or the whole OECD) would imply a transition towards a higher relative TFP level. Is this the case for the Central American countries during the 1990s according to the TFP growth rates calculated by Loayza, Fajnzylber and Calderón (2002)? For this period, given TFP growth rates (according to Klenow and Rodríguez-Clare, 2003) of 0.8 percent for the United States and 0.9 percent for the OECD of 0.9, we can see that only Costa Rica appears to be in a transition towards a higher relative TFP level in Central America. El Salvador and Guatemala have very low TFP growth rates, and Nicaragua and Honduras have *negative* growth rates.

There are, however, some concerns about these numbers. First, the accounting effect of Intel could well lead to an overestimation of Costa Rica's TFP growth rate in the 1990s. Rodríguez-Clare, Sáenz and Trejos (2002) provide a much more detailed and careful growth decomposition for Costa Rica that adjusts for the possible accounting distortion caused by Intel. This leads to a TFP growth rate of 0.9 percent for the period 1990-2000. This suggests that Costa Rica has just been able to maintain its relative TFP level. Second, Honduras' significantly negative TFP growth rate (–1.5 percent) could be due in part to the devastation caused by Hurricane Mitch. Unfortunately, I do not have a TFP growth calculation for Honduras up to 1998, before the effect of Mitch, but we can gain some insight into this matter by noting that Honduras' GDP declined by 1.9 percent in 1999. This decline, however, is too small to explain the whole negative TFP growth effect, which implies that in 2000 Honduras' TFP level was almost 15 percent lower than in 1990.

As an additional robustness check on these conclusions, I now consider a growth-decomposition for the Central American countries performed by Robles and Rodríguez-Clare (2003), which is reproduced in Table 10. The extreme conclusions drawn from the Loayza, Fajnzylber and Calderón (2002) growth decomposition continue to hold: Costa Rica is the country with the highest TFP growth rate in the 1990s, whereas Honduras has a significantly negative TFP growth rate. But El Salvador exhibits a higher TFP growth rate than in Loayza, Fajnzylber and Calderón, whereas Nicaragua's TFP growth rate is now positive.

Summarizing what has been presented thus far, it is clear that effective investment in technology adoption is low, as revealed by the countries' low relative TFP levels. Moreover, it is not the case that these countries are now in a transition towards higher relative TFP levels: in

fact, if anything, they could be transitioning towards a lower relative TFP level, with the possible exception of Costa Rica.

There are, of course, many other indicators of technology level that could be used, but all have serious weaknesses. Here, before ending this section, I review one such indicator, namely the number of personal computers per 1,000 people. The stock of PCs in relation to the number of people is a good indicator of technology adoption because computers represent a general technology that is a complement to many other new technologies. Thus, a low number of computers is indicative of low technology adoption efforts in the whole economy. Table 11 shows these data for the Central American countries and a group of comparators (both countries and regions). Consistent with what we have seen so far in this section, Costa Rica has the highest stock of PCs per person in the region, even higher than the figures for Chile and Mexico. The figure is much lower in the rest of the countries in the region, where it is substantially below the world's average.

C. Determinants of Innovation and Technology Adoption in Central America

1. General Remarks

In the previous two sections we have analyzed different indicators of innovation and technology adoption to conclude that both are very low in Central America. In this subsection we will briefly review the different explanations for this low level of innovation in the region. We will then explore two of those explanations in more detail: the first explanation is that low innovation is due to low education levels; the second is that low innovation is due to a weak Intellectual Property Rights (IPR) regime. The analysis in this subsection uses available aggregate data to explore these issues; in the next sections we turn to a more qualitative analysis.

In this section I will generally use the term R&D to refer to both formal and informal or unmeasured R&D. This broad concept of R&D is associated with both innovation and technology adoption.

Consider the model in Howitt (2000). In that model, discussed in the previous subsection, a low R&D investment rate can arise for two reasons: a low effectiveness of the National Innovation System (NIS), which means low productivity in converting resources into new ideas, and a high overall implicit tax rate on R&D. I say "implicit" tax rate on R&D, of course, because it is not necessary to restrict attention to explicit taxes on R&D. In fact, such taxes are likely to

be just as high as explicit taxes on other types of economic activity, and significantly lower than the high tax rates necessary to explain the low R&D investment rates seen in the data. But implicit taxes on R&D could be significantly higher than on other productive activities because the product of R&D effort is ideas, and it is clear that it is harder to protect ideas than physical assets: one generally finds that the IPR regime is weaker than the system that protects private property for other, more tangible assets.

This simple analysis leads to two hypotheses for the low R&D investment rate in the region: an ineffective NIS and a weak IPR regime. An additional and very common hypothesis is that the low education levels in the region explain the low R&D activity. There are two different reasons why this may be so: first, because R&D is intensive in human capital in relation to other activities; and second, because human-capital intensive sectors are also R&D intensive. Conversely, a low human-capital endowment may leads to specialization in unskilled labor-intensive sectors, which in turn lead to a low demand for R&D activities.

Two other common hypotheses in the literature to explain low R&D spending: one is lack of competition, and the other is lack of finance. In the rest of this subsection I will focus on two of these five hypotheses: education and the IPR regime. Using a more qualitative analysis, the rest of the paper will shed light on the other hypotheses, and the final section will pull together all the arguments and draw some conclusions.

2. The Education Hypothesis

It is clear that the education levels in the Central American countries are very low. Table 12, taken from Barro and Lee (2000), shows data for different education variables for the Central American countries and the usual comparator countries. El Salvador, Guatemala, Honduras and Nicaragua all have a labor force with an average of less than 5 years of education. Costa Rica has a corresponding level of 6, whereas Mexico has almost 7 and Chile almost 8. These levels stand in contrast to the U.S. level of 12 years of schooling.

Another education variable that may be an important determinant of R&D investment rates is the share of the labor force with some years of post-secondary schooling. Costa Rica tops the list in the region, with 18.6 percent, higher even than in Chile (15.8 percent). Guatemala, Honduras and Nicaragua have levels that are significantly below 10 percent, whereas El Salvador

reaches 10.6 percent, almost as high as Mexico (11.3 percent). These levels compare to the U.S. figure of 50.1 percent.

As a check on these data, Table 13, provides a decomposition of the labor force according to education levels, drawn from the IDB's collection of household surveys for the Latin American region. As in Table 12, the percentage of the population with some level of tertiary schooling is significantly lower than 10 percent in Guatemala, Honduras and Nicaragua, whereas it is 12.3 percent in El Salvador and 16.8 percent in Costa Rica. According to these data, however, Costa Rica's level is lower than Chile's (22.6 percent).

Whereas the previous data represent current stocks of education, Table 14 presents related data for the flows. In particular, it shows data on the gross enrollment ratio in tertiary education for 1991 and 1997, together with the proportion of students enrolled in scientific and engineering areas. For Guatemala, Honduras and Nicaragua, the low flows are consistent with the low stocks commented above. Honduras and Nicaragua show a significant improvement from 1991 to 1997, but this is not the case for Guatemala. It is interesting to note that Mexico exhibits a low tertiary enrollment ratio, even lower than its corresponding stock. Costa Rica has an enrollment ratio that is very similar to Chile's, which in turn is almost twice that of Mexico.

In spite of the low tertiary enrollment rates presented in Table 14, it is not possible to draw strong conclusions regarding the allocation of students to different fields. In fact, the country with the lowest share of tertiary students enrolled in scientific and engineering areas is the United States!

At this point, it is fruitful to analyze the cross-country data to examine how R&D spending relative to GDP varies with education levels. As one might expect, there is a strong positive correlation between these two variables across countries, both when education levels are measured as average years of schooling of the working-age population (25 to 65, from Barro and Lee's database), and when education levels are measured as the proportion of the labor force with some post-secondary education. As Figures 5 and 6 show, the relation between R&D investment rate and mean years of education appears to be quadratic, whereas the relation

between R&D investment rate and the second education variable just mentioned appears to be linear.[3]

In a regression of the R&D investment share on both the share of the working age population with post-secondary education and the square of the mean years of schooling of the working age population, only the coefficient on the second variable remains significant, as shown in Table 15. Given that R&D activities are likely to be intensive in workers with college education (engineers, scientists), it is surprising that the coefficient for this variable becomes insignificant in a regression when we also include the square of the mean years of schooling. This may suggest that the relationship between education variables and R&D intensity is not coming from the simple channel whereby larger numbers of scientists and engineers allow firms and other institutions to increase the amount of research they conduct. Instead, the relationship could be coming from a much more complex interaction, as we explain below.[4]

A low education level would naturally lead to a low R&D investment rate, since R&D is a human capital-intensive activity compared to other economic activities. The question is whether there is demand for research in poor countries that is not undertaken because of the scarcity of human capital. If this were the case, it would be because such scarcity drives up the cost of human capital and hence the relative cost of research. This is consistent with the finding that the Mincer coefficient is higher in poor than rich countries (see Bils and Klenow, 2000), but the difference appears too small to have much significance in accounting for the large disparity in R&D investment rates across countries.

Table 16 shows that, indeed, the Mincer coefficient is higher for the Central American countries than Canada (Bils and Klenow do not have an estimate for the Mincer coefficient in the United States) and most rich countries (not shown in the table), which have coefficients close to the one for Canada. Honduras has a Mincer coefficient that is more than four times higher than Canada's. To see the importance of this, we use the Mincer coefficient in each country to calculate an implicit skill premium for college-educated workers relative to those with only secondary education. The result is shown in the second column of Table 16. The maximum skill

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[3] For this exercise I used R&D data from Lederman and Sáenz (2003) together with GDP data from Heston, Summers and Bettina (2002). Observations are a pooled data set for as many country-years as I could obtain from these two datasets. I used year dummies in all the regressions.

[4] Another possibility, of course, is that the proportion of workers with some post-secondary schooling has higher measurement error than mean years of education.

premium would be for Honduras, with a skill premium of 2, whereas the corresponding level would be 1.2 in Canada. This would imply that, at most, the relative cost of R&D (in terms of output) would be two-thirds higher in Honduras than in Canada; it would be only 25 percent higher in Costa Rica than in Canada. It is difficult to believe that these higher relative costs of R&D would explain R&D investment rates that are an order of magnitude lower in Central America than in rich countries.[5,6]

This is not to say, of course, that low education levels are not important in explaining low R&D in poor countries. Imagine a country with a high proportion of workers with completed secondary education, but very few workers with post-secondary education. The estimated Mincer coefficient would probably be low, given the high proportion of workers with secondary education, but the wages of workers with college education may still be much higher than those implied by the single Mincer coefficient. This conjecture, however, is not consistent with the data, which shows that skill premia of workers with tertiary education relative to those with secondary education is not much higher in Latin America than in advanced countries (De Ferranti et al., 2002).

Another possibility is that what matters for R&D is not only the share of workers with college education, but also the share of workers with the right type of education, such as engineering. One would have to check the data for this, which I do not have, but my impression is that the relative wages of engineers are not much higher in poor countries than in rich ones. A related idea is that the market for workers is structured in such a way that prices do not reflect scarcity in the usual way. In other words, the scarcity of scientists and engineers may not lead to high wages for their services. Firms in this case would complain about lack of engineers more than about high cost of engineers. Indeed, as Table 17 shows, firms do complain about this in the region to a larger extent than in the United States. The countries that do best in the region are, by far, Chile and Costa Rica.

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[5] One could tell a story where low human capital leads a country to carry out little R&D even while the skill premium remains low because of international trade (factor price equalization). But if this were the case, then the fruits of research would have to be tradable, and the poor country would not have low productivity levels as a result of low R&D. Grossman and Helpman (1992) have a model discussing these possibilities.

[6] There is actually a way through which low education levels could lead to low R&D investment rates without generating the implication of high skill premia. This mechanism relies on non-convexities in R&D activities. Imagine that to conduct R&D a firm needs several specialized professionals. If there are very few such professionals in a country, then a firm may simply decide not to conduct R&D in the country. Thus, there is no demand and the returns for those professionals would remain low. This is a case where multiple equilibria could arise.

Another possibility, as mentioned above, is that low human capital matters for R&D through a different channel than the one we have explored so far. The idea is that the stock of human capital affects aggregate R&D in an indirect way: namely, through its effect on sectoral composition, since it is likely that human capital-intensive sectors are also intensive in R&D. Thus, low human capital leads to specialization in unskilled labor-intensive goods, which then leads to low R&D investment without generating a high skill premium.[7] It seems to me that this mechanism could actually be important, but exploring this idea falls outside of the scope of this paper.

To close this subsection, it is interesting to compare the predicted R&D share according to the regression mentioned above (Table 15) and actual R&D shares according to the Lederman-Sáenz (2003) database; the results are shown in Table 18. These results indicate that, in general, the Central American countries, and also Chile and Mexico, are carrying out less R&D than would be expected given their education levels. Clearly, then, there is something else that is constraining R&D in the region, beyond low education levels.

3. The Role of IPR in Inducing Innovation[8]

a) Introductory Comments

There is much empirical work on the role of intellectual property rights (IPR) in inducing innovation. Typically, a regression is run where the dependent variable is R&D/GDP and the independent variable is an index of the strength of the IPR regime. Unfortunately, most of this work is plagued by problems of endogeneity.

Recent work has tackled these problems through two approaches: the use of IV estimation for cross-country regressions, and country fixed-effects estimation with panel data. Given the difficulty in finding instruments in cross-section estimation, I think that the country fixed-effects estimation is the most promising approach, but it is still unsatisfactory because it is difficult to draw firm conclusions about causality: most countries institute IPR systems as a result of external and domestic pressure that arises precisely when countries start to increase

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[7] One criticism of this argument is that it would lead to a situation where terms of trade are dynamically improving for poor countries, since they would be producing goods with low R&D and hence low TFP growth, in relation to the goods produced by rich countries. There are two ways to avoid this implication: first, if preferences are continuously shifting towards more advanced goods (as in Stokey, 1991, and Young, 1991); and second, if instead of higher TFP, R&D leads to higher quality goods, as is the case with computers.

trade and productivity, which goes together with increased R&D spending. In some studies, this is tackled through the use of lagged variables as instruments, but it is not clear that the conditions under which this method is valid are satisfied in the present case.

Because of these problems with the econometric literature, in this section I will instead focus on more general issues regarding the possible role of IPR systems in inducing innovation. This is important because there is much confusion about the way the patent system works.

Patents are conceived as a title that confers exclusive rights to exploiting the invention for a specific period, in exchange for divulging the information related to the invention. More importantly for our purposes, patents are territorial, which means that a patent granted in a country only protects the invention in that particular country. Thus, if the developer of a new technology obtains a patent in El Salvador, then others cannot use that technology for commercial gain in El Salvador without purchasing a license. Others could, however, use that same technology in Costa Rica, or in the United States, without purchasing a license.

This implies that an inventor has to determine where to patent. Since patenting is costly, an inventor will patent in a country only if the benefits of having that patent in *that* country exceed the patenting cost. The patenting cost varies across countries. For instance, according to Silvia Salazar, a Costa Rican expert on IPR who wrote a short note for this project, the cost of patenting in Costa Rica is approximately $3,000, compared to approximately $20,000 in the United States. Still, the main determinant of patenting is differences in the benefits across countries.

There are two main determinants of the benefits of patenting in a country. The first and perhaps most important determinant is the size of the market for the invention. Unless the invention is very specific, this will be determined by total GDP. Thus, the benefit of a patent for a consumer product will be much more valuable in the United States than in Costa Rica, given differences in market sizes for consumer goods. This will not always be the case, however. An example presented by Salazar (2002) is a new technology related to the cultivation of bananas: a patent for such a technology would have zero value in the United States, whereas it would certainly be valuable in Costa Rica.

The second determinant of the benefits of patenting in a country is the risk that the innovation will be copied and exploited by somebody else in that country. Thus, it may not make

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[8] This section draws heavily on Salazar (2002).

sense to patent a new sophisticated technology in a poor country, not so much because of the small size of the country but because of the low risk that such a technology would be copied there.

Given these basic ideas, how could a strong IPR system help innovation in Central America? If there were profitable opportunities to introduce new goods and technologies in the countries of the region, then a strong IPR system would be necessary to create the right incentives to do so. It is hard to think that the small markets of Central American countries would be attractive for patenting consumer goods. But this may not be the case for technologies directed to areas where these countries have strong advantages, such as bananas, coffee, or flowers, among other examples. In these cases, the domestic market is large and there are other agents that could exploit the technology if it were not patented.[9]

Summarizing, a strong IPR system may spur innovation even in a small country in areas where it has a strong comparative advantage, *if* it has the human capital, adequate infrastructure, incentives and funding necessary to generate technological innovations. Perhaps this is a good way to understand the role of IPR in promoting innovation in small countries like Singapore, Taiwan and Ireland. The key question is whether the Central American countries have reached the stage where this kind of innovation can be significant. Given their low levels of labor productivity and human capital, it is hard to see how this could be the case, except perhaps for Costa Rica (particularly because its R&D investment share is lower than expected given its education levels). This should be kept in mind when examining the role of IPR systems in promoting innovation in the region, as I will argue below.

b) The Patent Cooperation Treaty

One issue that often arises in discussions about IPR systems relates to the Patent Cooperation Treaty (PCT). Contrary to what is sometimes asserted, this agreement *does not* imply that a patent granted in one country is also valid in the other signatory countries. The objective of the agreement is rather to facilitate the process of obtaining patents in multiple countries.

[9] Salazar (2002) observes that many domestic patents in Costa Rica are related to construction materials and methods. This could not be explained, of course, by arguing that Costa Rica has a comparative advantage in construction. Rather, this is a special case of idiosyncratic preferences that create a niche domestic market. I will not elaborate on this reason for domestic patenting because it is unlikely to have a significant aggregate effect.

An inventor in a country that is a member of the PCT has a choice between a purely national patent application and a PCT application. The PCT application has a list of the countries that are members of the Treaty, and the inventor marks those where she is interested in applying for a patent. The process takes place between the original country's National Patent Office (NPO), the World Intellectual Property Organization (WIPO) and other NPOs. These offices do a search to find patents related to the invention and provide valuable information to the inventor that she may use to decide if and where to patent. This is done in a much more thorough way than what is normally done in the original country's NPO. If the inventor wants to patent in a signatory country after this search process is complete, then the corresponding NPO does not have to do this search again, making the process cheaper and faster. Another advantage of using the PCT is that all the associated NPOs are advised of the PCT application, and this provides a temporary protection for the invention.

This brief explanation should make clear that by becoming part of the PCT, a country does not make domestic patenting by national innovators more attractive. Of course, being part of the PCT would likely increase domestic patenting by foreign innovators, as it would now be cheaper for them, but it is hard to see how this would increase *national* innovation. Applying this logic in reverse, perhaps a way in which the PCT would promote national innovation is by decreasing the cost of patenting in other countries. This could have a positive impact on national innovation for technologies with a global reach.

c) The Petty Patent or Utility Model

A more important issue to discuss in relation to the role of IPR systems in inducing innovation in LDCs has to do with the petty patent or utility model. This kind of patent is intended for less fundamental inventions, so the criterion for granting the patent is less stringent. The period over which the patent is protected is correspondingly shorter—10 years according to the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs).

The specific definition varies from country to country, but the general idea is that petty patents protect small adaptations of existing products or technologies. This is why this type of patent could be very important in technologically backward countries, where "new-to-the-world" innovations are much less important than technology adoption.

It has often been pointed out that there is a fundamental problem in technology adoption because its results cannot be patented. Thus, the argument goes, the IPR system cannot be used to generate the appropriate incentives. But this argument does not take into account the petty patent, which arose precisely to deal with this issue. In fact, some studies have found that the petty patent was much more important than the conventional patent in stimulating technological change in Japan.[10] Kim (1997) also makes the argument that South Korea used the petty patent intensively in the initial stages of its miraculous growth performance.

According to Salazar (2002), "all the countries in Central America have appropriate legislation for the petty patent." Unfortunately, there is no good data on the number of petty patents granted in these countries, so we do not know whether this is actually playing a role in the region. Salazar was able to get data of patent applications by type of patent for Honduras for the years 1999-2001. In both 1999 and 2000 the applications by nationals for patents was equal in number to the application for petty patents, which is not the case for foreigners. Still, the conclusion is not as clear, since in 2001 nationals applied for 23 patents, whereas they only applied for five petty patents.

Salazar also obtained similar data for Nicaragua, but it is difficult to extract any implications from that data since the number of applications and approvals for both patents and petty patents is zero for most years. We could not obtain data for Guatemala or El Salvador, and for Costa Rica we were told that the Patent Office does not have up-to-date statistics. In a speech delivered by the President of the Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICIT), he stated that as of August 21, 2001, Costa Rica had granted 2,610 patents and 166 petty patents. We do not know their breakdown according to nationality.

d) Other Benefits of IPR Systems

One argument that has been made in favor of developing strong IPR systems in LDCs is the supposed connection with Foreign Direct Investment (FDI). The empirical literature in this instance, however, is just as problematic as in the case of the role of IPR systems on R&D, so it is difficult to interpret causality from the regressions encountered in econometric work. Nonetheless, as we did above, it is useful to discuss the possible effects of IPR systems on FDI.

[10] See Maskus and McDaniel (1999) and Kumar (2002).

Consider the case of FDI whose objective is to exploit the domestic market (horizontal FDI). If knowledge spillovers are important, then foreign corporations could find that their investment soon leads other local entrepreneurs to copy their technology and compete for the domestic market. Thus, foreign corporations interested in horizontal FDI may opt to avoid countries with weak IPR systems.

This may be important for large markets, but it is probably a smaller issue in the case of FDI in Central American countries. Most FDI coming to these countries is export-oriented FDI (vertical FDI) looking to benefit from the region's low labor costs. How could the IPR system affect this kind of FDI? Even if knowledge spillovers are important (which is doubtful in the case of the poor Central American countries), local companies benefiting from such spillovers could not compete with the foreign investors in markets where they have patents. The local IPR system has no role here.

Another argument in favor of strong IPR systems is that, after the Uruguay Round, WTO member countries could otherwise suffer trade sanctions. This is of course a valid argument for individual countries, but it does not imply that strengthening its IPR system should be an important element of a country's *innovation* policy.

e) Conclusion

The discussion in this section makes us wonder how IPR systems could spur innovation in Central America. Given their small markets, and their low levels of labor productivity and human capital, it is unlikely that a strong IPR system would promote innovation in the Central American countries.

Given their commitments under the Uruguay Round, however, these countries have no alternative but to develop such systems. Indeed, over the last years all the countries in the region have passed modern IPR legislation, taking it to the levels encountered in rich countries. This does not imply, however, that the Central American countries have no choice regarding their IPR strategy. On the contrary, they should think hard about their innovation policy and develop their IPR systems in a consistent way. In particular, they should focus on developing the petty patent system, which could have the maximum impact on innovation at this stage.

D. Conclusion

In this section we have analyzed several different measures of innovation and technology adoption and arrived at the robust conclusion that both are low in the Central American countries. TFP growth was low during the 1990s, suggesting that these countries are not even engaging in enough technology adoption to keep up with the pace of technological progress in rich countries. The exception in the region is Costa Rica, which has relatively high innovation indicators (close to Chile's) and TFP growth as high as in the OECD countries.

What explains the low innovation and technology adoption efforts in the region? Unfortunately, there is no well-developed and generally accepted theory of the determinants of innovation and technology adoption in LDCs. The most accepted explanation is that low innovation is caused by low education. We explored this hypothesis in this section and found that there is a strong correlation between education indicators and measured investment rates in R&D.

What is the mechanism through which low education leads to low R&D investment rates? Answering this question is important for thinking about policy recommendations in the region: should countries invest more efforts in primary, secondary or tertiary education? Should they try to increase the proportion of people undertaking studies in science and engineering? Our discussion led us to two possibilities: first, that lack of specialized workers for R&D activities (presumably engineers and scientists) prevents firms from engaging in R&D; and second, that low education levels lead countries to specialize in sectors which are not R&D intensive.

According to these results, the low education levels in the region are the main reason why R&D investment is low. But we also found that Central American countries (at least the ones for which we have recent data) have R&D investment rates that are even lower than would be expected according to their education levels. As an example, Costa Rica's 1990 R&D share was 0.19 percent, whereas its predicted share was 0.76 percent. Thus, something else besides low education levels is behind the low R&D investment rates in the region.

One possibility we explored is that weak IPR regimes decrease innovation incentives in Central America. We concluded that this mechanism is not too relevant in the region: given their small markets, and their low levels of labor productivity and human capital, it is unlikely that weak IPR systems are behind the CA countries' low innovation efforts. We also concluded that

regional efforts to strengthen their IPR regime should place emphasis on the petty patent system; this type of patent appears particularly useful in promoting technology adoption in LDCs.

There are three additional explanations for the low level of innovation and technology adoption in the region: a weak National Innovation System, lack of financing for innovative ventures, and low competitive pressures on established firms. Using different methodological approaches, the next sections will attempt to shed some light on these elements.

3. Beyond the Numbers: Findings from Interviews with Regional Innovators

To better understand the kind of innovation that exists in Central America, as well as the motivation, limitations and idiosyncrasies associated with that innovation, I arranged some interviews with firms that are considered innovators in the region.

It was impossible, of course, to conduct all the interviews myself, so I established agreements with other parties to conduct some of the interviews. This naturally reduces the insights one can gain, but one can still extract valuable information. Finally, I must also acknowledge (and caution the reader) that it is not valid to make generalizations based on a few interviews. At most, this is a good source of inspiration to make hypotheses that can guide further research and discussion about innovation in the region.

A. Interviews with Innovators: Estrategia & Negocios

I established an agreement with *Estrategia & Negocios*, a regional business weekly, to conduct interviews with innovating firms in the region following a questionaire I designed. They interviewed the following firms: Fogel (refrigerated displays and freezers, Guatemala), St. Jacks (full-package *maquila* plus branded apparel El Salvador), ELCATEX (full-package *maquila*, Honduras) and Atlas Eléctrica (refrigerators, Costa Rica). The following table summarizes the most relevant findings from these interviews.

Innovations and Limitations, *Estrategia & Negocios* Surveys

	Type of innovation	Why?	How?	Limitations, financing, and other issues
ELCATEX (Honduras, 1986)	Process: cost and quality in apparel. Strategy has been to provide a wider range of services with more value added. For this, quality control is critical. This firm was selected because it is a pioneer in industrial upgrading in the Honduras apparel sector. Exports 98% of its production, has 1910 employees of which 85 have university degrees.	Although it is not clear from interview, a good guess is that the strong competitive pressure in this market, particularly from low cost producers in Asia, has pushed firms towards a strategy of industrial upgrading where they can take advantage of closeness to US market. There are two other firms in Honduras with similar business strategies in the apparel sector: one foreign and one domestically owned firm.	Clients provide opportunities for new projects, which are discussed by the management team of the firm. Clients and providers facilitate critical information for the new projects. Human resources are all from local origin, except in last years where more advanced processes have demanded hiring a few foreign experts. No help from NIS.	Financing has come from local and foreign banks, as well as clients. Still, the firm stated that long term financing is scarce and should be improved.
	Type of innovation	Why?	How?	Limitations, financing, and other issues
St. Jack's (El Salvador, 1974)	They invested in industrial upgrading, so that now their maquila operation is full package. More importantly, they complement the maquila operation with the production of own-brand apparel for export to regional markets (Puerto Rico, Venezuela, Ecuador, Central America, Dominican Republic). Competition is very intense here, so they have had to devote a lot of attention to keeping low costs. Exports 75% of its production, has 2467 employees of which 45 are engineers.	Visionary founder	They get information through magazines, assisting to fashion, machinery and technology shows. No help from NIS.	This is an activity that requires more qualified personnel than maquila, and the firm stated that lack of trained human resources was the main limitation. They have facilities to train their own workers. The company also stated that a weak IPR system is another limitation in the country, but it is not clear why this would matter to them.

Innovations and Limitations, *Estrategia & Negocios* Surveys, continued

	Type of innovation	Why?	How?	Limitations, financing, and other issues
Atlas Eléctrica (Costa Rica, 1961)	The firm claims to innovate on three areas: product, process and marketing. The products are refrigerators and ovens. Exports 88% of its production, has 1150 employees (26 engineers and 113 technicians)	The firm has its origins in the Central American Common Market. Its scale was such that when the CACM collapsed the only option was to export to other markets. Given the fast pace of innovation in this type of products, innovation has been a must for this company. There is no local competition for this type of product, but competition is strong in all markets they participate from foreign brands.	The firm has an engineering department, which collaborates with marketing and production departments to introduce new goods or change an existing product. Most of the people involved have been trained locally, although there are some trained abroad. They are engineers, designers and marketing experts. No help from NIS. Information is obtained through international trade shows, magazines and suppliers.	Finance comes from internal resources, borrowing and equity. Although the firm states that the skilled workers they hire graduated from national universities are good, they also say that they lack sense of urgency in completing innovation projects. The firm also complained about lack of venture capital and about academic nature of university research. It also complained about a weak telecommunciations system. They rely on the IPR system for branding but not for patents because – they claim – this is slow and costly, and because the economic life of an innovation in their field is very short.
	Type of innovation	Why?	How?	Limitations, financing, and other issues
Fogel (Guatemala, 1981)	The products are refrigerated displays for the beverage and beer industries, and freezers for the ice cream industry. This is done based on demand by clients. Their main competitive advantage is to have a fast turnaround. Exports 70% of its production, has 600 employees, of which 8 are engineers.	This is the only firm of its kind in Guatemala – there are no domestic competitors.	There is an R&D department, where there are 3 foreign engineers and 2 locals. They rely on free information supplied by their suppliers, as well as participating in international trade shows. The firm does not rely on any national institutions, and claims that there is no NIS. They do not rely on the national IPR system.	They use internal resouces. There is a lack of human capital, so firm imports expertise.

The first thing that stands out in this table is the fact that all firms stated that they did not benefit from the National Innovation System; some even mentioned that such a system did not exist. The table also suggests that a strong *domestic* rivalry has *not* been an important element in pushing these firms to innovate; in fact, none of these firms has any domestic rivalry. More generally, it is difficult to make the claim that innovation in these firms has resulted from strong

competitive pressure even from imports; perhaps the only case for which this could be asserted is Atlas Eléctrica, which experienced falling protection as Costa Rica dismantled its import substitution regime. It seems that innovation in these firms is the result of extraordinary entrepreneurs, more than a result of systemic conditions.

In terms of human capital, St. Jacks complained about lack of trained workers, whereas Fogel and ELCATEX stated that they had to import specialized engineers. This suggests that, except for the case of Costa Rica, there is a scarcity of engineers for innovating firms in Central America.

Finally, the case of ELCATEX is consistent with a notion one finds in the literature on industrial upgrading in apparel *maquiladoras*. This is that the main determinant of such upgrading (which entails some innovation but mostly technology adoption) is the evolution of conditions under which exports take place to the industrialized-country markets (in the case of Central America, this is obviously the United States). This is clearly what has happened in Mexico (see for instance Gereffi, 2000), and is consistent with ELCATEX's response that innovation is led by new opportunities offered by the clients.

B. Interviews with Innovators: EKA Consultores

I established an agreement with *EKA Consultores*, a Costa Rican financial weekly, to conduct interviews with national innovators. I sent several hypotheses I wanted to test to the staff of this publication, and they designed a questionnaire that was used in interviews with four firms: Cibertec (telecommunications equipment), ICIC (clinical studies), Xeltron (equipment for electronic grain selection), and Café Britt (gourmet coffee).[11] This led to a special report on innovation in Costa Rica, for which I wrote the introduction (*EKA*, No. 215, December 2002).

[11] EKA also interviewed a national software company, Lidersoft, but I excluded this interview from the analysis because the answers were so general as that it is very hard to extract any useful conclusions from them.

Innovations and Limitations, *EKA Consultores* Surveys

	Type of innovation	Why?	How?	Limitations, financing
Cibertec, 1979	New-to-the-world products for telecommunications. Technology is not too advanced, rather targets needs of LDCs that large international corporations do not attend	High-quality engineers from UCR with entrepreneurial drive plus idiosyncratic local demand (old telephone centrals)	Bootstrapping from local customers. High spending on R&D.	
ICIC, 1991	Entering new market, more adoption than innovation: clinical studies to test new drugs	Large number of high-quality physicians in the country.		
Xeltron, 1974*	New-to-the-world products for high speed electronic grain selection.	Local demand (coffee processors) plus high quality engineers with entrepreneurial drive. No local competition.	Mid-level technicians helped in R&D. They had an R&D department since mid 80s (3 people, now 8). Before, R&D was informal, all over the firm. No relation with universities except for a few graduation projects.	In the middle 80s, with a new machine, they tried to patent in CR and were rejected! But then they simply patented in the US. They have several patents there, starting with the first in the mid 70s.
Café Britt, 1985*	New more-direct ways to market high quality coffee, thus obtaining higher prices: take advantage of foreign tourists coming to the country. Coffee Tour, sales in Airport (duty free store), Internet sales – consumer led.	Foreign owner with vision.	This type of innovation requires no R&D or relation with the NIS.	Local regulations designed for traditional system of selling CR's coffee abroad. For example, they could not sell high-quality coffee domestically!

* These companies were part of a group of firms I interviewed directly.

Given the nature of these interviews, they provide less information than those conducted by *Estrategia & Negocios*, but they are nonetheless informative. They tend to corroborate the hypotheses that I extracted from the interviews above: the firms did not benefit from the National Innovation System, local rivalry was not relevant, and it is not clear that competitive pressures provided the innovation impetus.

C. Interviews with Innovators: Direct Interviews

Of the four firms I interviewed, Café Britt and Xeltron were also interviewed by EKA; the results of both sets of interviews are compiled above. The other firms I interviewed were Trimpot (an electrical components *maquila*) and CORMAR (logistics). I conducted these interviews to better understand the linkage process between foreign corporations in Costa Rica and domestic suppliers, the subject of another project for the World Bank. Nevertheless, the findings are also relevant for this study.

Innovations, Direct Interviews

	Type of innovation	Why?	How?
Trimpot (1979)	This subsidiary of a foreign corporation first established in Costa Rica as a basic *maquila* in electrical components. But the subsidiary did well in terms of quality and cost, allowing it to bring in more and more production through vertical integration and (later on) diversification. In the process, it has trained its workers and upgraded its operations, so that value added per employee is now much higher than it was originally.	Due to vision and ambition of the foreign manager in charge of the subsidiary in Costa Rica, together with the disposition of Costa Rican workers to learn new things and contribute with their own ideas to solve problems. The firm's manager in Costa Rica claims that Costa Rican engineers and technicians are eager to learn new ideas and work in teams, something that the company did not see when it was working in El Salvador.	There is no formal R&D and no research collaboration with universities, although they do have some students that do graduate projects in the company. The company has established a formal system of developing new projects called RTP (Road To Perfection). All employees take a course on this system. In terms of human resources, they have engineers graduated primarily from UCR and ITCR in several areas: industrial engineering, electronics, IT, chemical engineering and metal works. They also have technicians in similar areas.
CORMAR	New logistic services and quality improvement, led by Intel's demand in the country.	Joint venture with AEI (Air Express International, an international logistics company) led to opportunity to serve Intel locally, and this required new investments in quality and expansion of services.	CORMAR hired an industrial engineer (UCR) with an MBA from INCAE to run the department created to service Intel. The employees of this department received training from AEI, which had prior experience serving Intel. Moreover, AEI sent a manager to CORMAR for 6 months to make sure that the service matched the quality required by Intel.

These two cases provide different examples of innovation in the region. Trimpot is a subsidiary of a foreign corporation whose positive experience in Costa Rica led it to engage in a successful process of industrial upgrading. There was no support from the NIS, but the supply of engineers from UCR and ITCR has been crucial in this process. Trimpot has also benefited from the availability of well-trained technicians and from the general disposition of the Costa Rican workforce to learn and work in teams. This last element is very difficult to formalize or understand at a deeper level.

The case of CORMAR is also very interesting because it shows a process whereby a national supplier benefits from a linkage with a high-tech foreign corporation established in the region (Intel). As in the case of Trimpot, there was no support from the NIS, but the company was able to find appropriate professionals for the new tasks. An interesting element of this case is how CORMAR's foreign partner (AEI) helped in the process of upgrading to be able to service Intel with the required level of quality. This theme is explored more fully in Alfaro and Rodríguez-Clare (2004): as technology transfer from multinationals to domestic suppliers is not prevalent, the main benefit of multinationals is the pressure they exert on domestic suppliers to upgrade.

4. Case Study 1: Innovation in Software in Costa Rica[12]

A. Introduction

The software sector in Costa Rica boomed in the 1990s, leading many commentators (including Costa Rica's President) to state that for Costa Rica, software is the "coffee of the new millennium." Indeed, starting from a base of close to nothing in the mid-1980s, by the end of the 1990s Costa Rica had several software companies with global exports of over a million dollars.

According to CAPROSOFT, the industry association for software producers, there were approximately 150 firms in areas such as bank and finance, human resources, health, education, artificial intelligence, data migration, communications, tourism, production, Internet applications, and management. Also according to CAPROSOFT, around 85 percent of these

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[12] I wish to thank Carlos Mora de la O (from Mora y Beck, S.A.) and Ignacio Trejos (from CENFOTEC) for the interviews that were so useful in the preparation of this note. I also thank Carlos Araya, Roberto Sasso and Dianelos Georgoudis for comments on an early draft of this note. Several reports from *El Financiero* were also useful, as well as the outline of a talk delivered by Federico Zoufaly, Executive Vice President of ArtinSoft, at the University of Texas (http://www.lanic.utexas.edu/pyme/esp/publicaciones/biblioteca/itcr/ponencias.html).

firms have exported some of their production, although only around 50 percent are regular exporters. According to Costa Rica's Ministry of Trade, some 83.5 per cent of the companies are locally owned, 12.4 per cent are mixed capital companies and the remaining 4.1 per cent are foreign owned.

Ministry of Trade figures further show that the total exports of the six largest software development companies in 1997 surpassed US$25 million, and by the end of the decade total software exports in 1999 were $50 million. This figure is even more important than it appears, because the local value added of such exports is greater than 90 percent, whereas for exports out of the Export Processing Zone the local value added is surely lower than 50 percent.

One important element to note is that these software firms are all recently formed firms that, in contrast to many other firms in other sectors, never enjoyed any kind of fiscal incentives. Most of these companies were launched by young professionals with strong entrepreneurial drive that seems to be lacking elsewhere in the economy. Thus, this sector is a good area for studying both the drivers and limitations of emerging sectors in the economy.

B. Origins

The usual explanation for the dynamism of the software sector in the last decade revolves around three elements: the national program to introduce computers into schools, the elimination of import duties and other taxes on personal computers in the late 1980s, and the strength of the information technology (IT) departments at two public universities: UCR and ITCR.

The computers-in-schools program started only in 1988, so the first high school graduates who benefited from this program graduated in the mid-1990s, when the software sector was already booming. This does not mean that this program is not important for the sector. It is probably true that the high quantity of high school graduates who now are very comfortable using computers will allow the industry to grow faster in the coming years. The point is that this program was not a key element in the genesis of the sector.

The elimination of taxes on personal computers, which were originally 133 percent, probably had a larger impact on the growth of the sector. Import duties were originally high on computers, so the elimination of those taxes had an important effect on the local price of PCs. According to the interviews, this led to a significant increase in computer imports in the late 1980s. I have no data to verify this, but it is instructive to look at the data on PCs per 100

population compiled by the International Telecommunication Union (ITU). The first year for which there is data for Costa Rica is 1997. For that year, the country had 6.91 PCs per 100 population, the highest in Latin America. For comparison, the corresponding statistic for Chile was 4.47, for Uruguay 6.16, for Argentina 3.64 and for Mexico 3.35.

The high number of computers had two effects: first, the higher stock of computers increased the demand for software in Spanish for specific needs in Costa Rica. This can be seen as the importance of domestic demand emphasized by Michael Porter (1990), and which is formalized in economic geography models where there is a "home-market effect." Second, the lower price of PCs lower the cost of entry into the software business. Students and young professionals from middle-class families could afford computers and start their businesses at home.

The third element mentioned above, namely the role of two public universities, UCR and ITCR, is perhaps the most important factor behind the dynamism of the software sector in the country. The computer department was created in the UCR in the late 1960s and in the ITCR in 1976. The objective of the UCR was to produce human resources for the public sector (mainly the Treasury and the large public companies like ICE (electricity and telecommunications), CCSS (social security) and INS (insurance), as well as the national banks and the few large companies that at that time used large computer systems. In the case of the ITCR, the original objective was to produce software technicians for the private productive sector through a three-year program. The program was later extended in 1981 to a four-year bachelor's degree. One notable strategy used by both universities, which is now seen as a key element in their success, consisted of sending several of their professors to obtain post-graduate degrees at the best universities in the United States and Europe.

The quality of the education at these two universities is generally high, as shown by several facts:

- According to the *World Competitiveness Report* (WCR) of 2001/2002, Costa Rica ranks first in Latin America in the "quality of scientific research institutions" (rank 32), ahead of Chile (rank 43), and just behind Hong Kong (rank 31) and Korea (rank 27)
- A survey conducted by (Coalición Costarricense de Iniciativas de Desarrollo (CINDE) and Promotora del Comercio Exterior de Costa Rica (PROCOMER)

found that high-tech multinationals considered engineers trained at UCR and ITCR to be by far the best in the country. Moreover, the top management of these multinationals has stated that the engineers they hire in Costa Rica are very good in comparison with other countries in which they have operations or have considered for investment. This is surely what has led Intel to set up a center for software development and semiconductor design here in Costa Rica.

- The UCR has recently obtained international certification (CCAD from Canada) for its programs in civil, industrial and electrical engineering.
- A bibliometric study by Lomonte and Ainsworth[13] shows a relatively good record of publications, mostly coming from UCR and in basic sciences. Publications per capita are lower than in Chile and Brazil, but ahead of Argentina and Mexico. Moreover, the "impact index" of publications from Costa Rica is higher than in other Latin American countries.

So the quality of the UCR and ITCR is generally high. Is it the case that the quality of the computer departments of these two universities is high even relative to other disciplines in those universities? I only have one source of evidence for this, which is the World Economic Forum's *World Competitiveness Report* for 2001/2002, where Costa Rica ranks 26 in "IT training and education," the highest in Latin America, ahead of Chile (rank 29), and even ahead of Korea (rank 28).

In an interview conducted for this study, Ignacio Trejos (previously director of the Computer Department at ITCR and now director of CENFOTEC, a private center for training software technicians) observed that there has been a commitment to high quality in the computer departments of these two universities since their foundation. It is important to explore this idea, given that so many other public universities in Central America have not done as well. The case of the ITCR Computer Department is particularly interesting. According to both Trejos and Roberto Sasso, from ArtinSoft, when the ITCR decided to create a computer department, they sent Alberto and Daniel Cañas to undertake graduate studies in computer science in Canada and the United States (the University of Waterloo and the University of Texas at Austin,

respectively). When they finished their doctoral work, they returned to Costa Rica to organize the new Computer Department of the ITCR, placing strong emphasis on a commitment to applied research, intellectual curiosity and healthy competition among students and even between students and professors. After a few years, both returned to the United States, where they hold professorships at the University of Florida at Pensacola and Wake Forest, respectively. The most interesting phenomenon is that the culture developed by the Cañas brothers has been maintained long after their departure. This is what Trejos referred to as the "foundational impulse" whereby the "culture" developed by the founders of the institution remained after their departure.

This "experiment" at the ITCR had wider implications: it is generally believed that the high academic standard set by the Cañas brothers at ITCR led UCR to send a small team of mathematicians to undertake graduate degrees in the United States and Europe. In fact, the rivalry between the two universities has been a major contributing factor to the high quality they both maintain.

The whole process was strengthened by the fact that demand for entering into these computer departments at UCR and ITCR increased tremendously, so that the cut-off grade for acceptance increased to the highest level among the fields of study offered. This course of study was thus attracting Costa Rica's brightest students, and this of course allowed and encouraged high quality.

Towards the end of the 1980s there were not many interesting or well-paid opportunities in the public or private sector, and universities did not have room to hire more professors, or to finance research programs. The growing opportunities for applications in Spanish in the national market, itself in part the result of the increasing number of PCs available in the country, led some graduates to set up their own enterprises. This was much easier than in other sectors, because initial investment could be low, as evidenced by the typical example of the two university students who work in their parents' garage for a couple of months and then come out with a new product. Thus, starting up a new company and producing a new good is much cheaper in software than in other sectors.[14]

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[13] See Lomonte and Ainsworth (2000).

[14] According to one of the founders of a successful software company, during the first months of his start-up, there were former classmates who were willing to work without pay for several months just for the pleasure of doing something exciting.

In the year 2000 there was a report in a national financial weekly about five successful software companies. Two of them, Tecapro and ArtinSoft, were founded by university professors who quit their jobs and, together with their brightest students, started to develop software. Another company (Codisa) was founded by a group of students just graduating from the university, with an investment of $500. The other cases, Exactus and Sysde, reflect a similar pattern, as young engineers from UCR and ITCR set up their companies with a small amount of resources thanks to low entry barriers. Differing from the other cases, however, the founders first worked for well-established firms (e.g., banks, IBM, computer distributors), and only later did they found their start-ups.

C. Innovation in the Software Sector in Costa Rica

Before proceeding, it is useful to consider the characteristics of innovation in software. This is important because innovation in this sector differs significantly from innovation in other industries. For instance, in software, unlike other sectors, the introduction of a new good does not necessarily imply innovation. Consider a company that develops web pages. It has certain skills and tools for doing so, which are probably standard in the industry and which it applies to the circumstances of each particular client. Even though there is a new good produced each time, there is no innovation.

For a more interesting example, take the case of a software company that is specialized in the production of custom-made enterprise resource planning (ERP) software. It has skills and tools to develop this software for different clients. Each time it is hired to develop an ERP system for a particular company *in the same sector*, there is a new product, but this is just like producing one more unit of the same good, produced with the same process and using the same skills and tools as before. There is no innovation here, either.

Now imagine that this same software company is hired to develop an ERP for a client in a new sector, say banking. The company will have to do research about the particular needs of banks and the state-of-the-art concepts for banking ERPs. This entails the development of new skills and tools, which will then be used to sell ERPs to other banks. This is the kind of process that has applied in many of the most successful companies in Costa Rica, like Exactus and Codisa.

This is still not innovation, however, but rather adoption of foreign technology to local demand and conditions. It is not innovation because the new skills and tools are "new" only from the point of view of the company that has developed the product; the skills and tools involved are likely to be already known and in use in other parts of the world. Of course, the adoption of those skills and tools is extremely important, since it will increase productivity in that firm and perhaps even in other firms thanks to spillovers.

The previous discussion suggests that innovation really happens when a company develops a completely new software solution that does not exist anywhere else. In Costa Rica the best example is ArtinSoft, which performed research for several years (even sending three of the founders to do graduate studies in centers with the best knowledge in the field) before coming up with Freedom, which became the world leader in automatic software migration (see detailed discussion at the end of this section). There are other examples, of course,[15] but it is clear that this sort of endeavor is rare, as it implies a long-term and highly risky investment for which financing is difficult to secure.

To summarize the discussion so far, software encompasses three knowledge-based activities. The first is the development of customized software for new clients, which in most cases is simply like producing a new unit of the same good. The second is adoption, where the firm acquires skills and tools to produce software in new areas, but where such skills and tools already exist elsewhere. Finally, there is innovation, where the firm generates new applications that do not exist elsewhere. Given that growth is driven by both adoption and innovation, and given that the two activities have similar drivers and limitations, in what follows I will simply talk about innovation, but the reader should keep in mind that most of such innovation is really adoption. When I want to single out a case of new-to-the-world innovation, I will refer to it as "true innovation."

Based on this definition, is there innovation in the software sector in Costa Rica? How much is adoption and how much is true innovation? Which companies innovate? How is innovation conducted and financed? How do the innovative software firms interact with the National Innovation System in Software? Answering these questions rigorously falls outside the scope of this study, but a few remarks can be made here.

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[15] One example is the introduction of a packaged Spanish spell checker, by Tecapro. Unfortunately, this faced very severe competition from built in spell-checkers in Microsoft Word and other word processors.

At a general level, it is obvious that there has been innovation in the software sector, since all these companies are producing goods that were not produced before in the economy. Such companies have had to devote considerable efforts to accumulating skills and tools to allow them to provide the services that their local and foreign clients demand. Moreover, given that software is an industry with intense technological change, a software sector will simply not survive if it stops innovating.

Moving beyond such generalities, it is interesting to know how many companies have R&D departments, and how many people are engaged in such activities. Many software companies claim to have large R&D departments. For example, Carlos Araya mentions that ArtinSoft has an R&D department of 170 people, out of a total 240 employees. And according to an article in a Costa Rican financial weekly (*El Financiero*, December 18, 2000), Codisa has an R&D department of almost 50 employees. Some experts interviewed argued that most of these people are engaged in development, rather than research. For example, of 170 employees in Artinsoft's R&D division, only around 20 are engaged in research, only seven of whom hold PhDs. The figure is probably much lower in Codisa, and it is likely that there are very few people in research in most firms.

Of course, having a formal R&D division is not necessary for innovation. According to one interview, most companies develop new tools and skills in the process of servicing a large client. Such large contracts are used to do research through which new tools and skills are produced and then used to market new goods and attend new clients with new solutions. Costa Rica's experience provides several examples:

- In the late 1980s the largest state-owned bank, Banco Nacional, asked Tecapro to develop a program to keep track of telephone calls in order to lower total telecommunications costs. Tecapro came up with a new system named Sacet, which allowed the bank to reduce its total telephone bill by 60 percent. Tecapro then sold this program to thousands of clients worldwide. As an interesting note, telephone centrals now have this kind of program as part of their main system, so demand for Tecapro's software has diminished. This

is a good example of several key characteristics of the software sector, namely the high rate of competition, change and the short life cycle of new products.[16]

- In the mid-1990s Codisa won an international bid to develop a software system for Tricom, one of the largest telecommunications companies in the Dominican Republic. The system turned out so well that Codisa then signed an agreement with Tricom to allow it to sell this software to other telecommunications companies worldwide.
- Sysde was founded in 1991 to develop a software application for two clients in the financial sector. This same software was then commercialized in Ecuador, El Salvador and Mexico, and eventually Europe and Asia.

We see that innovation occurs even in start-ups with no formal R&D department. One would expect, however, that as the companies mature, they would separate research from production: it would have the best people devoted to the production of new tools and skills, which would then be transferred to other workers who would use them in software production. When this happens, how is formal research conducted? According to the interviews, almost all of it is done in house, without hiring outside experts or universities. And almost all of it is financed from retained earnings, a method called bootstrapping.

If this is the case, then what is the role of the NIS in promoting a favorable environment for innovation in software? Clearly, the most important element is the production of the human resources needed for the industry. The UCR and ITCR are of course the main players here, but there are several other elements that help. First of all, there is the program financed by a grant from the Republic of China (Taiwan), whose objective is to improve the curricula, the laboratories, the teacher training, and the integration of the education programs of the technical high schools, the national training institute (INA), the Community Colleges, and the ITCR. The three fields targeted in this program are electronics, informatics, and metalworks.

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[16] In fact, one of the experts interviewed argued that many of the firms in the sector had not been sufficiently innovative, relying instead on the relatively easy stage of introducing customized ERP software for firms in Latin America. Now they are facing difficult times due to the strong competition from large international firms and even a new Microsoft ERP, Great Plains, which is inexpensive and of high quality. This new competition has been made possible by new technology that allows packaged software to enter a market that was exclusively for customized software.

Second, there is a new technical school specialized in software education, Centro de Formación en Tecnologías de Información (CENFOTEC), started in 1999 by a group of software companies (Exactus, ArtinSoft, Codisa, and Sysde) together with Capital Empresarial Centroamericano (CEC), an investment fund specialized in innovation (see below). These companies and the CEC decided to invest in the formation of CENFOTEC because of the low capacity of the high quality public universities to fill the high and rising demand for software professionals. But instead of duplicating the four-year programs of the other universities, CENFOTEC has specialized in one and two-year programs, with many innovative features. For example, students work in an environment that replicates the one they will face in the real world: they work in groups, solve problems, and develop new software. CENFOTEC wants to promote a very close relationship with the software companies and the rest of the productive sector in the country. This is the first institution of its kind in Latin America.

Third, the generation of more and higher quality human resources for the software sector is one of the three elements of a national program to strengthen the software sector (ProSoftware), started in 1999 and sponsored by the IDB and PROCOMER. This program first conducted a survey to understand the needs of the industry and the perception of the software companies about the graduates from the different universities, and now is working to improve the curricula, teacher training, and integration among universities for certain advanced courses.

Finally, there is a new project to start a Ph.D. program in computer systems at the Centro Nacional Nacional de Alta Tecnología (CENAT), which is a national center for the promotion of high technology managed by the four public universities.[17]

Apart from the generation of human resources for the growth of the industry, the National Innovation System in Software has three other important elements. First, the people engaged in software production and computer education have strong ties to each other. Many of them met in the university, and share experiences in events promoted by the Software Industry Chamber (CAPROSOFT) as well as a Technology Club (*Club de Investigación Tecnológica*) which holds monthly discussions and presentations by foreign and national experts. It could be argued that

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[17] An interesting innovation that will be introduced in this Ph.D. program is a mechanism whose objective is to make the research projects conducted by the students more relevant for the needs of the national industry. The idea is that the private sector will propose projects and pay an incentive for professors supervising the research for those projects.

there is a true community, which allows people in the industry to share ideas, work together on certain projects, and receive feedback on their research.

Second, there are a series of programs and institutions at the “meso” level that contribute to the strengthening of the sector. One of these is the IDB-sponsored ProSoftware program mentioned above, whose three objectives are the generation of high-quality human resources for the industry; the improvement of the quality of software produced in the country through training, seminars and encouraging the formation of companies engaged in quality certification and advice; and the strengthening of the industry chamber (CAPROSOFT).

Another such program is the ICCI (*Iniciativa Costarricense para la Competitividad Internacional*), funded by the Canadian International Development Agency. One of the sectors targeted for support is the software sector, and there have been several projects financed in this sector by the ICCI and implemented through CAPROSOFT. Perhaps the most interesting and important is a series of studies on the problems encountered by software companies in obtaining finance in the country, as well as recommendations for how to solve these problems. One of the most interesting products coming out of these studies is a contract between CAPROSOFT and Mora y Beck, S.A., to set up a venture capital fund with $10 million. ICCI is also working together with CEGESTI (a Center that promotes technological upgrading, started up in the early 1990s with the support of the IDB) to promote alliances between Costa Rican and Canadian companies, as a way to improve the technological level and the marketing strength of the national software sector.

PROCOMER has a series of programs to help SMEs become exporters. Again, one of the sectors given priority is the software sector. Small and medium software producers first enter a program called *Creando Exportadores*, which trains SMEs in the ways of exports, marketing abroad, logistics, etc. Exporters then enter a program called PIVA (*Programa de Impulso al Valor Agregado*), whose objective is to help companies increase their value added to enter niche markets abroad. This is done through innovation in areas such as product design, packaging, branding, and quality control.

Third, although obtaining capital has been a very serious limitation for the growth of the industry, there are now three venture capital funds: CEC ($1.5 MM), PGI-WorldCap ($6 MM) and the Central American Investment Facility (CAIF), administered by the CDC Corporation.

These funds have been involved in several software firms in Costa Rica. CEC, for example, has invested in WordMagic (an English-Spanish translator that is among the top such products in the world) and CENFOTEC. The eventual plan is that Mora y Beck, S.A., which is a boutique investment bank, will take the companies that are ready to exit the fund and find a larger company willing to buy it. PGI-WorldCap, an accelerator fund, has so far invested in Codisa and Freeway Development Corporation; PGI-WorldCap's ties around the world allow it to help software companies improve their marketing, accounting, management, distribution channels, and make alliances, among other activities. CAIF has invested $3 million in Exactus. Finally, as mentioned above, CAPROSOFT has hired Mora y Beck, S.A., with funding from the ICCI, to develop a $10 MM VC fund for software. Branham Group Inc., a Canadian consulting firm with expertise in this area, has been contracted to help Mora & Beck in this challenging endeavor.

D. A Special Case: ArtinSoft

The case of ArtinSoft is particularly instructive regarding many of the issues discussed in this section. Founder Carlos Araya was part of the first cohort of graduates from the computer department at the ITCR. After graduating, he traveled abroad and obtained two Master's degrees and a Ph.D. He then returned to head the Computer Science Department and later the Center of Computer Research at the ITCR. In the early 1990s he decided to leave the university environment to pursue some of his ideas on how to apply knowledge and research in the solution of common life problems, and in 1992 he convinced three of his best students to leave the university to engage full time in research on the application of Artificial Intelligence in software migration.[18]

To finance this early research outside of the university, Araya and his colleagues obtained seed money from Oracle of Central America in the form of a grant for the application of ideas on Theorem Proving in Artificial Intelligence in the solution of software migration. This seed money was quickly consumed, so to support themselves and their research they started another, simpler project to develop software for manufacturing. This application became a success and is

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[18] Something very similar happened with Tecapro. The founder, Dianelos Georgoudis, was a professor at the computer department of the UCR and left the university together with his three best students to start the company.

now used in hundreds of companies in Latin America. This illustrates the bootstrapping method used to finance research in the software sector.

Several years later they met Richard Beck and Armando Gonzalez, prominent and visionary businessmen who believed in the project and put together some funds to invest in the company. Both also participated in the direction of the company at the strategic level.

In 1999, seven years after the start of the company, ArtinSoft released its main product, Freedom, which became the world leader in the area of software-language migration.[19] The clients now include companies in the United States, Europe, Asia and South America. This software is superior to the competition, as it can recover almost 99 percent of the original code, whereas the others can recover only around 70 percent, and it has been contracted by companies such as Microsoft to be embedded into their products.

The fact that there are thousands of companies and institutions with obsolete software but with enormous investments in code and knowledge and other complementary systems, imply that this software has tremendous growth potential. This convinced Intel Capital (the Venture Capital Fund established and managed by Intel) to invest in this company, the first such investment for Intel Capital in Latin America. Later, Microsoft, already an ArtinSoft customer, also became interested and entered into an alliance with the company in order to promote Freedom as a strategic component in the adoption of the e-business and the Internet (.Net).

E. Conclusion

If I had to point to one single factor that was responsible for the rise of the software sector in Costa Rica, I would undoubtedly select the existence of high-quality computer departments in the public universities (UCR and ITCR). Their contribution was not only the graduation of high quality professionals, but also the fact that they were trained in an intense, highly demanding atmosphere that valued creativity and generated confidence in the ability to solve difficult problems.

This seed found fertile soil at the end of the 1980s and the beginning of the 1990s. In particular, the elimination of import duties on computers led to a significant increase in the use

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With some money that Georgoudis had obtained from a contract with an international organization, Tecapro bought a computer and started working full time on developing software.

[19] Interestingly, ArtinSoft has no patents or any form of intellectual property protection, as secrecy is considered the best strategy for protecting the value of its knowledge.

of computers in the country, which created a large local demand for software that at the time could not be satisfied from packaged software from the leading international corporations. Combined with the low entry cost into this sector (a computer and a garage!), this allowed the most creative and ambitious IT professionals to set up their own firms and achieve fast growth.

Thinking about the applicability of these conclusions for other sectors, one wonders whether the same kind of boom would arise in biotechnology if a country had universities with high-quality biotechnology departments. There is probably an important local demand that is hard to satisfy from international sources, given the often idiosyncratic problems encountered in this area in different countries. But the problem is that the entry cost in this sector is high, so biotechnology professionals would face serious financing problems in starting up their own firms.

This comment takes me to the next conclusion, namely the important role of finance in the emergence of new sectors. Again, software start-ups have low financing needs thanks to the nature of the technology. It is easy for a group of young people to go without pay for a few months and work on laptop computers in their parents' house. But this is a special condition for software that does not exist elsewhere. Moreover, even the software sector in Costa Rica later suffered "growing pains" as it entered a phase where established firms needed to undertake important investments in R&D to keep growing (and survive!). My guess is that, if one asked today what was the critical problem of software firms in Costa Rica, the overwhelming majority would point to lack of finance.

Now that the software sector is well organized, there are important initiatives to tackle this financing problem. The question is whether the government should be more actively engaged in finding solutions to such financing problems not only for the now established software sector, but also for other emerging sectors. This, of course, hinges on whether the banking sector can deal with this by itself, which in turn depends on market and regulatory failures that affect lending to innovative activities. It seems to me that such failures exist and are severe, and governments need to think about short-run and long-run strategies to deal with them.

4. Case Study 2: Innovation in the Food Sector in Costa Rica[20]

A. Introduction

I chose to study this manufacturing sub-sector (from now on referred to simply as the "food sector") in Costa Rica for several reasons. First, as Table 19 shows, it is the largest manufacturing sub-sector in Costa Rica. Moreover, its growth rate over the 1991-2000 period has been 4.6 percent per year, the highest growth rate among all the two-digit manufacturing sub-sectors. As Table 20 shows, reveals, an important part of this growth has been thanks to rising exports: the average annual growth rate of food-sector exports over the 1994-2001 period has been 9.7 percent. Moreover, food sector exports have grown from 6.9 percent to 9.3 percent of total exports, excluding Intel. Together, Tables 19 and 20 show that the food sector has been a dynamic sector over the last decade in Costa Rica. Thus, it seems like a relevant sector in which to study innovation and technology adoption. Second, this sector has not escaped the process of trade liberalization that Costa Rica has experienced since the mid-1980s. Thus, studying this sector allows us to understand the way in which trade liberalization has impacted innovation in the country. Third, the food-sector national innovation system has two institutions, namely the food technology research center and the food technology department of the University of Costa Rica (UCR), which appear to be performing important supporting roles for innovation in the private sector. Focusing on the food sector will give us the opportunity to examine how and why these two institutions have been able to stimulate innovation. Finally, I believe that innovative firms in this sector will present clear examples of the activities associated with the abstract notion of "technology adoption."

For this study, I hired a Costa Rican consulting company, GAP Consultores S.A., which has experience with innovation, SMEs and the food sector. They conducted interviews with the following five enterprises: Sardimar (tuna products), Fideos Precocidos de Costa Rica (pasta), Productos Columbia (sauces), Dos Pinos (milk and its derivatives), Corporación Musmanni (bakery). They also studied MICIT's R&D Matching Grant System (FRC, for the initials of

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[20] The writing of this section was made possible by the collaboration of several people. I especially want to thank José Segura and Johnny Zuñiga, of GAP Consultores, for their excellent research, insights and suggestions. Floribeth Víquez, the Director of CITA, not only agreed to participate in two interviews but also made written comments and provided valuable data. Jackeline Aiero, the Director of the Food Technology Department of the UCR, and Franco Arturo Pacheco, of Musmanni Corporation and CACIA, also agreed to be interviewed and

name in Spanish, Fondo de Recursos Concursables) and conducted interviews with the directors of the two UCR institutions mentioned above.

B. Brief Description of Innovations

The five companies interviewed were selected because they are known as innovative firms in the last years. In this section I briefly describe the innovations performed by these firms.

1. Sardimar (seafood)

The following description appears on the company's web site (www.sardimar.com):

> Sardimar is one of the leading seafood processing companies in Latin America, enjoying a position as the market leader in specialty tuna and sardine products throughout Central America and the Caribbean. Today, Sardimar's gourmet seafood items can be found in more than 26 countries, including Spain, France, Italy, Greece, Holland, Venezuela, Mexico, Puerto Rico, Chile, the United States and Canada.

This company was created in 1973 to compete in the large domestic and Central American market for canned tuna and sardines. Annual per capita tuna consumption in Costa Rica is currently approximately 17 cans per person, which is considerably higher than in the rest of Central America and roughly 25 percent below the comparable figure for the US.[21] Given that Costa Rican per capita purchasing power is considerably lower than that of the US, clearly a higher percentage of Costa Rican disposable income is spent on tuna. The company later added other seafood products, mainly canned squid.

As a result of the maxi-devaluation that took place in Costa Rica in 1982, Sardimar was forced to design a way to offer reasonably priced canned tuna to a population whose purchasing power had been drastically eroded. Since over 90 percent of the cost of Sardimar's raw materials (e.g., tuna, cans, oil, labels) was US dollar-denominated, the company came up with the idea of combining tuna and locally grown vegetables in the can. This way, the cost and retail price of

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collaborated with very valuable insights. Representatives from the five companies cited here were also very generous with their time and collaboration for this study. All errors, of course, remain my own.

[21] According to a study performed by CITA (the food technology center at the University of Costa Rica), Costa Rica's high level of canned tuna consumption results not from its low price, but rather from its convenience.

the canned tuna with vegetables was reduced considerably and sales volumes quickly increased. In the following years, Sardimar introduced a series of new value-added products such as tuna with jalapeño peppers, tuna with sweet corn, tuna with garbanzos, tuna in marinade, tuna with garlic, and sardines with brown and black beans, among other products. Moreover, as Sardimar introduced the value-added variety, it became clear that brand awareness, brand loyalty and per capita consumption were much greater for the company's products than for those of other competing brands, which did not offer the value-added varieties. The value-added products also helped Sardimar deal with growing competition in the Central American region from tuna processors in Thailand, Ecuador, Mexico and the United States. Therefore, in the early 1990s Sardimar management adjusted the corporate strategy to one focused mainly on the value-added tuna markets both within and outside of Central America.

This innovative strategy required the company to carry out research on possible new products and test them with real consumers; it also required the company to understand how to add ingredients to the tuna and how this would affect the shelf life of the product. The company has a specialized research department to perform these activities. Apart from R&D, the company also focused on certifying its production processes in order to be able to sell in developed-country markets such as the United States, Europe and Japan. These efforts led to HACCP certification in 1998 and ISO-9002 certification in 1999, and the company expected to obtain ISO-14000 certification in August of 2003. Toward these ends, the UCR food-technology center (CITA) participated here in the validation of Sardimar's thermal processes, which is crucial in establishing food safety.

The strategy paid off: in the period between 1990 and 2002, Sardimar's sales achieved a compound average growth rate of over 12 percent, exports as a share of total sales went from under 15 percent in 1990 to over 50 percent in 2002, and the company's market share in the Central American tuna market more than doubled.

2. Corporación Musmanni (bread)

This company was created in 1902 and today is a successful and fast-growing family enterprise in the bread and bakery business.[22] It is one of the regional leaders in the bread industry, and it was the first enterprise in its sector to be ISO 9001 certified. Originally, it was a simple bakery, then it entered the business of selling bread to retail stores like supermarkets.

This market became heavily contested in the 1990s with the establishment in Costa Rica of two bread companies from Mexico (Bimbo and Breddy). On trip to Mexico, the manager/owner noticed that bakeries had become more efficient by introducing a self-service system for their clients. Based on this idea, and after considerable research, the company decided to implement a system of franchises for bakeries. This proved difficult because there was no prior experience in the country with the concept of a franchise, so considerable legal work was required.

One of the central ideas of the new strategy was to make it very easy to open and run a bakery, by having the whole system standardized, including equipment and furniture, store design, and—most importantly—delivery of bread dough from the central Musmanni plant. This last element was key, because it allowed bakeries to be operated by anybody, as there was no longer the need to have a baker in the bakery! As Franco Arturo Pacheco, the current CEO of Corporación Musmanni, mentioned in a "virtual interview," the company used technology to decrease their dependence on specialized labor. Given that bakers are a form of unskilled labor (they are production workers, and mostly have low education), this implies that their technology is skilled-biased!

This new system amounted to a radical change in its business: from selling bread to supermarkets and running a few bakeries, the company transformed itself into a seller of equipment, knowledge and bread dough produced at a large-scale plant with high productivity. This allowed the company to achieve enormous growth in a few years. The company now has 205 bakeries in Central America: 185 in Costa Rica, 13 in Nicaragua, and seven in Panama (although, according to Pacheco, this should increase by 12 in the very near future). The company also sells bread dough and other bread products in several countries in Latin America and the Caribbean; according to Pacheco, Musmanni can sell bread in different stages of

[22] Additional information on the firm is available at www.musmanni.net.

processing depending on the market and the client, which provides greater flexibility and market penetration.

Musmanni bought equipment from Italy and the United States for it bread-dough production unit, but it has also developed units of its own such as large volume mixers. Interestingly, for some of purchases, Musmanni designed its own equipment, mainly ovens, and then contacted major manufacturers in Europe to produce these units according to those own designs. A particular advantage that the firm enjoyed in these areas was that two sons of the manager/owner had studied bread production at modern centers in the United States.

One disadvantage that Musmanni had to face, however, according to Pacheco, was the high cost of credit in Costa Rica. The company's growing size and reputation, though, have allowed it to overcome this initial obstacle, and Musmanni can now secure financing from foreign banks at significantly lower costs.

A further difficulty involved the role of mid-level technicians in innovation, as these technicians may have became an obstacle in the process. This occurred because the system of selling pre-made bread made it possible to do without bakers in bakeries and to some extent at the central Musmanni plant as well. Bakers were in large part opposed to this strategy. Today Musmanni runs the whole operation with only two of its original bakers, an illustration of the skilled-biased technological change discussed above. Moreover, given that the national training institute (INA) continues to train bakers in the traditional way, Musmanni has had to innovate in the training aspect as well, developing their own training center (The Bread University) to share knowledge about their new ways of making and selling bread.

3. Dos Pinos Cooperative and La Meseta Coffee Roaster

Dos Pinos is a large cooperative with a near-monopoly on milk and its derivatives in the Costa Rican market. It also exports milk derivatives to the Central American and Caribbean region. Its cooperative nature implies that it must receive all the production from its associated milk producers, creating a constant pressure to launch new milk-based products to the market. The company has been doing this successfully for the last decades, taking advantage of its large distribution network; it also has modern facilities and a formal R&D department. This department is composed of 25 technicians in food products with degrees from the national

training institute (known by its Spanish initials INA) and six graduates from the Universidad de Costa Rica: one in chemistry, three in microbiology, and two in food technology.

La Meseta is a small gourmet coffee roaster that sells primarily to tourists and exports its products online to US customers. There are now several such gourmet-coffee companies in the country. Faced with declining prices and tougher competition, the company decided to develop new coffee products to sell in the domestic market. The company studied the beverage market in the country and found that there was an opportunity to introduce a cold milk-and-coffee beverage. To develop such a product, La Meseta contacted Dos Pinos and signed an agreement to develop the product jointly.

La Meseta focused on producing the coffee concentrate, and Dos Pinos used its R&D lab to develop the process of combining the milk and coffee in such a way that the product would maintain consistency for an appropriate length of time given the marketing and distribution system. The second part of the development process was not easy, since in various initial attempts the product kept breaking down in a short time. Dos Pinos received technical support from its substance and chemical suppliers for its other milk-based products. After the appropriate stabilizers were found, Dos Pinos used its already-established research system to perform the appropriate taste tests for the new product, which was eventually launched successfully. Currently, production is undertaken at the Dos Pinos plant, using the coffee concentrate produced by La Meseta.

An interesting fact, which is relevant for understanding the way the NIS works in this area, is that Dos Pinos has had the country's most up-to-date food production and testing laboratories in recent decades. Because of this, INA and CITA have signed agreements with Dos Pinos to use its facilities to train their students. But now, with the help of CITA, INA is investing in modern equipment and infrastructure, and new cooperation agreements with Dos Pinos are being discussed.

4. Productos Banquete (sauces)

Promotional materials for this company included the following description:

> The company has 50 years in the food business with the brand BANQUETE which produces ketchup, steak sauce, barbecue sauce, pizza sauce, chunky sauce, hot sauces, soy sauce, jalapeno sauce, mustard, vanilla, etc. The company has

71.1% of the market share of the Costa Rican ketchup market. Ketchup brand BANQUETE is also sold in Nicaragua, Honduras, El Salvador and Panama. The line of Tropical Sauces and Salsas (made of mango, pineapple, etc) have been a success and are now on sale in countries like USA, Canada, Sweden, the Virgin Islands, Portugal and Spain. The company also offers the possibility of private label for their clients on this line of products.

Additional facts of interest are that Productos Banquete has 170 employees and annual sales of US$15 million. Exports represent 20 percent of the company's total sales.

The innovation that we studied involves the introduction of a new line of hot sauces made from different varieties of tropical fruit (bananas, passion fruit, tamarind and mango). As in the previous cases, this innovation was born from the increasing competition in the domestic market in the sauces sector.

Faced with these conditions, the company looked for ways to increase its exports. It was clear, however, that the company could not compete in large markets (e.g., the United States Europe) for basic goods such as ketchup, given that it could never match the economies of scale achieved by the large companies in those markets. After some research, the company realized that Costa Rica had a clear comparative advantage in the production of high-quality chile and tropical fruits. This led to the idea of developing a line of hot sauces made from tropical fruits such as bananas and mangoes. This product line was named "Typical Tropical Sauces."

The development process for this line of sauces first involved research in the target markets to understand consumer preferences, the sauces that were consumed, the way they were packaged and presented, their prices and their distribution channels. It is interesting to note here that PROCOMER participated in the process by undertaking a general study that had been solicited by the group of sauce-making enterprises.

After this initial study, the company devoted its attention to the development of the product in its plant. The know-how that the company had accumulated allowed it to accomplish this task in a short time. The next step was to organize "focus groups" and tasting trials to verify consumers' acceptance of the product. With positive results at home, the company took its product to the "Fancy Foods" fair in the United States (also with the support of PROCOMER).

The result was very positive not only for the US market, but also for European distributors who participated in the fair.

Having such positive prospects, the next step was to coordinate with local suppliers for inputs such as the glass containers and labels for the product. The problem was that, for both of these inputs, Banquete needed something different than was customary in the Costa Rican market. The company therefore contracted a local glass company (VICESA) to develop a glass container with a similar design to other fancy or gourmet sauces sold in the target markets. It also contracted a printing company (Fotolit) to develop a high-quality label for which there was little experience, given that it had to cover the whole product.[23] This process of joint development of product components with local suppliers illustrates the importance of having sophisticated local suppliers as a requisite for successful innovation.

Another important step was to develop proper manufacturing standards so as to be able to meet the rigorous quality controls of the US and European markets. There were also rigorous standards in terms of information that had to be provided in the product label. According to the interview, this was one of the main obstacles that the company faced in entering this kind of sophisticated markets. The company sent some of its employees to participate in Manufacturing Process and Quality Control courses given by CITA. This is another example of how the existence of suppliers and service providers (in this case training) is essential for innovation.

Having taken the previous steps to design the product, the company now had to acquire some equipment for its manufacture. In particular, it needed a machine to stamp the labels on the salsa containers, and a special oven. These machines were installed by the foreign supplier, and repairs are performed by Banquete's technicians.

According to the interview, an important element that helped to make this innovation successful was the experience that the company had accumulated during previous innovation efforts. This reduced uncertainty and helped to provide a map for the steps that had to be taken for a successful process. This illustrates a kind of learning by doing in innovation.

It is interesting to note that after this successful innovation, the company established a formal innovation group called the "Committee for New Products." Three employees participate

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[23] Interestingly, Fotolit was then able to sell this type of product to other local companies; thus, in this case, both backward and forward linkages are observed.

in this group: the general manager (MBA), an engineer (UCR) and a food-technology graduate (UCR).[24]

5. Fideos Precocidos de Costa Rica (pasta and noodles)

The company's web site (www.vigui.com) provides the following description:

> Fideos Precocidos de Costa Rica is a leading producer of food products in Central America, with specialties such as "Wheat Pre-Cooked Pasta", "Rice Pasta Products, Gluten Free" and most recently "Instant Noodles Soup, Ramen Style". Owner of the trademark "Vigui", this company began in 1968. It experienced a rapid period of expansion 15 years ago, under the Caribbean Basin Initiative. Vigui has managed to successfully penetrate competitive markets in the USA, Mexico, Caribbean and Central America. Vigui products are well known for their quality in Costa Rica. They comply with the USA FDA standards. Vigui employs 200 Costa Ricans and has facilities measuring 11,000 sq. meters.

The company was created in the late 1960s to produce instant noodles for the local Chinese community. Since then, the company has specialized in pasta and noodle products that have special niche markets. For example, today the company produces gluten-free rice pasta products for people who suffer from gluten or gliadin wheat allergies.[25] In recent years Vigui has been engaged in an innovative process to produce and export low-fat Ramen-style noodle soup, positioning itself in the quick-lunch market with a healthy product. We chose this company because, in the course of this innovation process, it has developed its own technology and now even sells the equipment to other companies. It is interesting to read how the company describes this technology:

> Whereas before the production line used to fry the noodles in hot oil, now it uses an intensive steam process to prepare the pasta, making the pasta firm and adding

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[24] A few years after this innovation was undertaken, Banquete was acquired by Heinz. Having a different strategy and vision for its Costa Rican operation, Heinz discontinued the production of the tropical salsas, and only maintained the production of Banquete ketchup. Nevertheless, according to the interview, there is an intense innovation process in Heinz and more resources available to finance it.

[25] It is interesting to note that this was undertaken through an alliance with a U.S. firm. The alliance was helpful in accessing some of the technology involved in this type of pasta, which was not known in Costa Rica. In exchange, Vigui agreed to produce rice pasta with the U.S. firm's private label.

an excellent texture as well. . . . One of the most important advantages of this new technology is that the shelf life of the product is longer (1 year guaranteed). This is because the oil has been eliminated. In addition, it does not require the use of preservatives, thus creating a more natural and healthy product. In fact, the total fat has been reduced from 20% to 4%. The noodles also have only 9% of final moisture, because they are dehydrated in a continuous hot air tunnel at 110C.

VIGUIMATIC-2000 is the new Costa Rican continuous production line that Vigui has designed, built and put into operation. It produces 600 to 700 Kg per hour, using raw materials from hrs [hard red spring] wheat. Vigui is capable of offering this new production technology to bigger plants that produce up to 1000 Kg per hour. This makes Vigui Technology a leader in America, in producing instant noodles products and instant noodles production plants that don't use the frying process.

It is interesting to note that the company has no R&D department as such. The manager mentioned in the interview that the company insists that all employees be involved in the innovation process, rather than be undertaken by a specialized group of people. The idea for the new product (a fat-free Ramen-style quick lunch) came from the marketing department, which noticed that there was no such product in the international market.

One of the first stages of the development process involved focus groups with real consumers to understand preferences and test some ideas. CITA helped the company to organize this exercise. The company subsequently sent technicians to several countries (Argentina, Canada, United States and even South Korea) to see what equipment was available. Unhappy with what they saw, they decided to develop their own equipment. They adapted some of the equipment they were already using, designed some new parts and machines with local tool shops, bought some discarded equipment from another company in the country, and in this way put together their new production line. The company also had to import some parts, which were from a different system than the other parts they already had. To allow the different parts to work together, they had to design and construct new tools, again with the help of local tool shops in

the country. The manager now claims that this technology is among the most advanced for cooking with steam, and it is unique in its application to Ramen-style pasta.

One final issue concerns the motivation for engaging in this innovation. In contrast to the cases described above, it is not clear whether there was a stimulus from globalization. As José Segura argued, this company has been looking for niche markets since its creation; in a sense, this company has been engaged in innovation for several decades now, so one could see this latest innovation as a continuation of that trend.

C. Lessons

It is clearly not valid to derive general conclusions from the analysis of only five cases of successful innovation. What I will do in this section is to examine some hypothesis and see what these cases tell us about them, keeping in mind that such conclusions are tentative at best.

Hypothesis 1. Excluding the role of universities and training institutes (see below), the National Innovation System has not played a significant role in the innovation process of most successful companies.

The five cases studied support this hypothesis. None of the companies required any kind of IPR protection beyond basic protection of registered brands and trademarks. All the companies answered that they did not think there was an NIS functioning in the country. They acknowledged that there were some efforts by the Public Sector, but these were seen as isolated cases and not part of a system.

In three cases companies mentioned specific help they received from public institutions. Sardimar contacted CITA for the validation of its thermal processes, an important element for its objective of penetrating developed-country markets. Productos Banquete mentioned that they benefited from export-market information from PROCOMER and from quality-management training from CITA. Pastas Vigui acknowledged that CITA helped them put together focus groups to study consumers' reaction to their new product.

What are the implications of this hypothesis? One could use these cases to argue that a properly functioning NIS is not important for innovation. But we must be careful, because these five companies may be extraordinary cases; indeed, that is why they were chosen for the interviews. One could equally argue that had there existed a properly functioning NIS, growth in production and exports in the food sector would have been even higher.

In any case, given that export growth was significant during the 1990s, as shown in Table 20, it is safe to say that a proper NIS is not essential for innovation. This does not, however, rule out the possibility that setting up an effective NIS may generate high returns. One should note that Costa Rica spent a considerable amount of resources on export subsidies. Perhaps it was thanks to such subsidies that the country was able to achieve high export growth. Perhaps with a proper NIS, however, such export subsidies might not have been necessary!

Hypothesis 2. Most of the innovation in the food sector is not part of measured R&D. Of the five companies studied, only two had formal R&D departments: Dos Pinos and Sardimar. The other three companies carried out their innovation projects with production and marketing personnel, and with intense involvement from management.

It is revealing that Dos Pinos and Sardimar are by far the largest of the five companies studied. The other three are medium-sized enterprises whose scale is not big enough to justify a formal R&D department. At most, they have "innovation groups," composed of personnel from production, marketing and management that meet regularly to review innovation projects.

Hypothesis 3. Contrary to what some recent research suggests, lack of access to proper equipment for the production of new goods is not a significant obstacle to innovation.

All the cases studied showed that companies are well informed about modern equipment. They get this information mostly through trade shows and specialized magazines. Once they know what they want to produce, they generally know where to ask about the proper equipment. Once the equipment arrives, the company usually devotes some effort to training employees in its use; the foreign equipment manufacturer often collaborates in this training.

This does not imply that innovation is simply a process of buying new equipment. On the contrary, the interviews suggest that this is not at all a vital element of the innovation process. The key element is research regarding markets, costumer preferences, product design, quality control, and several other areas where it is not possible to buy solutions "off the shelf."

The cases studied also suggest that some successful companies master the technology to such a degree that they end up developing their own designs (Musmanni) and even selling their newly developed machinery to other companies (Vigui). In other cases, like Sardimar, the company is able to use off-the-shelf equipment and thus can focus its attention on developing the appropriate software to integrate the equipment with the rest of their production process.

Hypothesis 4. The increase in competitive pressure associated with globalization (unilateral trade liberalization, bilateral trade agreements, and increasing flows of FDI) has increased innovation efforts in the food sector.

The cases analyzed lend some support to this hypothesis. All the cases except Dos Pinos-La Meseta and Pastas Vigui stated that increased competition in the domestic market had pushed them to introduce new products and strategies to increase market share at home and expand exports. Of the three companies who stated this, only Corporación Musmanni was previously devoted completely to the domestic market; the other three companies were already exporting, although most of their production was targeted to the domestic market.

A question arises here: if innovation is profitable, why do firms wait until they are forced by globalization to engage in innovation? There is an extensive literature exploring this issue; see, for instance, Boone (2000). The results of the theoretical literature are ambiguous: there are reasons why stronger competitive pressure would lead to *more* innovation and reasons why it would lead to *less* innovation. Empirically, this topic has not received enough attention. Thus, Hypothesis 4 is by no means trivial, nor is it necessarily correct. Moreover, it is not the case that all companies who suddenly face stronger competition due to globalization increase innovation. It is safe to say that many companies adopt conservative strategies and accept lower market shares; some even close down or go bankrupt. What differentiates companies that face the increased competition challenge through innovation from the more conservative companies? What can governments do to increase the share of companies who choose to compete through innovation? The following hypotheses may shed some light on these important questions.

Hypothesis 5. Faced with increased competition in their domestic market, companies that have the "right stuff" will turn to an innovation-based strategy to differentiate their products and thereby increase market share at home and expand sales abroad. Two elements appear to be the key ingredients of the "right stuff": access to finance and specialized human resources.

The Costa Rican financial system evolved to serve traditional exporters and producers of industrial goods during the Import Substitution period. One conjecture is that they have not adapted to the new circumstances where many projects do not involve hard collateral, where risk is higher, and where project maturity is longer. This may be due to lack of competition in the banking sector, together with tight regulation that slows down innovation by banks. Whatever the reason, it seems that access to finance is a significant obstacle to innovation in the country.

Two companies, Musmanni and Banquete, mentioned that the banking sector does not have the proper "culture" to deal with innovative projects; they mentioned that the strategy of banks is too conservative. In the case of Vigui, the Banco de Costa Rica (the second largest state-owned bank and one of the largest banks in the country) rejected the loan when the engineer in charge of evaluating the proposal concluded that the project was not "technically feasible" in the country. It was able to continue in part thanks to the alliance it developed with a U.S. firm for which it manufactured rice pasta for the U.S. firm's private label. Later on, Pastas Roma, the largest Costa Rican-owned pasta manufacturer in the country, acquired a stake in Vigui, providing fresh funds for continued investment and innovation.

Sardimar, Dos Pinos and Musmanni are large corporations that have very good access to the banking sector and plenty of cash flow to finance their operations and innovations. Vigui and Banquete, on the other hand, were able to rely on cash flow and credit from their suppliers.

In sum, the hypothesis is that many small and medium-sized firms are liquidity constrained and that this affects their ability to respond to the competitive challenge presented by globalization. Only large corporations, which generally have very good access to bank credit and good cash flow, together with small and medium-sized companies going through a good cycle in their financial position, can afford to invest resources in innovative ventures. It is likely that many companies with good innovative ideas and a high probability of success succumb to foreign competition because of their lack of access to external finance.

The second key ingredient for the "right stuff" is high-quality human resources. None of the companies mentioned lack of human resources as a constraint on their innovation projects. My conjecture is that this is because of the effort that has been made for the last three decades at the University of Costa Rica. As the next section argues in detail, over the last three decades this university has produced hundreds of professionals with practical and up-to-date knowledge in critical areas such as quality management and innovation; these professionals have been essential in turning around the food sector in response to trade liberalization.

Hypothesis 6. It is often the case that innovation is spurred by a crisis (point made emphatically in Kim, 1997). We uncovered two examples of this: Vigui and La Meseta. In the case of Vigui, the sudden scarcity of wheat that pushed the company to study pasta made from rice. In the case of La Meseta, very low coffee prices and increased competition in the gourmet-coffee market led the company to look for new coffee-based products.

It can also be conjectured that there is a kind of hysteresis in innovation: once a crisis leads to an innovation process, those the people become enthusiastic and often install innovation groups that continue with innovation even after the crisis has been surpassed. Moreover, there seems to be a process of learning by doing in innovation. As in the model described roughly in the Appendix to this chapter, the crisis destroys the safe option and forces the firm to shut down or innovate. The hypothesis is that the firms that take the innovation option with success embark on a sustained innovation path thanks to learning by doing.

D. The Role of the UCR in Food-Sector Innovation

As indicated in Hypothesis 1 above, the interviews suggest that there is no properly functioning National Innovation System associated with the food sector in Costa Rica. But there was one institution that was mentioned in three of the five cases studied: the food-technology center at the University of Costa Rica (CITA).

Moreover, as indicated in Hypothesis 5, the existence of highly qualified food-technology professionals with UCR degrees also appears to be an important input in the food sector's innovation efforts. Indeed, all the companies have UCR food-technology professionals in their plants: Vigui has one in charge of quality control. Dos Pinos has two in its R&D department, and Musmanni has eight. Sardimar has a total of 19 people in their Quality Assurance Department, of whom two focus exclusively on R&D. Finally, before being taken over by Heinz, Banquete had one food-technology professional in its Committee for New Products.

Franco Arturo Pacheco, whom I interviewed mainly in his capacity as Director of Musmanni Corporation, is also the current president of the food-sector industry association (CACIA). I asked him about CACIA's opinion of the quality of the food-technology graduates from UCR. According to Pacheco, CACIA trusts the quality of these graduates, who often end up in key positions in the innovative firms in the sector. Even though private universities have recently opened similar programs, companies continue to prefer UCR graduates.[26]

Motivated by these findings, in this section I will discuss the origins of CITA and the Food-Technology Department (FTD) at UCR, and their role in the food sector in Costa Rica. The

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[26] Addressing a related issue, Pacheco also mentioned that companies in the industry are not as pleased with the quality and relevance of the training programs offered at INA. He complained that INA does not collaborate enough with CACIA in the design of these programs.

purpose is to understand how it is that these twin institutions have been able to play a constructive role in the modernization of the domestic food sector. This may provide valuable ideas about policies to implement in other Central American countries.

Although university research centers are usually created by an existing university department, this was not the case with CITA. CITA came first, and only later was the FTD created. As we will see, this unusual history may help to explain the success of both CITA and FTD.

1. Basic Information on CITA and FTD

CITA was created in 1974 by an agreement between the UCR and the Ministry of Agriculture (MAG). The objective was to aid in the development of the food sector in the country, based on the common notion that it would help the economy and the agricultural sector by adding value to primary output. As part of the agreement, MAG makes a yearly monetary contribution directly to CITA. In 1996 the Ministry of Science and Technology (MICIT) joined the agreement, with the obligation of transferring an additional yearly sum. In the year 2001, the combined transfers from MICIT and MAG amounted to 85 million colones, equivalent to approximately US$250 thousand, representing 40 percent of CITA's total budget; the rest was covered by the UCR. In 2002 CITA had a total budget of approximately $1 million. The UCR financed 49.2 percent, MICIT 17.7 percent, and MAG 8.1 percent. The rest was financed by CITA through research projects, grants, and services such as training, laboratory services, and consulting.

The approach adopted was multi-disciplinary from the start. Floribeth Víquez, the current general director of CITA, believes that this explains the center's success over the years. The center's more than 60 employees, 70 percent of whom are technicians and professionals, have the know-how and infrastructure to perform sensorial, chemical and microbiological analysis, as well as cost estimation, marketing studies and product development.[27] They engage in research, laboratory analysis, training and paid consulting for the private sector. Based on the steps followed by Banquete in its innovation process, it is clear that the combination of all this expertise in a single center could be very valuable for innovation in the food sector.

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[27] CITA is the only sensorial analysis laboratory in Latin America that has started a certification process for its analyses according to ISO 17025.

The FTD was created a few months after CITA started operations. This unit's approach was also multidisciplinary: in fact, the creation of the FTD was a joint effort by CITA, the School of Agronomy, the School of Microbiology, the School of Chemistry and the School of Chemical Engineering, all of the UCR.

As mentioned above, the fact that the FTD was created after CITA reverses the usual sequence of events at universities, where research centers are usually created by established departments. This may explain why the FTD has been able to maintain a very practical orientation in its program. The collaboration between CITA and FTD is very intense: FTD professors generally engage in research at CITA, which provides a way for them to keep abreast of current developments, understand the needs of the private sector, and supplement their normal UCR salaries. Similarly, all CITA researchers have to teach at least one fourth of a normal load at FTD. Moreover, all FTD students do their dissertations at CITA, which allows them to work on relevant issues with modern equipment and with knowledgeable colleagues in a stimulating atmosphere. According to Jackeline Aiero, director of FTD, all the student dissertations in the last year were undertaken in close collaboration with the enterprises that could use the research findings.

Together, CITA and FTD have four Ph.D.'s, eight Master's in science, one MBA and nine "licenciados" in food technology. The universities where these professionals have undertaken their post-graduate studies are: UCR, ITCR, the University of Rhode Island (United States), the University of California at Davis (United States), Greenwich (England), Hohenheim (Germany), Politécnico de Valencia (Spain), Montpellier (France), Iowa State (the United States), and Purdue (United States) CITA and FTD have collaborative agreements with foreign research centers and universities, such as CIRAD (France), Purdue University, Michigan State University, and Iowa State University.

2. The Role of FTD in the Modernization of the Domestic Food Sector

Besides its multidisciplinary approach, the Food Technology program of the UCR's FTD is also characterized by a strong emphasis on innovation. During the third semester, students have to develop an original product. Moreover, throughout their academic life, students are encouraged to participate as assistants in the projects run by CITA. According to Jackeline Aiero, it is there that students learn and apply many of the techniques that they will use in their professional

careers. Towards the end of their fifth year, students take a course that emphasizes productive applications. Aiero mentioned that four projects developed as part of this course during 2002 received awards in the National Innovation Contest (run by the Entrepeneurship Center of the ITCR). One of these projects took first place in the contest.

The final years of the program are devoted to the dissertations. These are supervised by professors with masters or Ph.D. degrees and are undertaken at CITA. In recent years, all dissertations have been undertaken directly with enterprises that can potentially benefit from their results. In fact, two recent projects have generated valuable products or technologies, but the UCR does not have a well-defined IPR system to determine how to benefit economically from these innovations.

The FTD admits 30 students per year. The actual time to completion is between seven and eight years, although the program is designed for five years of study and one-and-a-half years for the dissertation. There is a strong demand by the private sector for the graduates of the FTD program, and here are several ways to confirm this high demand. First, there is actually a "problem" for the FTD in that, even before completing their studies, students receive attractive offers from the private sector, prompting many to leave the program, usually during the fifth year (just before starting their dissertation). Thus, counting only the roughly three hundred FTD graduates of the last three decades underestimates the total contribution of the department to the food sector in Costa Rica.

Second, there is a high and rising demand by prospective students for enrollment in the program. Given its budget and other university constraints, however, the program has not been able to expand, leading to a high cut-off grade for admittance in the FTD. Finally, as mentioned above, CACIA has a very good opinion of the quality of FTD graduates, and thinks that they execute key activities in the country's food-sector enterprises. Moreover, all the companies interviewed have hired FTD graduates, often in key positions for their innovation processes.

The above considerations suggest that there is a high demand for FTD graduates, who perform important roles in the enterprises of the food sector in Costa Rica. It is natural to wonder, however, whether FTD graduates also contribute more directly to innovation and economic growth through the creation of new enterprises, as has been documented in the case of the software sector.

Jackeline Aiero mentioned that this is not common in the case of FTD graduates. She estimates that less than 1 percent of FTD graduates have created their own enterprises. My conjecture is that this is due to the fact that the investment needed to launch a new product in this market is much higher than for software. Thus, lacking access to finance, most graduates become employees of established corporations.

Motivated by this type of considerations, in December of 2002 the UCR signed an agreement with the Banco Nacional creating a system to finance productive projects proposed by FTD students in the final stages of the program. Under this agreement, students could access loans of up to $6,000, backed by a guarantee fund constituted by the UCR that would cover up to 30 percent of the loan in case of failure. At the early stages, projects may even use UCR facilities (e.g., land, buildings, technology). Perhaps with this system more graduates can start their own firms and contribute more directly to increasing innovation in this sector.

3. The Role of CITA in Innovation and Technology Adoption

It is my presumption, based on the interviews and the data collected from UCR and CITA, that this university research center is the one that has established the most intense and productive ties with Costa Rica's private sector. According CITA's web site, the center has received more than 8,000 support applications, 70 percent of which come from the national and regional productive sectors. More revealing, it has developed or reformulated more than 150 products for the national and international markets since its creation.

Based on these kinds of data and on what I had heard about CITA in my previous interviews concerning innovation in Costa Rica, I expected contract R&D for the private sector to be an important activity for the center. In fact, however, as explained by Floribeth Víquez, this is very rare.[28] Most of the services that CITA provides to the private sector are laboratory analyses (many of them certified under ISO), consulting (which includes help with product

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[28] This may now be changing, as CITA is currently engaged in three projects to develop specific technologies for private firms. It is developing technology to improve production of concentrated banana juice for Florida Products; it is engaged in a project for a local company (Caminos del Sol) to adapt and then transfer French technology for frying with less fat absorption; and it is involved in a project to develop a canned *palmito* (hearts of palm) product for the Asian market (for Conservas del Valle). CITA was also contacted by EARTH University (Universidad para el Trópico Húmedo, an international university based in Costa Rica) to transfer technology for the production of dehydrated fruit bars, which EARTH wants to produce and commercialize. Moreover, contract R&D was given priority in the new strategic plan adopted by CITA for the 2002-2006 period.

development), a telephonic information service system, and training.[29] The most common services provided to firms are aid with the implementation of "Good Manufacturing Practices," "Food Quality Control" and the application of a diagnostic process developed by CITA that measures the technology level of a company.

Although Mrs. Víquez stressed that the center is constantly learning and improving its services thanks to its intense relation with the productive sector, most of the activities described above are not research from CITA's point of view. Still, even if these activities cannot be characterized as research and even if, strictly speaking, they do not involve innovation, they certainly aid in the process of technology transfer. As we discussed in the first sections of this paper, this is probably much more important for productivity growth in developing countries than "pure" innovation.

CITA does perform R&D, but it is rarely paid for by the private sector, except for the few projects that are performed as part of MICIT's R&D Matching Grants System (FRC) that the government introduced in the year 2000; this will be discussed below. For the most part, the funding for the center's R&D comes from the UCR as well as grants from foreign institutions and some local NGOs. The obvious question then becomes: how are the R&D projects selected? More importantly, are the results of this R&D helpful for the private sector?

It turns out that the private sector has no direct role in the determination of the R&D performed in CITA. For the common university research center or academic department, this would suggest that the private sector does not derive significant benefits from such R&D. But this is most probably not the case with CITA. Recall that CITA is not at all a "common" research

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[29] In a recent issue of "Revista Alimentaria" (No. 64, 2002), the magazine of the Food-Sector Industry Association (CACIA), there are advertisements by two private laboratories specialized in microbiology for food and other industrial products (Laboratorio SupliLab, S. A. and Laboratorio Químico Lambda S.A.). CITA claims that it offers a wider variety of services with higher and certified quality control. This is, in part, a result of the fact that CITA must strive for the highest standards, as this is part of the goal of academic excellence of the UCR. In particular, the highest standards, with proper certification, are necessary for respectable research in this area. Interestingly, a representative from the National Industry Chamber, whom I interviewed about the contribution of universities to innovation in the whole industrial sector, criticized the participation of university laboratories in the market for such services. She argued that this was unfair competition to private laboratories. There are two replies to this interesting comment. First, these services involve "new-good externalities," and thus subsidies coming from universities could generate welfare improvements if they lead to the introduction of services that the private sector would not have introduced. This could be true for CITA for the case of sensorial analysis, which I did not see offered by the private laboratories. Second, and perhaps more important, a university may need to make this kind of investment anyway, as a tool for education. If this were the case, then it would also make sense to use such equipment for commercial gain. It is true that this may hurt private sector laboratories, but it would still be efficient.

center, in that it was created at the request of the Ministry of Agriculture, it receives direct funding from the Government, and it has a multidisciplinary approach.

According to Mrs. Víquez, the intense interaction between CITA and the private sector through all the activities mentioned above, even if not contract R&D, does help to make CITA's staff aware of the challenges and opportunities faced by the productive sector. This becomes an important element in the determination of R&D activities. Thus, one can argue that the private sector has an indirect but important role in the process. There are other, formal but still indirect ways through which the productive sector (represented by CACIA) has a role: first, through its participation in the review of CITA's five-year plans; second, by having a seat in CITA's Directing Council; and third, through a bilateral CACIA-CITA commission whose goal is precisely to improve and strengthen the collaboration between these two institutions.

The other important element in the determination of CITA's R&D activities is of course the organizations that finance these activities. Although this imposes some constraints on what CITA may do, in fact it is CITA that assembles the proposals that compete for funds in competitions organized by the international organizations. The center chooses the projects according to its own strategic interests.

In sum, CITA's R&D activites are determined in a complex process whereby its staff, aware of the situation in the private sector, interacts with the UCR, the government and international organizations that provide research grants to the center. It is not unreasonable to conjecture that this arrangement is superior to one where CITA's R&D activities were determined by the interaction with individual enterprises through contract R&D. One has to keep in mind that the main goal of a public institution such as CITA should be to increase R&D with the highest social return. It may well be that, thanks to CITA's nature, as argued above, the way through which CITA is determining its R&D activities is more conducive to choosing this type of R&D than contract R&D.

Once this research is performed, in what precise ways does it contribute to innovation in the private sector? One way, of course, is simply the increase in knowledge that it generates for CITA's researchers, which is then diffused to the private sector through the services CITA provides. But there is also a more direct way: often, the results of these R&D projects lead to new products or processes that CITA then tries to "sell" to the private sector. A recent example is the development of a process whereby the liquid discharges produced during the production of

cheese can then be used to produce isotonic beverages (like Gatorade). CITA talked to Dos Pinos about this new process, but it was not interested. There are other similar processes underway, which CITA could not disclose because of confidentiality clauses.

An additional issue that came out in the interviews with CITA's Floribeth Víquez concerns the center's budget and infrastructure. The lack of funding for keeping infrastructure and equipment up to date with current technology came up as a significant issue in the interviews I conducted with several center and department directors at UCR and ITCR. CITA and the FTD were no exceptions. Mrs. Víquez mentioned that CITA's infrastructure is 20 years old and could become obsolete in a few years if current investment flows are not increased. Part of the problem is that the government has never transferred the sums stipulated by the agreements. The center's net revenues from the services it delivers to the private sector have been just enough for buying basic materials and inputs like computers, raw materials, chemicals and office supplies, but not for buying equipment or renovating infrastructure. The increased revenues earned by the center thanks to its several winning bids under the FRC system (see below) have been helpful here, and so have the resources obtained from foreign grants. But this is not enough to solve the problem. Unfortunately, keeping up to date with fast-developing technology requires much more investment: most of the equipment they need is expensive, running from US$12,000 to US$100,000 per unit.

UCR recently approved a transfer of 60 million colones (approximately US$150,000 at 2003 exchange rates) to be disbursed in 2003 for improvements in CITA's infrastructure, and CITA is currently running a fund-raising program directed to the producive sector (donations would be tax deductible for firms). But this may not be enough. Based on the arguments made in this and the previous section, it would seem that government investment here would have high social returns, although this would obviously require a more formal investigation.

E. MICIT's R&D Matching Grant System and its Role in the Food Sector

In 2000 the government introduced a new R&D Matching Grant System (FRC, for its Spanish initials for Fondo de Recursos Concursables) through the bylaws 28681-MICIT; the methodology and other details can be found at www.conicit.go.cr. As stated in the program's bylaws (Article 8) the objective is to "finance projects that contribute to improving the processes

of innovation and technological change which includes the participation of industry associations, SMEs and Research Units." Articles 9 and 10, translated below, are also worth noting:

> Article 9. The State's support of a project consists of a grant based on the project's externalities. Such externalities will be determined according to an Evaluation Table to be prepared by CONICIT [Consejo Nacional de Ciencia y Tecnología] and MICIT.
>
> Article 10. All SMEs and industry associations that wish to improve their competitiveness through investing in technological research and development, and that generate a positive impact on behalf of their sector, can participate.

The yearly sum devoted to the system since it was launched in 2000 has been 500 million colones, approximately US$1.7 million at year 2000 exchange rates. The yearly selection of projects consists of two phases. In the first phase, individual SMEs and industry associations submit proposals for evaluation by MICIT according to the following criteria: quality, clarity of objectives, justification of the technological need of the sector, the promised financial contribution, creativity and novelty of the proposal and the potential impact of the technology on the environment and the country's economy. Qualifying projects are then assigned a contribution share according to their perceived externality, per Article 9.

In the second phase, certified research units present their offers for the projects that qualified in the first phase. The winning offer is selected according to criteria of quality and price. At the end of the second phase, there is a list of projects, each of which is assigned a research unit, a total cost, and the percentage of the cost that the government has promised to pay. The SME or industry association that presented the proposal is then called upon to place its share of the cost in a trust fund. Once this is done, the government makes its contribution to the trust fund and the project starts. MICIT conducts periodic monitoring of the projects to make sure that the resources are being spent according to the plan and to evaluate the results

There are several interesting features of this system that deserve comment. First, the demand comes from the private sector and not from the research units, as was the case before. This should increase the likelihood that the projects lead to commercially useful technologies. A possible drawback is that, as technologies become more applied, their externalities also diminish;

in this way, the government's resources could end up financing projects that would have been undertaken anyway. The system is designed to prevent this, as it restricts financing to projects whose benefits go beyond the companies that present it. Moreover, as the externalities decrease, so does the government's contribution.

Second, there is competition on the part of research units for each project. This is a new feature; in the past, research centers presented their own projects, making it hard to select among them following objective criteria. Moreover, competition was generally low. Now there is intense competition among research units, presumably leading to lower costs for the projects. This should also have the additional benefit of increasing the centers' fundraising capabilities.

Third, the formal nature of the system leads to the generation of information about the projects presented and those that finally obtain financing. This information is useful for the private sector and also for the government's overall science and technology policy. The periodic evaluation of the projects should provide valuable feedback on how to improve the system in the future.

To date, MICIT has financed 30 projects: 11 from the first competition in 2000 and 19 from the second competition in 2001. The program suffered a legal problem in 2002 but was renewed in 2003. Interestingly, of the 11 projects financed under the first competition, 10 are associated with the agriculture and agro-industrial sectors, and only one with the industrial sector. This pattern did not change much in the projects financed in the second competition: of the 19 projects selected, 15 are related to the agriculture and agro-industrial sectors and only four with the industrial sector. From conversations with people involved in the selection process it became clear that this pattern is not due to the selection process: the same bias against the industrial sector is present in the number of proposals. Providing an explanation for this goes beyond the scope of this paper; here I can only venture the hypothesis that this is because externalities are stronger in innovation and technology adoption in agriculture and agro-industry than in the industrial sector.

The role of FRC is illustrated by the projects in which it is involved. Thirty projects are currently underway, and five are being executed by CITA. These projects are the following:

- Utilization of discarded bananas for the production of alcohol and other chemical products. This project was proposed by CORBANA, the national institute for the promotion of banana production and commercialization.
- Improvements in quality control for sausage production. This project was proposed by CACIA.
- Design of a plant specialized in the processing of dehydrated chile. A single company, ALFAVILA S.A, proposed this project.
- Development of appropriate technology to produce dehydrated cream of "ayote" (a local type of squash) and secure proper packaging to prolong shelf life.
- Modernization of the Association of Diary Producers in Turrialba, through standardization of production methods and reducing environmental damage.

Reflecting CITA's dominant role in the food sector's technological improvements, most of the proposals that are made to the FRC in this area are previously discussed with the center beforehand. This is in part because companies and industry groups are not experienced in the preparation of this kind of proposals, so they approach CITA for guidance in how to structure a successful proposal. This is also due to the food sector's high regard for the center and their desire to participate in the center's technological projects.

F. The CAATEC Survey

The Costa Rican High Tech Advisory Committee, known by its Spanish acronym CAATEC, is an NGO whose mission is to promote Costa Rica's transition towards a knowledge economy. It has been conducting studies about the level of preparedness of the Costa Rican economy for this transition, as well as understanding the way firms approach technology and innovation in the country. As part of these efforts, CAATEC conducted a firm-level survey on innovation in the second half of 2002. Here I report some of the findings from this study that bear some significance for the issues explored in this section.

The survey covered 33 firms in the food sector. Twenty-six of these firms were small (under 30 employees), six were medium-sized (from 31 to 100 employees), and only two had more than 100 employees. Thirteen of these firms were created after 1990, and 13 were created

before 1980. These 33 firms produced a total of 73 different goods; of these, only goods classified as “canned or preserved fruits and vegetables” were exported.

In terms of the most relevant results, 27 firms reported some type of innovative activities, and nine out of the 33 firms reported being engaged in research and development activities. Unfortunately, the survey did not inquire whether firms had their own R&D department or how much they spent on R&D as a share of total sales or value added. In addition, 17 firms reported activities associated with technical assistance, and 20 reported engaging in training for their human resources.

The 27 firms that reported some innovative activity were asked whether they buy new equipment, and 22 reported having done so. Of these firms, 17 firms report having bought made in 2000 or more recently.

The 27 innovative firms were further asked about the impact of different elements on their ability to innovative. Twelve agreed that lack of financing was a constraint; 24 agreed that a high cost of financing was a constraint; eight agreed that lack of information about technologies was a constraint; 14 agreed that unclear regulations constrained innovation; 11 agreed that lack of institutions related to science and technology was a constraint; six agreed that a weak IPR regime was a constraint; and seven agreed that the lack of specialized skilled workers was a constraint.

The 27 innovative firms were additionally asked to rate the importance of different elements for their ability to innovate. The elements that scored the highest levels were “having access to qualified human resources,” “having access to finance,” “having local suppliers,” and “obtaining market information.”

All the firms were asked whether they knew of four public programs to improve productivity: FRC (1 yes, 32 no), SME program at INA (13 yes, 20 no), “reconversión productiva” for agriculture (4 yes, 29 no), and “creando exportadores” at PROCOMER (12 yes, 21 no).

All firms were also asked to mention whether they had received support from different institutions. Their responses are reported in Table 21. The five firms that received support from CITA were asked what type of services they received. Four firms mentioned technical assistance, two firms mentioned information and two firms mentioned training.

It is difficult to extract conclusions from this survey: the number of firms is small and the questions were not formulated to test the hypotheses presented above. Still, some comments are in order. First, the share of firms engaged in R&D, 33 percent, is higher than expected. More generally, firms seem to be devoting efforts to innovative activities and renovating their equipment. Second, PROCOMER and INA appear to be playing an important role for the sector. Third, although not as high as expected, lack of access to finance is mentioned as a constraint by almost half of the firms engaged in innovative activities. In contrast, less than one quarter of innovative firms mentioned a weak IPR regime as a constraint. As to the importance of lack of specialized skilled workers, the survey's results are ambiguous: a small number of firms (25 percent) say that this is an important constraint on their ability to innovate, but then when asked to rank different elements in terms of their importance for innovation, this issue came at the top.

6. Case Study 3: The Role of UCR and ITCR in Costa Rican Research

I conducted several interviews with officials from Universidad de Costa Rica (UCR) and Instituto Tecnológico de Costa Rica (ITCR) to better understand the role of universities in supporting research. I approached the issue with the idea that a significant part of R&D in the country was conducted in collaboration with universities. I was surprised to learn that the opposite is true: in spite of the fact that there is a general understanding at the UCR and ITCR of the need to deepen their relationship with the productive sector, especially with regards to R&D, contract R&D is basically nonexistent. Most collaboration is at the level of what are normally called "repetitive services" which include laboratory analysis, consulting and training. When I pressed for examples of university-firm collaboration involving research, I was usually referred to cases where students carried out their dissertations project in firms' production facilities; firms that have been involved in this way are CIBERTEC, TRIMPOT, and INTEL.

Of course, both UCR and ITCR are engaged in various research projects, but almost all of these are financed through grants from foreign universities and NGOs. In recent years, the new R&D Matching Grant System (FRC, the Spanish initials for Fondo de Recursos Concursables) has become another important source of funding for research executed at universities.

Why is it that the productive sector does not contract university research centers to engage in specific R&D projects? Some of the people I interviewed placed the blame on universities, mainly because they do not have the proper incentives or the appropriate "culture" to work at the pace required by firms. But this seems incompatible with the fact that there is a significant amount of "repetitive" services sold by universities to the productive sector. It also seems inconsistent with the fact that university research centers have been very aggressive in pursuing research projects selected and financed through the FRC.

Before looking for an explanation to this phenomenon, we should first explore universities' role in conducting R&D for the productive sector in developed countries. The National Science Foundation's *Science and Engineering Indicators* for the year 2000 is very informative in this respect. As we can see in Table 22, which is reproduced from this report, the productive sector ("industry") invested $149.6 billion in R&D in 1998. Out of this total, "universities and colleges" performed only $1.9 billion. This is just above 1 percent of the total R&D investment by the productive sector!

There are fundamental reasons for university's small share of industry R&D. As we can see from the table, there is a mismatch between industry and universities: whereas industry spends only $11.3 billion in basic research out of a total of $149.6 in R&D, almost 70 percent of university-executed R&D was basic research. This reduces considerably the scope for industry-university collaboration. Furthermore, there is an additional mismatch between industry and universities in non-basic R&D: whereas most industry spending on non-basic R&D is on development ($104.7 billion out of a total of $138.3 billion), most university execution of non-basic R&D is on applied research ($6.3 billion out of a total of $8.2 billion).

It is important to emphasize this second mismatch, because it may be even more relevant for the case of developing countries. As we have argued in other chapters, most of the research conducted in the region is directed towards technology adoption. The typical case is that of a firm that wants to expand its product line, or that wants to increase its levels of quality. Such a firm will turn to specialized magazines, international trade shows and equipment providers for advice on how to upgrade its production facilities in order to meet its targets. The main challenge entails learning how to use that new equipment, find the right raw materials, organize its workers and commercialize the new products. It is difficult to see how university research can be valuable to firms engaged in this kind of process.

The puzzle that remains is why universities do not become more engaged with the more sophisticated R&D performed by the productive sector. Returning to the case of the United States, why is it that universities perform only $567 million out of the total $33.6 billion spent by industry on applied research? The puzzle arises because of the presumption that firms could save a great deal by contracting out their applied research with universities, who could focus their academic efforts, especially graduate-student dissertations, on that kind of research. Such savings would arise from economies of scale and cross-project spillovers as many different projects are performed in the same institution. So why is it that, in spite of these potential benefits, so little R&D is performed by universities on behalf of industry?

We may find an answer by going back to one of the interviews I conducted in Costa Rica with Xeltron. Up to the mid-1980s, all the technology that Xeltron had developed for coffee-bean selection was based on channels where the coffee beans moved down towards the optic mechanism that discarded the "bad" beans. Xeltron realized that this technology was not appropriate for Brazil's type of coffee and thus engaged in new R&D that eventually led to the introduction of rotating rollers. These new mechanic adaptation of Xeltron's machines proved very efficient, as it kept the beans raised and perfectly aligned as they moved down towards the optic mechanism.

I asked Arturo Agüero of Xeltron why his firm did not contract out this R&D project to a university. His response was that their knowledge of this particular technology was much superior to what could be found at Costa Rican universities. This points to a more fundamental problem, namely that firms accumulate a great deal of specific knowledge that is essential for conducting new R&D. Were they to contract out an R&D project to a university, they would first have to transfer this knowledge to the university, and this would be a costly process that could easily wipe out the potential savings discussed above.

Arturo Agüero mentioned an additional reason why Xeltron was and remains reluctant to contract out its R&D with a university: university R&D carries a high potential for knowledge leaks. This issue also arose in an interview with Intel. Thus, even if it is efficient to have universities perform a sizable share of privately-financed applied research, this would not happen because companies want to minimize leaks. This is obviously inefficient from a social point of view, and it explains why governments would want to transfer resources to universities to perform research.

To understand when these problems of specialized knowledge and knowledge leaks may be milder, it is instructive to consider a case where there is contract R&D. As mentioned in the section on Innovation in the Food Sector in Costa Rica, UCR's CITA is currently engaged in three projects to develop specific technologies for private firms. It is developing technology to improve production of concentrated banana juice for Florida Products; it is engaged in a project for a local company (Caminos del Sol) to adapt and then transfer French technology for frying with less fat absorption; and it is involved in a project with Conservas del Valle to develop a canned *palmito* (heart of palm) product for the Asian market.

What do these projects have in common that differentiates them from the case of Xeltron discussed above? It is mainly that the knowledge needed to perform the different R&D projects is not as specialized as in the case of Xeltron: in particular, this knowledge applies to a wide family of productive processes where the chemical properties of food compounds is a key issue. With many firms in Costa Rica engaged in food manufacturing, it proves very efficient to have a center such as CITA accumulate sector-specific knowledge and then engage in R&D projects with different firms in this sector.

A second reason why contract R&D is possible in the case of the food sector in Costa Rica is that for firms in this sector, their technological superiority is not a dominant factor in their competitive strategy. Their technological capability is obviously important, but their strategy relies more on branding, logistics, marketing and quality control. Thus, they are not as concerned about knowledge leaks as in other cases.

Summarizing the discussion so far, there are fundamental mismatches between the productive sector's needs and universities' interests and capabilities. These mismatches considerably reduce the scope for industry-university collaboration on R&D, as evidenced in U.S. data. The area where such collaboration is most likely to occur is applied research, but even here there are also fundamental problems, since often a firm's R&D requires very specialized knowledge that only the firm has. Contracting out this R&D would require transferring such knowledge to the university and this could prove very costly and also lead to knowledge leaks that firms want to minimize. Thus, industry-university collaboration on R&D is most likely to occur in applied research where the same principles and ideas can be applied to a wide range of productive processes, and where firms care less about knowledge leaks. Efficiency gains in these cases can be substantial.

The fact that efficiency gains can be substantial does not, of course, imply that such gains will be realized. Setting up the incentives and organizational infrastructure conducive to performing contract R&D on a regular basis for the private sector is a daunting challenge for universities. It is far more difficult than the organization required for providing repetitive services, because each project is different in terms of its duration, the required inputs and equipment, and, most importantly, in the team of people that will be involved, both from the university and from the contracting firm. Thus, it is only under very particular circumstances that a university will be able to put together an effective organization to engage in contract R&D on behalf of the productive sector.

In the case of Costa Rica, my conclusion is that CITA is the only case where these circumstances have materialized. In fact, the food sector presents very favorable conditions for the development of a knowledge cluster in the country. First, there is CITA. Second, CITA's twin institution, the Food Technology Department at the UCR, is producing the required specialized human resources to feed the growth of the sector. Third, there is a well-organized industry association (CACIA) that has the resources and capability to propose a strategy for the sector and then establish collaboration agreements with other institutions to implement such a strategy. Fourth, there is already strong competition from foreign firms as well as a several Costa Rican firms that are exporting a good share of their output. Finally, perhaps as a result of the previous points, there are several domestic firms that have chosen an innovation strategy and are growing rapidly as a result.

My main recommendation would thus be for the Government and the UCR to transfer more resources to CITA, the FTD and CACIA, to make sure that this knowledge cluster is consolidated. As to other areas where the right circumstances could materialize in the country, it seems to me that the Government is already following the right strategy through the FRC. Perhaps more could be done by promoting the diffusion of knowledge about CITA's success to other departments and universities, and also by granting special incentives to university research centers that take positive steps in the direction of collaborative R&D with the private sector.

7. The Role of Higher Education Systems in Innovation in Central America

One of the main conclusions that emerge from this study is that, given the stage of development of the countries in the region, the most important issue to focus on is the quality and quantity of specialized human resources. Accordingly, in this section I turn to a discussion about how universities and training institutes in the region contribute to innovation through their "production" of such human resources.

The information for this analysis was collected through interviews with people in universities, business associations and government organizations in each of the five Central American countries. This was complemented by Internet research and the World Bank 2001 study "La Educación Superior en Centroamérica y República Dominicana."

In the course of this study I was pleasantly surprised to learn that a great deal of attention has been paid to the problems of the region's higher education systems. The World Bank, the Inter-American Development Bank, and the United States Agency for International Development have provided grants and loans to governments as well as directly to old and new universities to improve their infrastructure, their curricula, and their teacher training, as well as other areas. The World Bank study mentioned above is another example of the high level of attention paid to universities in the region. At a more general level, there is also the realization that universities are a key element for development in poor countries: this was the conclusion reached by a special study conducted at the request of the World Bank and UNESCO to explore the future of Higher Education in the Developing World.[30]

A. Higher Education Systems in Central America: A Brief Description

There are typically one or two public universities in each country, except for Costa Rica and Nicaragua where there are four; public universities are the oldest and largest universities in each country. The interviews I conducted together with material from the Internet and the World Bank study referred to earlier suggest that the quality of these institutions has dropped in recent decades. Indeed, representatives from the private sector in Honduras, El Salvador and Guatemala mentioned that the quality of the graduates from the public universities is very low. Presumably,

[30] "Educación Superior en Países en Desarrollo, Riesgos y Promesas," 2000, The International Bank for Reconstruction and Development, World Bank ("Higher Education in Developing Countries, Peril and Promise"). The complete text of this document can be found in http://www.tfhe.net/report/report.htm

this has been the result of institutional-design failures (e.g., recruitment policies, low salaries, lack of accountability), a strategy that favored quantity rather than quality, and, in the cases of El Salvador and Nicaragua, armed conflict and natural disasters (El Salvador and Nicaragua).

Whatever the causes, the deterioration in quality of public universities, together with their inability to meet rising demand, led to the appearance of private universities. The oldest such institution is Nicaragua's Universidad Centroamericana, a Jesuit university created in the 1960s. Similar Jesuit universities exist in El Salvador (Universidad de Centroamérica, UCA) and Guatemala (Universidad Rafael Andívar). A more recent trend has been the creation of technical universities, modeled after the Massachusetts Institute of Technology in the United States and Mexico's Instituto Tecnológico de Monterrey.

Unfortunately, private universities have not been able to compensate for the weaknesses of public universities. First, they still only meet less than half of demand, except for El Salvador, where private universities account for 75 percent of enrollment. Second, like their public counterparts, private universities suffer from problems in quality, in part because of underdeveloped certification systems, other information problems and lack of competition. In some cases, the quality of private universities is still below that of public ones, as in Costa Rica and Nicaragua. Finally, only a small share of professors have full-time appointments, and they conduct very little research.

B. Universities' Contributions to Research

For both public and private universities it is hard to find examples of research that is relevant for the productive sector. Public universities in Costa Rica, especially UCR and ITCR, are the ones that have moved further in the direction of engaging in R&D collaboration with the productive sector. Still, as noted above in Section 6, the vast majority of university-firm collaboration in these universities is at the level of repetitive services. Where research is conducted, it is usually financed by foreign organizations rather than domestic firms. In short, contract R&D is basically nonexistent. This finding for Costa Rica was corroborated in the interviews I conducted in the rest of the region.

As explained in Section 6, there are fundamental reasons for this lack of contract R&D. It is only under very particular circumstances that we should expect to find significant university-industry collaboration in research. This does not imply, however, that governments should give

up efforts in this area. There are two strategies that seem useful. The first is implementing a policy such as the FRC in Costa Rica to stimulate the first steps in the development of university-industry interaction in research. The second is to be alert for cases where the right circumstances are present to provide financial support for the consolidation of a knowledge cluster knowledge cluster can consolidate around an industry association and a corresponding university research center.

The main contribution of universities to development, of course, does not arise from their research but from their production of high quality specialized human resources. It is here where most efforts in the region should be concentrated in the years ahead. Thus, the rest of this section is devoted to this dimension of universities and, in the last subsection, to training institutions (the last subsection).

C. Quality of Human Resources

Unfortunately, Say's Law does not apply to human resources: supply does not generate its own demand. We all know, for example, the stories of engineers driving taxicabs. In an interview with Jorge Arraiza of the Asociación Salvadoreña de Industriales" he mentioned that there is an excess supply of electrical, chemical and industrial engineers in El Salvador. It is clear, then, that the objective should *not* be simply to increase the supply of engineers or other professionals. Two elements are crucial to avoid the "engineers driving taxicabs" syndrome: quality and relevance. This subsection and those that follow will explore these elements.

The quality element of human resources has two dimensions: how well workers are trained to meet the needs of established firms, and how well prepared and motivated they are to become entrepreneurs and start up their own companies. Let us first consider the first dimension, which is the usual element that comes to mind when we talk about quality of human resources. As I mentioned above, industry representatives from El Salvador, Honduras and Guatemala complained about the low quality of the professionals graduating out from public universities. Jorge Arraiza mentioned that the industrial engineers coming out of El Salvador's universities are not well prepared for the *maquila* sector, because they learn nothing about human-resource management. Thus, firms have to train these engineers for one or two years before they can meet their needs. He also mentioned that large corporations prefer to hire people who have just earned their degrees, so that their more senior engineers can train them.

In the case of private universities, the problem of insufficient quality has different origins. For private universities, the problem arises because of asymmetric information, such as exists in many other markets. Below I will discuss the type of regulation that could improve the workings of the higher education market. For public universities, the problem has more to do with the incentive structure for professors and administrators, hiring practices, the university's relation to the government, and the way in which fiscal transfers are determined. These issues, however, lie beyond the scope of this project, and the interested reader is referred to the World Bank study on Higher Education in Central America mentioned above.

Turning now to the second dimension of the quality problem, the entrepreneurial drive of students is something that some universities have been addressing in the last years. This came out clearly in interviews I conducted in Nicaragua with Eduardo Bolaños, from the Ministerio de Fomento, Industria y Comercio (MIFIC), and with Dr. Ernesto Medina Sandino, the President of UNAN-León. Bolaños mentioned that in Nicaragua there is increasing support for the view that universities must modify their vision so that they can graduate entrepreneurs, "people that can go out and create jobs instead of looking for jobs." Dr. Medina mentioned several initiatives of UNAN-León to get students engaged in entrepreneurial projects while they are studying. As he argued, this has the double benefit of generating income for the universities while also getting students involved in other aspects of running a business, such as accounting, management, and finance.

Costa Rica offers additional examples of this new approach. The university that has made the most progress along these lines is the ITCR, where an entrepreneurship course is already part of the standard curriculum for its students, as well as a business incubator and a yearly entrepreneurship contest. In the UCR, the Food Technology Department and other related departments have also begun to take steps in this direction: they have established a guarantee fund and an agreement with a national bank to improve the opportunity for students to obtain financing if they want to turn their dissertation projects into commercial ventures.

This new approach presents universities with an enormous challenge: since they themselves do not have the entrepreneurial drive, it is hard to see how they are going to transmit it to students. But there are grounds for optimism in that, as the above examples make clear, some universities in the region appear to be making progress along these lines. It is also my

sense that there is a movement in LDCs towards universities that are more responsive along these lines. This topic seems an important one for future research.

D. *Relevance of Human Resources for the Productive Sector: Supply versus Demand*

It is obvious that quality of human resources is not enough: the skills transferred to students must be the ones needed by the productive sector. In other words: supply must respond to demand. The transformation of the *maquila* sector in Honduras, for example, into a textile and clothing cluster, requires people with skills in computer-aided design, marker making, cutting software, screen printing, job costing, etc. The question is: will the market provide these skills?

One could expect that, as a sector is growing, the following sequence of events should take place:

1. Demand for those specialized skills would increase, driving wages up.
2. This would lead to a higher demand for education in those skills.
3. Higher demand would drive up the tuition for that kind of education.
4. Universities or training institutions would then invest in capacity to provide that education.
5. Supply of those specialized skills would finally increase, driving down the high skill premium down.

Clearly, this does not seem to describe what goes on in the education sector. There are several reasons for this discrepancy. First, wages may not increase enough to generate a supply response; this may result from efficiency wage considerations that limit wage dispersion and from discontinuities. To understand the importance of discontinuities in this context, imagine that there is a new business opportunity that requires a certain type of skilled worker. If investment were not lumpy, then an entrepreneur could create a very small firm, be a price taker, and hire the required skilled workers at the going wage. But investments *are* lumpy (hence the discontinuities), so that an investor has to form expectations about the wages he would have to pay to obtain workers with the required skills once the investment is made. If very high wages

are expected because of a shortage of those skills, then the investment would not take place. Hence, wages would not increase and the whole process outlined above would not occur.[31]

Even if wages do increase, that information may not be available to people deciding on their educational investments. In principle, such information could become available through several channels, but all have their problems. University departments wishing to increase the number of applicants (either to have more students or to be able to select better students among a larger pool of applicants) could provide the information, but the problem is that such university departments may not exist or may not have spare capacity, as will be discussed below. Students could acquire the information by themselves, but this is obviously costly and inefficient. Such information could be sold, but there are well-known market failures for these information production and dissemination activities. Perhaps the most effective way for this information to reach decision-makers is through the news media, but this information is very noisy.

Assume that wages do increase and prospective students obtain timely and accurate information. What would happen then? Consider first public universities. There would be an increase in demand for education for the now highly paid skills, but there may not be a supply response because incentives are generally not aligned with social preferences, and because there is strong inertia in the way budgets are allocated. This is clearly what has happened in Costa Rica, where applications to certain engineering departments have increased very rapidly in recent years and supply has barely responded. The equilibrating mechanism has been an increase in the cut-off admission grade.

In the case of private universities, the problem is that demand may not materialize because of liquidity problems: people who do not have the cash to pay for private university education may not be able to get loans. But imagine that there was a system of loans to finance education expenses. A problem could still arise if there is no supply response from private universities. This could happen for a couple of reasons. First, it may be difficult for people to assess the quality of private universities, and this would create uncertainty for students contemplating such an investment. Second, good professors may want not only to teach, but also

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[31] It could be argued that firms could just import the required skills. This actually happens to a certain extent, but only in very small numbers. That is, MNCs regularly import managers, or people with very specific skills, but this does not occur when the number of workers required is larger. In this case, the firm simply sets up operations somewhere else.

to do research. If public funding is directed exclusively to public universities, then private universities may find it very difficult to attract good professors.[32]

This analysis should make it clear that the education market suffers from several failures. Without a clear higher education policy, it is doubtful that education investments will be allocated in an optimal way. The analysis suggests the areas where public intervention is most important. Perhaps most importantly, the government should establish a system to gather and provide public information about wages and job prospects in different fields to prospective students. This system should also include information about the jobs obtained by graduates of different programs and universities. This could be complemented by a system of voluntary quality certification for universities. The hope is that such an information system would lead to more effective competition and efficiency and also to a better allocation of education investments.

The second policy recommendation entails changing the current system of fiscal transfers to public universities. These transfers are currently independent of results and hence universities have no incentives to reallocate resources towards areas of growing demand. This is a difficult matter, of course, because any conditioning of fiscal support to universities could be seen as a violation of university autonomy. One should also be careful with establishing incentives when results are hard to measure, since it is well known that in such cases incentives could actually lead to worse outcomes. Imagine, for example, that wages and job opportunities were to improve significantly for electronic engineers. If public universities offered the best programs in this field, it would be socially optimal to expand the their capacity there. The government could generate incentives for public universities to do so by tying transfers to the number of electronic engineers graduated each year. But if other results are not appropriately measured, this could

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[32] Saying that markets for higher education will work imperfectly does not mean, of course, that they will not work at all. In fact, there are several examples in the region where universities have been created to supply resources needed by the productive sector. This could explain the recent appearance of several technical universities in the region, like UNITEC in Honduras, Universidad Galileo in Guatemala, Universidad Tecnológica in El Salvador, and Universidad Politécnica in Nicaragua. In Costa Rica, this need was partially met by the creation of a new public university in the 1970s: the Instituto Tecnológico de Costa Rica. Norman García, the former director of FIDE in Honduras, mentioned that there was a high excess demand for industrial engineers for the *maquila* sector, and that UNITEC was now responding to this demand through an agreement with the Tecnológico de Monterrey." Another good example is the creation of programs in tourism management in several private universities, a phenomenon that obviously responds to the growing tourism sector in all the Central American economies.

lead to an emphasis in quantity that could be detrimental to quality. The point, then, is that there is much more we must learn in this area.

A third policy recommendation is to put together a system of loans for students. This is an area where market failures are evident, and public intervention is clearly justified. There are many positive experiences in the world from which the Central American countries could extract valuable lessons. In the region, the most developed system is Costa Rica's CONAPE, which has been able to maintain high coverage and repayment ratios.

The fourth and final recommendation is to have public support for research based on professors and research topics, rather than tied to public universities. This would allow private universities to improve the quality of professors they can attract, thereby allowing them to compete on an equal footing with public universities and, more importantly, to better respond to changing demand for skills in the productive sector.

E. What about Technical Training and Education?

All the discussion so far has focused on universities and professional education. And yet, it is likely that given the development stage of the Central American countries, technical training and education is just as important. Consistent with this view, Oscar Villagrán, the director of Guatemala's National Industry Chamber, mentioned that there was a lack of high-quality human resources at the technical level. He said that this was the major weakness in the area of human resources in Guatemala.

All the countries in the region have the same basic system for training, where a tax on wages (usually at a rate of 2 percent) is used to finance a national training institution (NTI).[33] There are well-known market failures that can be used to justify government intervention in the training market, although it is not clear why the government itself has to provide the training. The problems with this type of national training institutions have been well documented. Here I am particularly interested in the often-heard complaint from the private sector that the programs offered by these institutions do not correspond to the needs of the productive sector; in short, that supply does not meet demand. As in the case of public universities, NTIs have weak incentives to allocate their resources towards areas of growing demand. Part of the problem is that they

[33] INTECAP in Guatemala, INFOP in Honduras, INSAFORP in El Salvador, INATEC in Nicaragua and INA in Costa Rica.

suffer from hiring rigidities that lead them to offer programs for a period much longer than required by society. If private firms often suffer from a lack of focus on the needs of their clients, it is not surprising that public institutions, hampered by weak incentives and strong rigidities, fail to respond to demand.

The general advice given today by institutions such as the World Bank and the Inter-American Development Bank is to follow the Chilean model, where firms have to spend a certain amount on training, which they can contract with a number of certified institutions. The benefit is that there would be competition and diversity, which is essential in this field. Presumably, this system would make supply more responsive to demand from the productive sector.

I agree with this recommendation, but it is nevertheless interesting to discuss simpler approaches that are being followed in the region to establish stronger linkages between NTIs and the productive sector. Gilda Gutiérrez, from Nicaragua's Corporación de Zona Franca, mentioned that Nicaragua's NTI (INATEC) signed an agreement with CZF to develop a program directed towards the apparel and textile sector, with support from the Republic of China (Taiwan). In Honduras, Vilma Sierra (FIDE) mentioned that the association of maquiladoras has established an agreement with INFOP (Honduras' NTI) for the same purpose, although she claimed that the agreement had not been very effective. In El Salvador, Jorge Arraiza mentioned that there are discussions underway to have INSAFORP establish a mechanical school in order to deal with the current lack of technicians for equipment maintenance in apparel and textile firms.

Costa Rica has followed a more systematic approach in this area, whereby the NTI (INA) promised to set aside a budget ($1.2 million in 2001) to invest in specialized training programs agreed with industry associations and groups of SMEs. The Ministry of Economics serves as a promoter and intermediary of this approach, which has led to several collaborative programs between industry groups and INA.

So far the discussion has focused on training systems. I now turn to a brief discussion of technical education. I have not conducted any systematic research on the importance of technical education in the different Central American countries, but it follows from the interviews that this type of education is much more important in Costa Rica than in the rest of the region. Indeed, interviews with innovating firms in Costa Rica, such as Xeltron and Trimpot, suggest that

graduates from technical schools are a source of skills in Costa Rican firms. In no other country did I get a sense that technical schools had any aggregate relevance.

One issue that arises with technical or vocational schools is the tension between general and technical education. The common view is that this type of school teaches particular skills for current technologies rather than general problem-solving skills. Thus, graduates from technical schools will be at a disadvantage in dealing with technological change.

I think that this view is mistaken. Imagine that there are firms that require specific technical skills. There are three ways to fill this need. One is to have students go to a technical school that teaches these skills. Another is to have students finish general high school and then go through a training program. Finally, the student could finish general high school, and then get hired by the firm, which would conduct the training. Clearly, if skills are firm specific, the third approach is much more efficient. But consider the case where skills are not firm specific. It is probably more efficient to have students learn these skills in technical schools or training institutions than in firms. So the choice is between technical schools and general schools plus training programs. Clearly, students that opt for the second alternative end up with a better education. But the question is: at what cost? It seems to me that much of what students learn in the final years of high school is general education that is useful only if they go to university. If this were the case, it would seem more efficient to have students that will end up as technicians to finish high school in technical schools. The German system follows this basic idea, with one additional element that appears vital, namely a strong degree of collaboration between technical schools and the productive sector.

There are at least two additional points to consider in thinking about the benefits of technical schools. One is the usual problem that technical schools often end up teaching skills that are no longer needed in the marketplace. If this is inevitable, it may be better to avoid technical schools altogether. But there are ways around this problem. In Costa Rica, for example, the government has implemented a program sponsored by Taiwan to link up technical schools with the ITCR, so that teachers and equipment are kept up to date, teaching relevant skills for today's needs. This could be an interesting model for the rest of the region.

The second point is that students often get discouraged with general education because they do not see the benefits in terms of skills, job opportunities and wages. Technical schools could help in this regard.

8. Conclusion

In spite of major market-oriented reforms implemented in the last 15 years, the Central American countries have not yet been able to embark on a process of sustained and rapid growth. Recent research suggests that this lack of growth is due to low TFP growth; with the exception of Costa Rica, all the Central American countries experienced TFP growth rates below those achieved in the OECD (around one percent per year).

The main hope in the region now rests on the possibility of signing an FTA with the United States. But this agreement must be accompanied by other measures if the region wants to derive the highest benefits from it and increase TFP growth rates. This conclusion emerges clearly in the context of Mexico in a recent report Lederman, Maloney and Servén (2003). Among the different measures that the Central American region must undertake, perhaps one of the least studied is the role of technology. What is the role that technology can play in increasing TFP growth in these countries? How can the region increase the pace of technology diffusion and adoption? Can the region achieve some technology innovation in some sectors? Which policies would have to be followed to improve the rate of technology innovation and adoption in these countries? How can the governments of the Central American countries prepare themselves to implement these policies successfully?

Before discussing the conclusions that emerge from this study in regards to these difficult questions, I would like to make a general point. When we hear of innovation, we tend to think of formal R&D departments in established corporations, patents, IPR systems and fiscal incentives to increase R&D. I think this comes from reading about innovation issues in developed countries. When I first started working on this project, I also thought about innovation in these terms. But I quickly realized what may be perhaps obvious to many readers, namely that this are *not* the key issues associated with technological progress in LDCs. In fact, most research is not formal R&D and is not directed towards obtaining patents. Moreover, most technological progress is associated with technology adoption rather than innovation. This poses two significant challenges: first, technological progress is harder to measure; and second, there is no simple way of understanding technological progress; it is a broad phenomenon with many differences across firms, sectors and countries. To tackle these challenges, this study has chosen an eclectic approach, which entails using a mix of methodologies (aggregate data analysis, interviews, qualitative research) to look at different issues: aggregate data, innovative firms, innovative

sectors, universities, research centers, public technology programs, etc. This implies that the study is richer in data and insights, but it comes at the cost of making it harder to extract a coherent message. This said, the rest of this section attempts to draw the main conclusions from the study and presents the main policy recommendations.

The first conclusion that emerges is that both innovation and technology adoption are low in the Central American countries. Innovation indicators such as patents obtained in the United States, published research papers, R&D investment rates, number of scientists and engineers devoted to research, and perception of firms about research all point to very low innovation levels in the region. Costa Rica emerges here as an outlier, with innovation levels above those in Mexico and close to those in Chile. The same pattern is observed in regards to technology adoption, where we use TFP relative to the U. S. level as the main indicator: all the Central American countries except Costa Rica have experienced a deterioration in their relative TFP level, indicating very low and even declining investments in technology adoption. This first conclusion is consistent with the conclusion in De Ferranti et al. (2002) for the whole Latin American and Caribbean region.

Why are innovation and technology adoption so low in the region? In all economies there are going to be extraordinary individuals who will innovate, regardless of local circumstances. It is more crucial, however, for the economic system to lead more *ordinary* individuals to innovate and adopt. An economy with many distortions, high corruption and instability (political or macroeconomic) will lead entrepreneurs to allocate their time to rent-seeking and protecting their investment. This would naturally lead to low innovation and technology adoption. In fact, the low levels of technological investment in the region could just be part of a more general problem of low investment in *all assets*, including physical and human capital, caused by such bad overall economic and political conditions. The implicit assumption under which this study has been conducted is that this is *not* the case, that is, that there is something that constrains investment in technology to a larger extent than investment in physical and human capital. Such an assumption is consistent with the finding that the Central American countries are carrying out less R&D than would be expected given their education levels. It is also consistent with the message of Lederman and Maloney (2003) and Klenow and Rodríguez-Clare (2004).

Given the above considerations, the next question is why technological investments are lower than investments in physical and human capital. What constrains innovation and

technological adoption in the Central American region? Unfortunately, there is no clear and generally accepted theory that we can use to answer this question. At best, what we have is a collection of hypotheses that have received some theoretical and empirical attention: a weak National Innovation System (NIS), a weak IPR regime, low competition, lack of finance for innovation ventures, and low levels of education. These hypotheses are discussed one by one in the following paragraphs.

Theoretically, a weak NIS can be interpreted as low productivity in research activities. This amounts to a lack of effectiveness in converting resources into ideas. In the model of technology adoption presented in Howitt (2000), this leads to both a negative *direct* effect, as it implies a lower relative TFP level given some R&D investment rate, and a negative *indirect* effect, as it leads to a lower R&D investment rate. The question, of course, is what a weak NIS implies in practice. Does it imply low quality human resources? Is it related to weak universities that do not contribute to private sector research? Is it related to lack of support from public institutions? Or is it associated with a weak IPR regime? These questions reveal that the hypothesis that low innovation is driven by a weak NIS is not very useful in terms of deriving concrete policy implications for the region.

An alternative hypothesis is that low innovation is caused by a weak IPR regime. In spite of some supporting empirical work in the literature, the analysis conducted in Section 2 leads to the conclusion that for the small and poor countries of Central America, it is hard to make the case that strengthening IPR regimes will do much to spur domestic innovation. Moreover, the reforms that have been undertaken in this area in recent years have *not* been part of a strategy to promote local innovation. In fact, the goal of these reforms has been to comply with the TRIPS Agreement of the Uruguay Round, which was motivated by the desire of corporations in the developed countries to protect their innovations from piracy in LDCs. Thus, it is doubtful that these reforms will have a positive effect in boosting local innovation.

Another popular explanation for low innovation in LDCs is lack of competition. The problem with this explanation is that innovation has barely increased in the region in spite of a dramatic increase in competition in the last 15 years resulting from trade liberalization and deregulation of some domestic markets. Moreover, the intuitive idea that more competition leads to more innovation is not always supported by the theoretical literature. Rodrik (1992), for instance, shows that by reducing market share of domestic firms, import liberalization may lead

to lower innovation efforts. Boone (2000) shows that the effect of competition on innovation depends on the situation of firms: if domestic firms are significantly below the productivity level of foreign firms, then import liberalization may lead to less domestic innovation.

In addition, interviews with innovative firms in the region did not reveal any special role of local rivalry in inducing innovation. The situation is less clear with trade liberalization: at least for the case of the food sector in Costa Rica, it seems that an increase in imports was partially responsible for inducing firms to engage in more innovation to confront increased competition or to compensate for lost domestic sales by expanding exports.

The two remaining explanations of the low innovation efforts in the region are lack of finance and low education levels. In contrast to the previous hypotheses, both of these explanations are very relevant. Problems with financing innovation have long been recognized as a fundamental problem even in developed countries (Hall, 2002). In LDCs with underdeveloped financial systems this problem is even more important. Lack of finance did not come up as an important constraint in the interviews with innovative firms in the region, but this probably is caused by a sample-selection problem: the firms here were selected for having been successful in innovative activities, and so it is natural that they do not complain about lack of finance. The case study of the software sector in Costa Rica sheds more light on this issue: the conclusion to that section noted that the software boom had been possible precisely because of the low financing needs of new start-ups in this sector. In other sectors, such as the food sector, the problem of lack of finance comes out more clearly, although here again we run into the same sample-selection problem as above. In the survey undertaken by CAATEC, which is designed to avoid this problem, around half of the firms mentioned lack of finance as an important constraint for innovation.

Finally, we come to the claim that low education imposes an important constraint to technological efforts in the region. This is the main message in De Ferranti et al. (2002) for the Latin American and Caribbean region as a whole, and it is consistent with the conclusions that emerge from this study for the CA region. In Section 2 we saw how the average years of education of the working age population correlate closely with R&D investment efforts across countries. The problem is that it is not clear what is the channel through which low education constrains innovation and technology adoption. Presumably, it comes from a mixture of two channels. First, a lack of specialized professionals (i.e., scientists and engineers) limits

companies' R&D efforts (a supply explanation). Second, low education levels lead the economy to specialize in sectors that are not intensive in R&D efforts (a demand explanation). Given the high social rates of return to R&D in LDCs (Lederman and Maloney, 2003), then any of these channels implies the need to undertake policies to increase education levels in the region in a way that translates into more innovation and technology adoption. In Section 3 we saw how even the highly innovative firms in the region complain about lack of specialized skills for conducting research and innovation. In contrast, the case study of the software sector in Costa Rica revealed how adequate human resources, *together with the right conditions* (in this case high local demand and low financing needs), can lead to innovation and growth in a technologically demanding sector. The case study of the food sector also showed, although less dramatically, the importance of the Food Technology Department of the University of Costa Rica in generating the specialized human resources that now are employed in most research efforts in the private sector. Moreover, in CAATEC's survey of firms in the food sector, an appropriate supply of specialized workers was the element considered most important element for conducting innovative activities.

Having summarized and discussed the main explanations for the low levels of innovation and technology adoption in Central America, I finish this last section with a discussion of policy recommendations. The main policy recommendation that emerges from this study is the need to develop an appropriate higher education system. Without strong universities graduating high-quality professionals that respond to the needs of the private sector, it is doubtful that any innovation policy can be effective. As we discussed in Section 7, the education sector is plagued by market imperfections, so the role of the government here is crucial. To summarize the conclusions of that section:

1. The government should establish a system to improve information flows and decision-making in regard to education choices. This system should provide information about wages and job prospects in different fields to prospective students, and it should provide information about the jobs obtained by graduates of different careers and universities. This should be complemented by a system of voluntary quality certification for universities.

2. The government should make sure that fiscal transfers to public universities provide appropriate incentives to reallocate resources towards areas of growing demand. As discussed in Section 7, this is not easy and requires further study.
3. The government should put together a system of loans for students. There are many positive experiences in the world from which the Central American countries can extract valuable lessons, including the case of CONAPE in Costa Rica.
4. The government should establish a system of public support for research based on the quality and relevance of proposals, rather than tied to public universities. This would allow private universities to improve the quality of professors they can attract, thereby allowing them to compete on an equal footing with public universities and, more importantly, to better respond to changing demand for skills in the productive sector.

The previous recommendations are all intended to improve the performance of the market for higher education in the region. But it is also important to advance on the institutional front by promoting a close collaboration between universities and private sector associations at the sector-specific level: in contrast to the usual recommendation, however, here we are referring not only to research, but also rather to collaboration to improve the correspondence between university curricula and the needs of the private sector. An interesting model here is the one that has emerged in Costa Rica in the food sector, where the Food Research Department of the UCR and its sister research institution, CITA, have developed strong links with CACIA, the food sector association in the private sector. In contrast to the reforms outlined above, measures to promote this type of institutional collaboration could be carried out without the need for legislative changes. Moreover, governments have already been devoting some efforts to support private sector organizations based on clusters that could perform this role. But the way these cluster organizations interact with universities, and the way in which the government provides public funds for joint projects with universities, deserve much more thinking and experimentation.

Such close institutional collaboration is also needed between the private sector organizations and the national training institutions in the region, so that the training is up to date

and relevant for private sector needs. Interesting developments are already taking place in the region in this regard, as we discussed in Section 7. Over time, an increasing amount of the resources earmarked for training purposes are allocated according to some type of collaborative public/private mechanism such as those that have been emerging in the region.

An additional issue in regards to education policy has to do with technical education. In De Ferranti et al. (2002), the recommendation is to promote academic education rather than technical education. The view is that technical education teaches particular skills for current technologies rather than general problem-solving skills. Thus, graduates from technical schools will be at a disadvantage in dealing with technological change. I think this view is mistaken, but—at the very least—this is a topic that deserves much more research.

Finally, there are two issues that deserve attention: improving financing flows to innovative projects and strengthening the petty patent system. In regards to financing flows, much of the current discussion relates to venture capital. But, as rightly pointed out in De Ferranti et al. (2002), this would have a limited impact and would be very hard to get going, except in special cases like the software sector in Costa Rica. Thus, countries should focus on improving banking regulation and developing special financial programs to promote credit flows on more flexible and appropriate conditions for innovation projects. This is an area that deserves more research. As to the petty patent system, this is something that could be relatively easy to do, and the payoff could be large, as discussed in Section 2.

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Tables and Figures

Table 1. Per Capita US Patents
(Patents granted, per 100,000 people, classified according to year of application)

Average	1970-1972	1973-1977	1978-1982	1983-1987	1988-1992	1993-1997
Costa Rica	0.04	0.10	0.09	0.04	0.03	0.09
Nicaragua	0.06	0.01	0.00	0.00	0.01	0.00
Honduras	0.05	0.01	0.00	0.00	0.01	0.03
El Salvador	0.01	0.04	0.00	0.01	0.00	0.01
Guatemala	0.07	0.02	0.01	0.01	0.01	0.01
Central America	0.05	0.03	0.01	0.01	0.01	0.02
Mexico	0.00	0.00	0.00	0.00	0.03	0.05
US	21.53	19.40	16.79	15.85	20.87	25.57
Brazil	0.00	0.00	0.00	0.00	0.02	0.04
Chile	0.00	0.00	0.00	0.00	0.03	0.06
Singapore	0.21	0.11	0.16	0.31	0.83	2.99
South Korea	0.02	0.02	0.05	0.18	0.95	4.75
Taiwan	0.01	0.19	0.49	1.44	3.40	10.84

Source: U.S. Patent Statistics, National Bureau of Economic Research.

Table 2. Domestic Patents Granted to Nationals and Foreigners, Annual Average

	Nationals	Foreigners	Total	Percentage to nationals
Honduras (99-01)**	9.3	100.7	110.0	8.5
El Salvador (99-01)**	6.7	30.7	37.3	17.9
Guatemala (90-95)*	2.0	50.2	52.2	3.8
Nicaragua (95-02)**	1.1	56.7	57.9	2.0
Costa Rica (90-98)*	7.2	6.9	14.1	51.2
Mexico (90-00)*	174.1	3,461.7	3,635.8	4.8
Chile (90-99)*	55.6	258.7	314.3	17.7
Canada (90-98)*	942.2	10,986.8	11,929.0	7.9

Source: ** National Patent Offices of respective countries, from Salazar (2002).
* RYCYT.

Table 3. Publications in Academic Journals by Country

(Publications by country, 5 year averages)

	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua
1981-1985	112	7.4	58.2	11.2	2.4
1986-1990	139.4	4.2	46.6	10.6	8.2
1991-1995	164.8	5.2	65.6	14.8	14.2
1996-2000	231.4	9.4	61	23.4	23.8

Table 4. World Competitiveness Report 2001-2002, Opinion about Level of R&D Spending for Different Countries

	Companies' R&D spending in your country*
Chile	3.7
Costa Rica	3.8
El Salvador	2.8
Guatemala	3.0
Honduras	2.5
Mexico	3.2
Nicaragua	2.7
Panama	3.5
United States	6.0

* 1=is non-existent, 7=is heavy relative to international peers

Table 5. Actual and Predicted R&D Spending Based on Countries' Income Levels*

	R&D/GDP	Predicted
Chile, 1998	0.54	0.86
Costa Rica, 1998	0.27	0.44
El Salvador, 1998	0.92	0.34
Guatemala, 1988	0.16	0.40
Honduras, 1965	0.74	0.59
Mexico, 1998	0.38	0.68
Nicaragua, 1997	0.13	0.09
United States, 1998	2.62	2.97

* The R&D data come from Lederman and Sáenz (2003). With these data and GDP data from Heston, Summers and Bettina (2002), I ran a regression of R&D/GDP on GDP per capita, with year dummies. The result is reported in the text.

Table 6. Relative TFP Levels (percentages)

	2000 Rel. Y/L	Rel. TFP	Rel. A	Equivalent in years	1990 Rel. Y/L	Rel. TFP	TFP Growth 1990-2000
Chile	38.9	68.9	57.3	25	31.2	62.1	1.9
Costa Rica	23.0	53.4	39.2	42	26.3	57.5	0.1
Guatemala	20.6	67.0	55.0	27	23.3	71.8	0.1
Honduras	9.9	31.0	17.4	79	13.4	43.2	-2.5
Mexico	38.1	66.4	54.3	28	39.7	68.5	0.5
Panama	24.6	44.2	29.6	55	25.6	49.3	-0.3
El Salvador	21.0	62.8	49.9	31	21.0	62.4	0.9

Source: Klenow and Rodríguez-Clare (2003) and author's calculations.

Table 7. Relative TFP Decomposition

	Rel. Y/L	(Rel. K/L) ^alpha	(Rel. H/L) ^(1-alpha)
Chile	0.39	0.68	0.83
Costa Rica	0.23	0.55	0.79
Guatemala	0.21	0.43	0.71
Honduras	0.10	0.43	0.75
Mexico	0.38	0.70	0.82
Panama	0.25	0.64	0.87
El Salvador	0.21	0.44	0.76

Source: Klenow and Rodríguez-Clare (2003) and author's calculations.

Table 8. Relative Income and TFP Levels According to PWT and WDI (adjusted)

	PWT		WDI (adjusted)	
	Rel. Y/L	Rel. TFP	Rel. Y/L	Rel. TFP
Chile	0.39	0.69	0.35	0.64
Costa Rica	0.23	0.53	0.32	0.67
Guatemala	0.21	0.67	0.19	0.64
Honduras	0.10	0.31	0.11	0.34
Mexico	0.38	0.66	0.38	0.66
Panama	0.25	0.44	0.23	0.43
El Salvador	0.21	0.63	0.20	0.61

Source: Klenow and Rodríguez-Clare (2003), World Bank *World Development Indicators* (WDI), and author's calculations.

Table 9. Growth Decomposition, 1991-2000, from Loayza, Fajnzylber and Calderón (2002)

	Y/L	Human K	Physical K	TFP
Chile	5.7	0.42	2.89	2.4
Costa Rica	3.5	0.61	1.48	1.4
El Salvador	2.9	0.63	2.03	0.3
Guatemala	2.0	0.53	1.32	0.1
Honduras	0.9	0.59	1.83	-1.5
Mexico	2.0	0.35	1.57	0.1
Nicaragua	1.0	0.96	0.69	-0.6

Table 10. Annual TFP Growth Rates, from Robles and Rodríguez-Clare (2004)

	1990-95	1995-2001	1990-2001
Costa Rica	2.7	1.6	2.1
El Salvador	2.1	0.2	1.1
Guatemala	0.5	0.2	0.3
Honduras	0.1	-0.7	-0.3
Nicaragua	-0.5	1.9	0.8

Table 11. PCs for Every 1,000 People, Year 2000

Chile	82.3
Costa Rica	149.1
El Salvador	19.1
Guatemala	11.4
Honduras	10.8
Mexico	50.6
Nicaragua	8.9
Panama	37.0
High income	392.7
Latin America & Caribbean	43.6
Low & middle income	20.1
Low income	5.1
Lower middle income	21.1
Middle income	33.1
Upper middle income	69.9
World	78.3

Source: WDI.

Table 12. Educational Attainment of the Total Population Aged 25 and Over, Year 2000

Country	Population over age 25 (1000s)	No Schooling	First level Total	First level Complete	Second Level Total	Second Level Complete	Post-Secondary Total	Post-Secondary Complete	Average Years of School
		(Percentage of the population aged 25 and over)							
Chile	8443	5.3	42.9	9.6	36.0	15.1	15.8	10.7	7.89
Costa Rica	1834	9.4	60.7	13.6	11.3	4.7	18.6	12.7	6.01
El Salvador	2547	35.0	45.6	10.1	8.8	3.7	10.6	7.2	4.50
Guatemala	4495	47.1	37.6	8.3	9.5	2.8	5.8	4.0	3.12
Honduras	2444	25.9	57.0	12.4	10.6	6.0	6.5	4.4	4.08
Mexico	47996	12.4	47.3	19.4	29.0	13.3	11.3	6.6	6.73
Nicaragua	1824	31.7	43.0	9.5	16.5	4.8	8.9	6.0	4.42
Panama	1436	11.4	40.4	21.0	28.5	16.1	19.8	13.5	7.90
U. S.	178443	1.0	9.3	4.5	39.6	21.6	50.1	30.3	12.25

Source: Barro and Lee (2000).

Table 13. Labor Force Decomposition by Education
(complete and incomplete levels, in percentages)

Country	Year	Primary	Secondary	Tertiary
Chile	1998	18.5	58.8	22.6
Costa Rica	2000	52.2	31.0	16.8
Guatemala	1998	76.6	18.5	4.9
Honduras	1999	74.0	20.5	5.5
Mexico*	2001	28.5	47.7	23.8
Nicaragua	2001	61.8	30.7	7.5
Panama	2000	32.1	43.8	24.1
El Salvador	1999	53.8	33.8	12.3

* Urban population only.
Source: Household surveys, IDB.
Note: workers are classified according to whether they achieve some amount of a particular education level. Thus, for example, people with incomplete secondary education are classified as having secondary education in this table.

Table 14. Tertiary Enrollment Rates and Proportion of Students in Science and Engineering Areas

	Tertiary enrollment (% gross)		S&E rate**
	1991	1997	1995*
Chile	21.28	31.48	37.96
Costa Rica	27.58	31.27	20.19
El Salvador	16.78	17.75	55.06
Guatemala	8.27	8.38	
Honduras	8.89	11.70	24.03
Mexico	14.07	16.76	34.17
Nicaragua	8.13	11.85	32.86
Panama	23.39	33.04	28.76
United States	79.98	79.97	18.63

* For Nicaragua the year is 1996, for the United States the year is 1991.
** Science and engineering students out of total tertiary students.
Source: WDI

Table 15. Regression Results of R&D Share on Education Variables for Pooled Country and Year Data from Lederman and Sáenz (2003)

Source	SS	df	MS		
Model	.009758136	10	.000975814	Number of obs =	268
Residual	.011608246	257	.000045168	F(10, 257) =	21.60
Total	.021366382	267	.000080024	Prob > F =	0.0000
				R-squared =	0.4567
				Adj R-squared =	0.4356
				Root MSE =	.00672

rdgdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Post sec sh.	-.0000619	.0001601	-0.39	0.699	-.0003771	.0002533
M.Y.S. sq.	.0001783	.00002	8.93	0.000	.000139	.0002176
_Iyear_1965	.0030915	.0049634	0.62	0.534	-.0066826	.0128656
_Iyear_1970	.0024434	.0049374	0.49	0.621	-.0072795	.0121662
_Iyear_1975	.0031426	.0049512	0.63	0.526	-.0066074	.0128926
_Iyear_1980	.0022041	.0049377	0.45	0.656	-.0075195	.0119276
_Iyear_1985	.0034494	.0049033	0.70	0.482	-.0062063	.013105
_Iyear_1990	.002611	.0049275	0.53	0.597	-.0070925	.0123144
_Iyear_1995	.0003335	.0049003	0.07	0.946	-.0093164	.0099833
_Iyear_2000	.0029355	.0050089	0.59	0.558	-.0069283	.0127993
_cons	-.0000663	.0047575	-0.01	0.989	-.0094349	.0093023

Table 16. Returns to Education and Skill Premium

	Mincer coeff.	Skill premium*
Canada	0.042	1.18
Chile	0.121	1.62
Costa Rica	0.105	1.52
El Salvador	0.096	1.47
Guatemala	0.142	1.76
Honduras	0.172	1.99
Mexico	0.141	1.76
Nicaragua	0.096	1.47

Source: Bils and Klenow (2000).
* Letting *z* be the Mincer coefficient, the skill premium is exp[4*z*]. This would be the wage of someone with a college degree (16 years of schooling) relative to someone with only completed secondary (12 years of schooling).

Table 17. World Competitiveness Report 2001-2002,Opinion about Quantity of Scientists and Engineers for Different Countries

	Scientists and engineers in your country are*
Chile	5.5
Costa Rica	5.1
El Salvador	3.5
Guatemala	3.4
Honduras	3.5
Mexico	4.3
Nicaragua	3.6
Panama	4.3
United States	6.2

* 1=non-existent or rare, 7=widely available

Table 18. Actual versus Predicted R&D Shares (percentage)

	Year	R&D Share	Predicted*
Chile	2000	0.54	1.28
Costa Rica	1990	0.16	0.76
El Salvador	1995	0.33	0.51
Guatemala	1970	0.16	0.28
Honduras	1965	0.74	0.29
Mexico	1995	0.31	0.92

* According to y = 0.00239 + 0.0001676*MYS squared

Table 19. Share and Growth of Manufacturing Sub-Sectors in Costa Rica (in percent)

	Relative*	Growth 1991-2000
Food (including tobacco products)	41.9	4.6
Textiles, apparel, leather products	8.1	-1.9
Forestry, wood products	2.0	3
Paper, paper products, printing	8.4	3.8
Chemicals, oil products, plastics	20.5	3.7
Products made out of non-metal minerals	4.9	6
Basic metal industries	1.2	0.6
Metal products, machinery and equipment	12.0	4.7
Other	1.0	2.5

* This is the relative contribution of the two-digit SIC sector to total manufacturing value added excluding EPZ and other special regimes, for the average of the period 1998-2000.

Table 20. Importance of the Food Sector in Costa Rican Exports
(figures other than percentages in millions of dollars)

	1994	1995	1996	1997	1998	1999	2000	2001	2002*
Food sector exports	199	272	316	312	378	387.2	390	381.3	419
Total exports without Intel	2,869	3,453	3,730	4,277	4,541	4,018	4,174	4,110	4,033
Total exports	2,869	3,453	3,730	4,277	5,528	6,577	5,850	5,040	4,901
Growth rate of food exports		36.6%	16.2%	-1.5%	21.4%	2.4%	0.7%	-2.2%	9.8%
Share of food exports in total exports w/o Intel	6.9%	7.9%	8.5%	7.3%	8.3%	9.6%	9.3%	9.3%	10.4%
Share of food exports in total exports	6.9%	7.9%	8.5%	7.3%	6.8%	5.9%	6.7%	7.6%	8.5%

* January - November data

Table 21. CAATEC Survey: Importance of Different Institutions for Firms' Innovative Activities

Institution	Number of Firms	Percentage
Suppliers	19	57.6
INA	12	36.4
Industry chambers	9	27.3
Related enterprises	8	24.2
Public universities	6	18.2
Private universities	5	15.2
PROCOMER	5	15.2
CITA	5	15.2

Table 22. U.S. R&D Expenditures, by Performing Sector, Source of Funds, and Type of Work 1998 (Millions of U.S. Dollars)

Type of work/ sources of funds	Performer: Federal Government	Industry[a]	Universities and colleges	U&C associated FFRDCs[b]	Other nonprofit institutions[a]	Total	Percent distribution by sources
TOTAL R&D							
Federal Government	17,189	24,589	15,558	5,517	4,077	66,930	29.5
Industry	..	146,706	1,896	..	1,051	149,653	65.9
Universities and colleges	..	..	7,049	..	..	7,049	3.1
Other nonprofit institutions	..	..	1,840	..	1,702	3,541	1.6
Total	17,189	171,295	26,343	5,517	6,830	227,173	100.0
Percent distribution, performers	7.6	75.4	11.6	2.4	3.0	100.0	
BASIC RESEARCH							
Federal Government	2,920	1,816	11,248	2,721	1,531	20,235	53.4
Industry	..	9,625	1,205	..	483	11,313	29.9
Universities and colleges	..	..	4,479	..	..	4,479	11.8
Other nonprofit institutions	..	..	1,169	..	681	1,850	4.9
Total	2,920	11,441	18,100	2,721	2,695	37,877	100.0
Percent distribution, performers	7.7	30.2	47.8	7.2	7.1	100.0	
APPLIED RESEARCH							
Federal Government	5,421	3,087	3,130	1,545	1,144	14,326	28.0
Industry	..	32,701	567	..	357	33,625	65.6
Universities and colleges	..	..	2,107	..	..	2,107	4.1
Other nonprofit institutions	..	..	550	..	613	1,163	2.3
Total	5,421	35,788	6,354	1,545	2,114	51,221	100.0
Percent distribution, performers	10.6	69.9	12.4	3.0	4.1	100.0	
DEVELOPMENT							
Federal Government	8,848	19,686	1,181	1,251	1,403	32,369	23.4
Industry	..	104,380	121	..	210	104,715	75.8
Universities and colleges	..	..	463	..	..	463	0.3
Other nonprofit institutions	..	..	121	..	408	529	0.4
Total	8,848	124,066	1,888	1,251	2,021	138,075	100.0
Percent distribution, performers	6.4	89.9	1.4	0.9	1.5	100.0	

Notes:

FFRDC = Federally Funded Research and Development Center

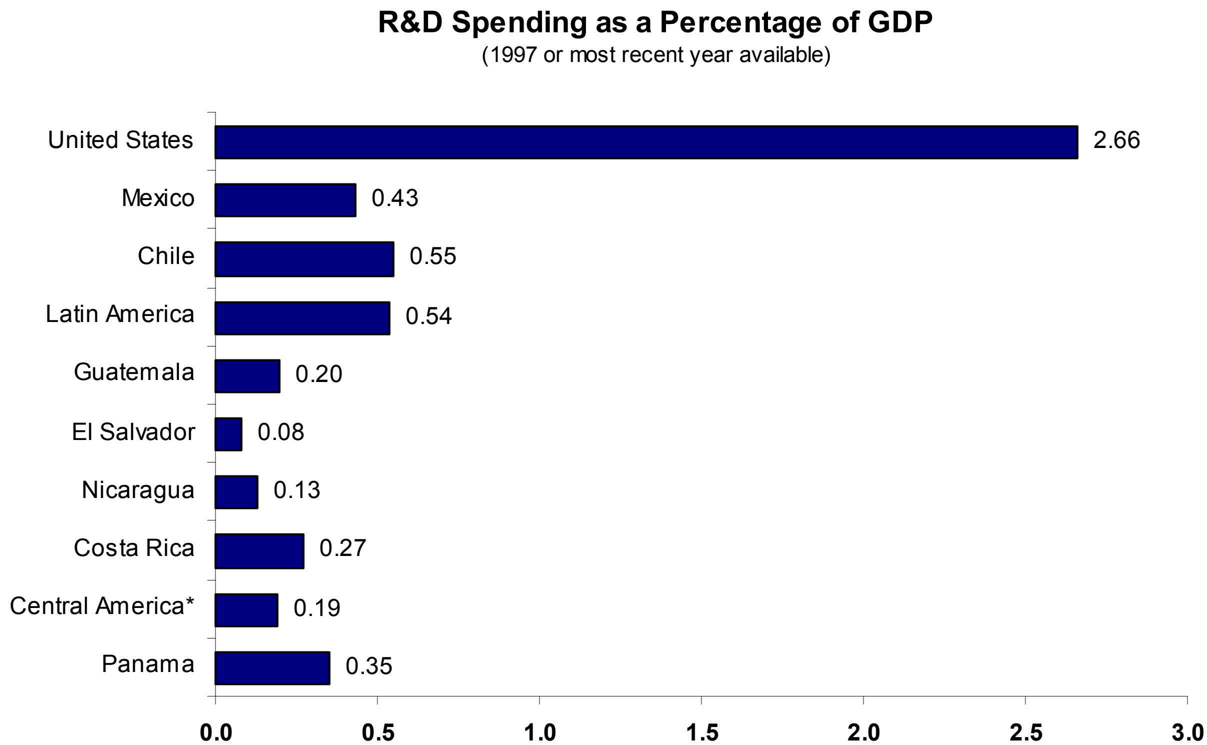
State and local government funds are included in industry funds reported to industry performers, and in university and college funds reported to university and college performers. Details may not add to totals because of rounding.

[a]Expenditures for FFRDCs administered by both industry and nonprofit institutions are included in the totals of their respective sectors. They are estimated to account for less than 2 percent and 12 percent, respectively, of the industry and nonprofit institutions performance totals. FFRDCs are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes.

[b]FFRDCs administered by individual universities and colleges and by university consortia.

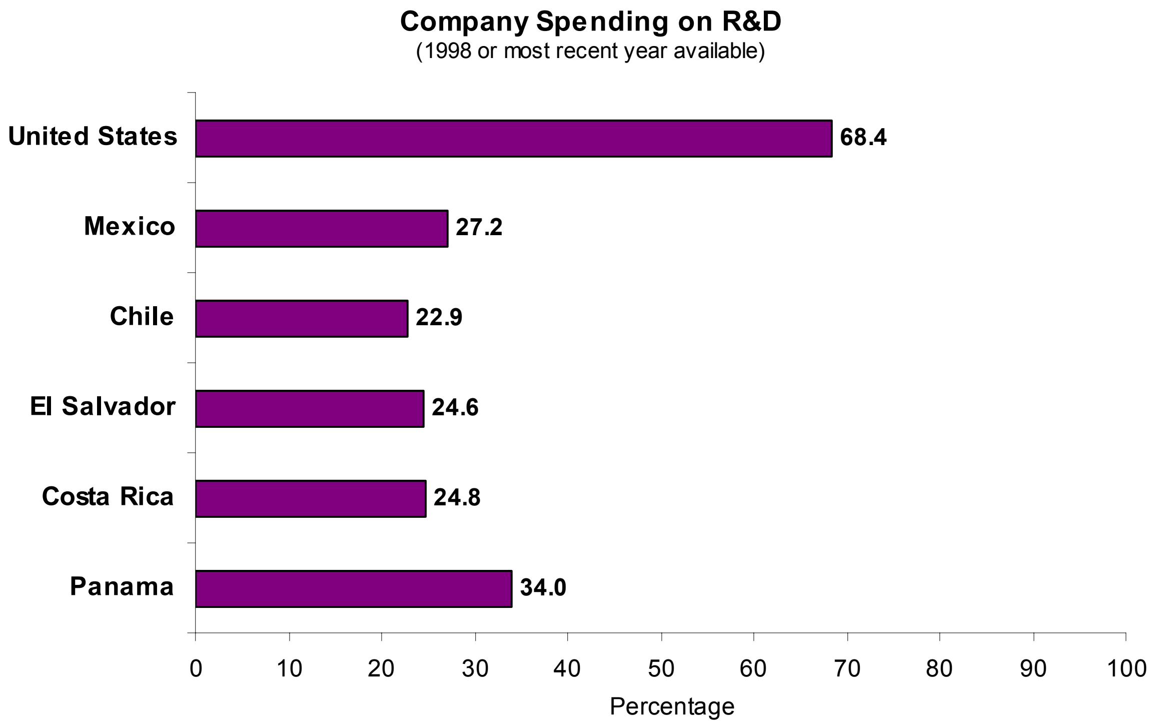
See Appendix Tables 2-3, 2-7, 2-11, and 2-15 of the U.S. National Science Foundation's *Science & Engineering Indicators 2000.*

Figure 1.



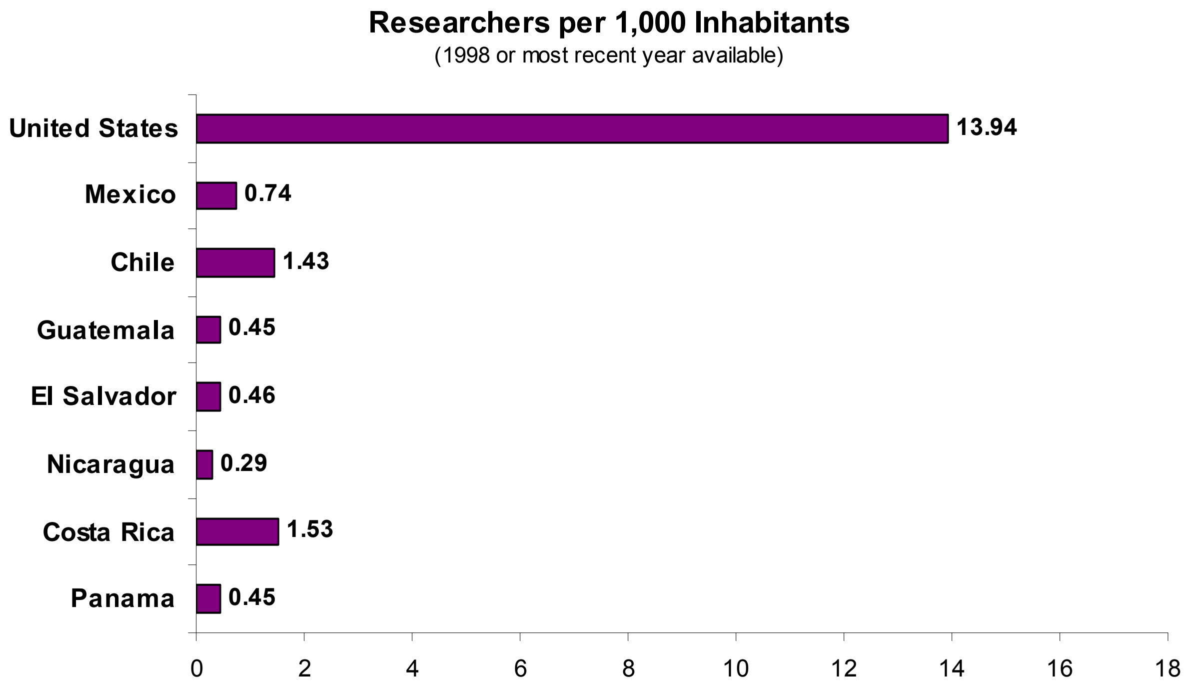
* Does not include Honduras.
Source: RYCIT (2002).

Figure 2.



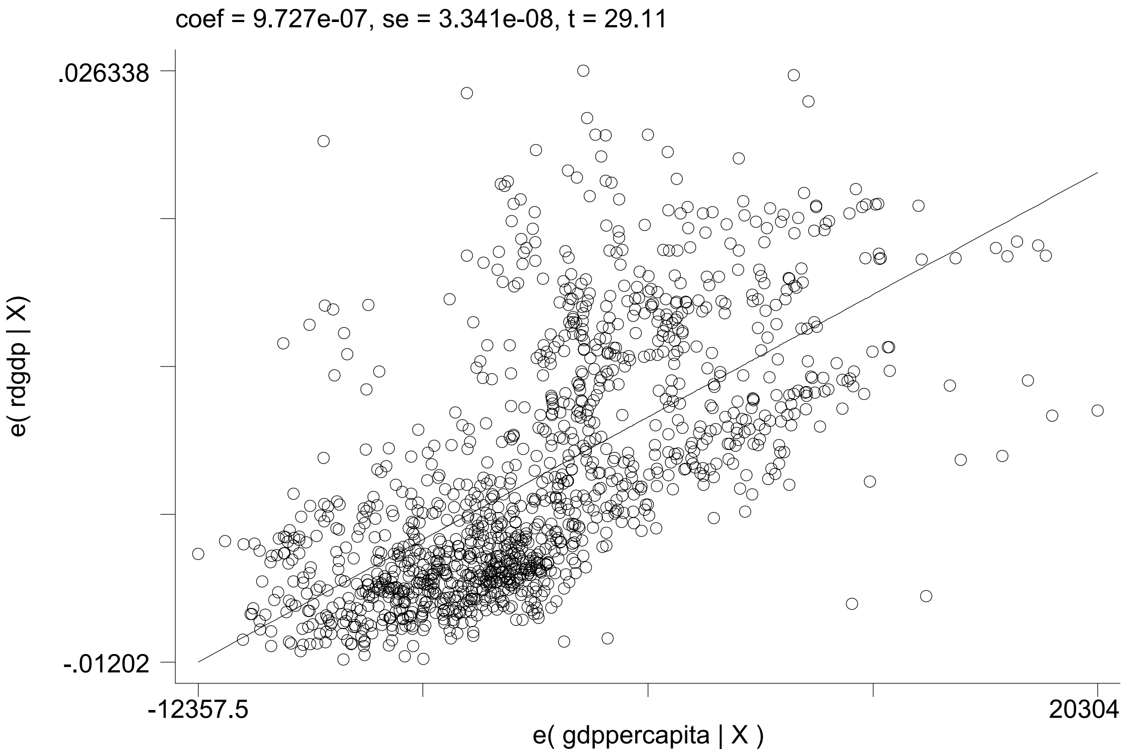
Source: RYCIT (2002).

Figure 3.



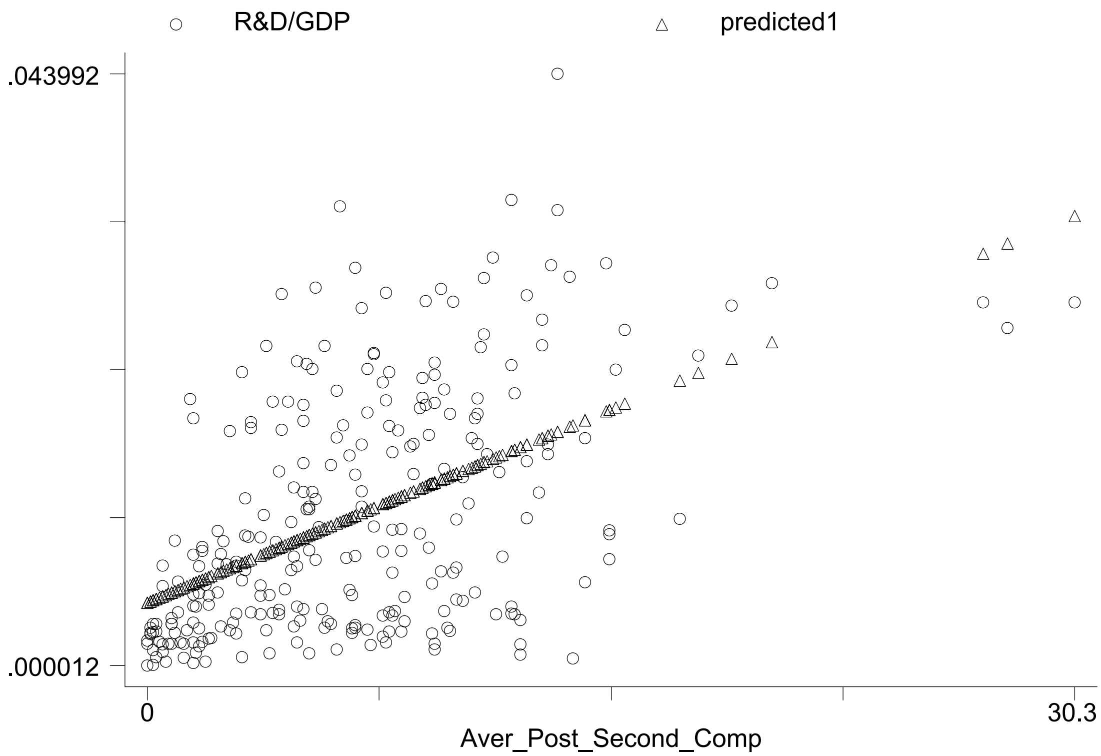
Source: RYCIT (2002).

Figure 4. R&D/GDP against GDP per capita (partial correlation)



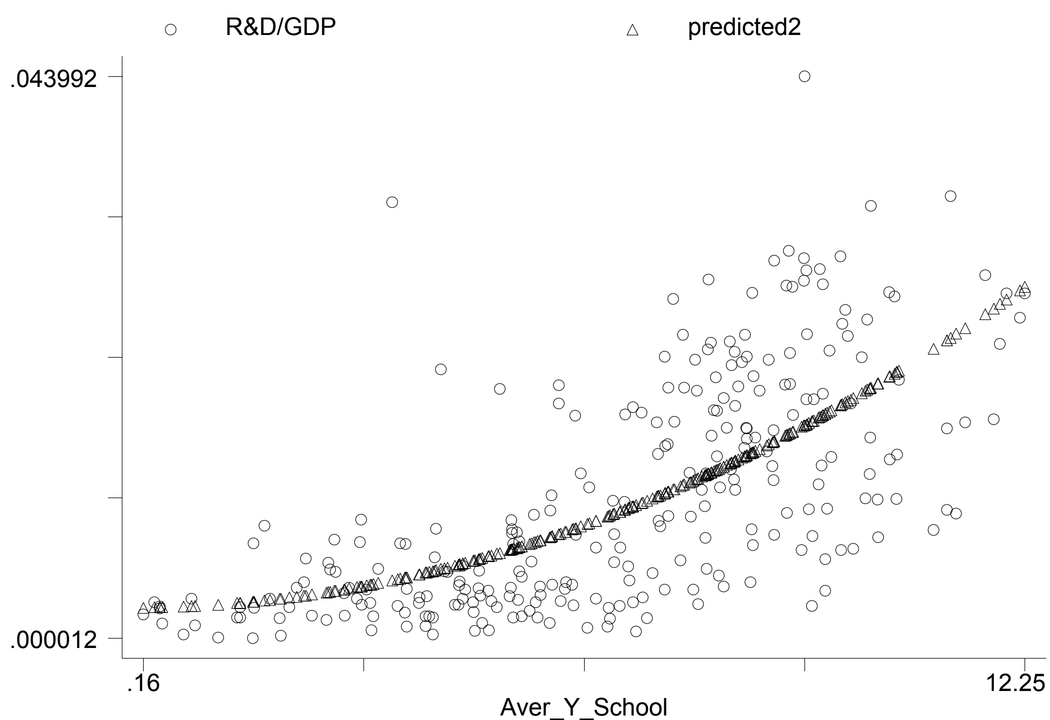
Source: Author's calculations using data on R&D/GDP from Lederman and Sáenz (2003) and on GDP per capita from Heston, Summers and Bettina (2002).

Figure 5. R&D Intensity versus Percentage of Working Age Population with Post-Secondary Education



Sources: Lederman and Sáenz (2002) and Barro and Lee (2000).

Figure 6. R&D Intensity versus Mean Years of Schooling Squared



Sources: Lederman and Sáenz (2002) and Barro and Lee (2000).