Identifying R&D Shortfalls in LDCs

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Introduction

The perception is that both the OECD and Latin America face an innovation problem roughly proxied as a low R&D investment rate as a share of GDP (RDI). In pursuit of "turning the EU into the most competitive knowledge-based economy in the world" the March 2002 meeting of the European Council in Barcelona announced a goal of increasing the average RDI from 1.9% to 3% by 2010 so as to close the gap with the US (2.7%) and Japan (3.0%).[1] As numerous international agencies have noted with concern, Latin America with an average level of investment of roughly .4%, is in a different league altogether.[2]

However, such diagnostics often proceed as if innovation were a free floating activity independent of other factors affecting the level of a country's development. Figures 1 and 2 suggest that this is not the case. The first shows a very strong relationship of TFP against the capital-labor ratio suggesting that the accumulation of knowledge related capital, what in theory drives TFP, is likely complementary to and driven by many of the same forces determining the accumulation of and physical capital. This informs how we view Figure 2, which shows a very strong relationship of R&D investment with GDP per capita. In this light, a finding of low R&D rates for Latin America (or certain European countries) may simply be restating that these countries are relatively poor. Put differently, it raises the question of whether a country's perceived innovation shortfall results from problems common to accumulation overall, or whether in fact the activity of innovation itself is somehow especially impeded.

In this paper we explore ways in which one could tell whether a country suffers from a true innovation problem, as opposed from a general accumulation problem.[3] In other

[1] See OECD (2004)
[2] See OECD 2004, World Bank Institute 2005, De Ferranti et. al. 2003
[3] In part, this paper is inspired by the recent contribution by Hausmann, Rodrik and Velasco (2005), titled "Growth Diagnostics," in which they argue that different countries may be affected by different binding constraints to growth, and that the goal of development economics should be to identify those constraints. A significant difference in our approach compared to theirs is that whereas they argue that one should look at shadow prices, we instead look at quantities but use theory to infer the corresponding shadow prices.

words, do LDCs with low R&D investment rates suffer from barriers toor lack of incentives for innovation above and beyond the common problems that one generally encounters in these countries. To gauge the usefulness of the analysis, we illustrate most of our discussion and results with the case of Chile, the Latin American country with perhaps the best micro economic management and most transparent system of incentives.

We begin this task in the next section by laying out a model that captures the interactions among accumulation of different types of capital, including "knowledge capital," and allows for both barriers to general accumulation and barriers that are specific to the accumulation of knowledge. We then calibrate it to explore its quantitative implications for Latin American countries. Looking more in depth at Chile, we discuss some considerations that complicate inference about whether there is, in fact, an innovation problem. After some appropriate adjustments, we conclude that Chile does indeed suffer from an innovation problem: its R&D investment rate is significantly below what would be expected given its stocks of human and physical capital.

One concern with this result is that it is based on a one-sector model. The question arises as to whether the low R&D rate observed in Chile (and other LDCs) could be a result of its specialization in sectors with a "low R&D intensity." This is relevant because, just as with physical capital, one can imagine models where trade allows for factor price equalization in spite of different per capita stocks of knowledge capital. In that case, a low R&D rate would not be something to worry about. We explore this issue in Section 3 and conclude that although specialization in low-R&D-intensive sectors explains part of Chile's R&D shortfall, a significant unexplained gap remains.

Finally, Section 4 discusses possible explanations to the innovation problem that we identify in LDCs, and particularly in Chile.

II. A model of knowledge capital accumulation

There is a long literature that tries to understand the relative contribution of capital accumulation and productivity growth to economic growth. More recently, research has focused on what is sometimes called "development accounting," the goal of which is to understand the determinants of income differences across countries at a particular point in time. In particular, the exercise explores whether a country's low income level is due to low investment in physical capital, human capital, or to a low TFP level. One problem with development accounting is that it is almost never acknowledged that TFP, just as the stock of physical and human capital, is the result of investments in some kind of capital, perhaps "organizational" capital or technology. In other words, TFP is also the result of accumulation of some sort.

To tackle this issue and undertake a more meaningful development accounting exercise, Klenow and Rodríguez-Clare (2004) formulate a model in which TFP is the result of accumulation decisions. The authors used the model was to explore the relevance and magnitude of international spillovers, and also to understand whether policies that affect appropriability in general, together with exogenous differences in the relative price of investment goods and investment levels in human capital, can explain the international variance of income levels, or whether one also had to postulate significant differences across countries in their treatment of innovation and technology adoption. The conclusion was that this latter element was important: to explain differences in labor productivity across countries, one has to assume that there are significant cross-country differences in policies or institutions that affect the cost of technology adoption.

In this section we turn our attention to a slightly different matter. We are interested in applying the framework of Klenow and Rodríguez-Clare to understand the different reasons behind an LDC's low income level. Perhaps there are some countries where low income is due to low appropriability, others where low income is due to low human capital, others where it is mainly due to a high relative price of investment, and yet others where low income is due to a high implicit cost of technology adoption. In a sense, we are interested in exploring this framework to conduct a sort of "R&D diagnostics," so that one can see whether a country suffers from low R&D beyond what would be expected given its low investment in other types of capital. We take the case of Chile for an illustration of this methodology, and to discuss its advantages and disadvantages, as well as the way in which it is sensitive to different assumptions.

We first explain briefly the main workings of the model. As customary, we postulate a Cobb-Douglas production function of the form $Y = K^{\alpha}(AhL)^{1-\alpha}$, where Y is total output, K is the physical capital stock, A is a technology index, h is average human capital per worker, and L is the total labor force. We follow the Mincer specification, so that $h = e^{\gamma s}$, where s is years of schooling, assumed constant and exogenous. Output can be used for consumption (C), investment (I), or research (R), $Y = C + pI + R$, where p is the relative price of investment and is assumed constant through time. Physical capital is accumulated according to: $\dot{K} = I - \delta K$.

The only thing left to specify is the way that A evolves. A complete description is beyond the scope of this paper, and the reader is referred to Klenow and Rodríguez-Clare (2004). Here we just provide a brief sketch. First, there is a world technology frontier, denoted by A*, that increases thanks to the R&D performed in all countries. The rate of growth of A* is denoted by g_A.

Second, each country's A relative to the world level – which we denote by $a = A / A^*$ – is determined by the country's efforts in technology adoption, which we equalize to a broad concept of R&D.[4] Thus, R&D in our model has two functions: it contributes to increasing the world's technology level frontier and it allows the country to come closer to the world's frontier (i.e., decrease a). Given that R&D is more effective in increasing the country's A when the country has a lower relative A level (i.e., there are benefits of

[4] The reader may be concerned here that this formulation implies that all TFP differences result from differences in technology adoption. Below we explore this issue quantitatively.

backwardness), then low R&D does not translate into lower growth, but rather into a lower steady state relative A, with all countries in steady state growing at a common rate. Moreover, there is also a "free flow" of ideas from the rest of the world to any particular country, and this happens at a rate denoted by ε. It is also assumed that the basic productivity in R&D is the same across countries, although the actual labor productivity in R&D may differ due to differences in the amounts of physical and human capital. We denote this basic productivity in R&D by λ. Thus,

$$\dot{A} = \left(\lambda R / L + \varepsilon A\right)\left(1 - A / A^*\right)$$

In steady state we have:

$$a = 1 - \frac{g_A}{\lambda s_R k + \varepsilon} \qquad (1)$$

where s_R is R&D as a share of GDP (i.e., $s_R \equiv R/Y$) and $k \equiv h(K/Y)^{\alpha/(1-\alpha)}$ is the "composite" capital-output ratio (incorporating both physical and human capital).

As usual, $y \equiv Y/L = Ak$, so that labor productivity is the product of the technology index and the capital-output ratio. This expression takes into account that – just as in the neoclassical model – an increase in A leads to an increase in the rate of return to capital, so that to bring the economy back to steady state an increase in the capital-labor ratio is called for. The full effect of an increase in A, once one takes into account the indirect effect through the induced capital accumulation, is a proportional increase in labor productivity (see Klenow and Rodríguez-Clare, 1997). But here there is an additional interaction between *A* and *k*, since a positively affected by k. The reason for this is that R&D uses the same technology as production of output, which relies on human and physical capital, hence a high level of *k* makes R&D more effective in accumulating A. Thus, this model incorporates both the effect of technology on capital accumulation, and the reverse effect from capital accumulation to increased technology adoption.

Third, a country's R&D investment is the sum of R&D performed by firms, who undertake R&D together with accumulation of physical capital to maximize the present value of their future stream of profits, which are equal to total income net of wages paid and net of taxes. Apart from general income taxes, there are also policies and institutions that affect the cost of R&D, which we capture by the parameter ϕ, so that the unit cost of R&D in terms of units of output is $1+\phi$. Apart from this implicit R&D tax, we allow for an R&D externality, so that a firm's A increases not only thanks to its own R&D but also thanks to R&D performed by other firms in the economy. We use a parameter μ between zero and one to capture this externality, with $\mu = 0$ implying no externalities and $\mu = 1$ implying full externalities, in the sense that A is determined completely by average R&D efforts among all the firms in the economy.

The firm's decision about how much to invest is determined by a dynamic optimization problem, which yields two first order conditions: one for investment in physical capital, and one for R&D. The first order condition for investment in physical capital yields the following steady state restriction:

(2) $$p(K/Y) = \alpha\left(\frac{1-\tau}{r+\delta}\right)$$

where τ is the tax on profits, and *r* is the equilibrium steady state real interest rate, which is assumed equal across countries. Assuming a common interest rate across countries, and using data for each country for *p* and *k*, equation (2) yields an implicit τ for each country. Note that τ and *r* are "interchangeable" – that is, the model cannot differentiate between low accumulation due to high taxes or low finance, since both work through the same channels. As mentioned, however, we assume that r is the same across countries, so that all international differences in the "nominal" capital-output ratio are explained by differences in tax rates.

The second first order condition determines R&D, and hence relative A in steady state. This condition is:

(3) $$\Omega(1-\alpha)\lambda k(1-a) - ga/(1-a) + \varepsilon(1-a) = r$$

where $\Omega = (1-\tau)(1-\mu)/(1+\phi)$ is a composite distortion term that captures the effect of taxes and externalities. To see this better, the difference between the social and the private rate of return to R&D can be shown to be equal to:

$$\tilde{r} - r = (1-\Omega)(1-\alpha)\lambda k(1-a) + g_L$$

where g_L is the rate of growth of the labor force. The wedge between the social and private rates of return to R&D is thus composed of two components: the first component is generated by taxes and the domestic R&D externality, as captured by the term Ω, whereas the second term is associated with the rate of growth of firms, which in the model is equal to the rate of growth of the labor force, and arises because of an assumption in the model that new firms are born with a productivity equal to the average productivity of existing firms. Equation (3) determines the relative A level of a country given its measured levels of *k*, and the two tax parameters τ and ϕ.

Calibration

For the calibration, we follow Klenow and Rodríguez-Clare in having $\alpha = 1/3$, $\gamma = 0.085$, $\delta = 0.08$, $r = 0.086$, $g = \varepsilon = 0.015$, $\lambda = 0.38$, and $\mu = 0.55$. The interested reader can consult that paper to understand the details of this calibration. Here we just provide a brief explanation. The values used for the parameters α, γ, and δ are standard in the literature. The interest rate is obtained by noting that with a tax rate of 25% in the U.S. (i.e., $\tau = 0.25$) and given data for the capital-output ratio and the relative price of investment in the U.S., then equation (2) implies $r = 0.086$. The steady state growth rate of A*, *g*, is obtained from the average growth of TFP in the OECD for the period 1960-2000. We assume that $\varepsilon = g$ to generate reasonable steady state properties. Finally, parameters λ and μ are calibrated to U.S. data. In particular, these parameters are set so as to have that the social rate of return to R&D in the U.S. be three times the net private rate of return given an R&D subsidy of 20% (i.e., $\phi = -0.2$), and given an R&D investment rate in the U.S. of 2.5%.

Initial Results

Table 1 presents the results of this exercise for several Latin American countries plus the U.S. Columns 1-3 come from Barro-Lee data on human capital and the Penn World Tables, using $\alpha = 1/3$, $\gamma = 0.085$, and a procedure to construct capital stocks as described in Klenow and Rodríguez-Clare (2004). Column 4 calculates the income tax τ implied by equation (2) above assuming that all countries have the same interest rate as in the U.S., calibrated above as $r = 8.6\%$. The country with the lowest implied income tax is Mexico, which has a physical capital-output ratio equal to that of the U.S. in spite of having a relative price of capital that is twice as high. The only way for this to be an equilibrium is to have an income tax much smaller than that of the U.S.

Column 5 presents the composite capital-output ratio $k \equiv h(K/Y)^{\alpha/(1-\alpha)}$ as a ratio of the U.S. level. Column 6 uses equation (3) to calculate the value of a *assuming that all countries had the same implicit tax on R&D as the U.S. (i.e.,* $\phi = -0.2$), and presents it also as a ratio of the U.S. level. Column 7 shows the associated R&D investment rate, using equation (1). Column 8 shows the product of relative *k* and relative a, which yields labor productivity relative to the U.S. Thus, for example, if Chile had $\phi = -0.2$, given its levels of human capital, the relative price of investment, and the (real) physical capital-output ratio K/Y, then its labor productivity would be 38% of that of the U.S. Column 9 presents the social rate of return to R&D given $\phi = -0.2$.

The exercise continues in columns 10-13 of Table 1. Columns 10 and 11 show labor productivity and technology level A calculated directly from the data expressed as ratios of corresponding U.S. levels, respectively. (The level of *A* is obtained from *y* and *k* by applying $y = Ak$). Column 12 calculates the R&D investment rate implied by a country's “measured” a using equation (1). Finally, column 13 shows the R&D tax ϕ necessary for the model to be consistent with this R&D investment rate. Comparison of columns 6-8 with columns 10-12 reveals the impact of innovation policies and regulations, and column 13 summarizes this comparison in a single index. Finally, column 14 presents the implied social rate of return to R&D.

As way of illustration, consider the case of Peru. According to the model, with $\phi = -0.2$ Peru’s labor productivity would be 61% of the U.S. level, rather than the 18% recorded in the data; the reason for this is that given its (implied) low income tax ($\tau = 9\%$), a 20% R&D subsidy (i.e., $\phi = -0.2$) would lead Peru to an R&D investment rate of 3%, implying a steady state technology index equal to 93% of the U.S. level. In contrast, Peru’s actual R&D rate is only 0.4%, implying a level of A of only 28% of the U.S. level, and hence a labor productivity of only 18% of the U.S. level. For this to be an equilibrium phenomenon, the model requires an R&D tax of 154%, which implies a social rate of return to R&D of 51%. Thus, Peru appears to suffer from a true innovation problem, that is, a case of policies and institutions that negatively affect broad R&D.

Something quite different happens in Chile. In this case the labor productivity that would obtain with a 20% R&D subsidy would be 38%, which is very similar to what is recorded in the data. In both the hypothetical and “real” cases, the implied R&D investment rate is close to 2%. In line with this, the model’s implied R&D tax for Chile is –24%. Thus, according to this exercise, Chile’s problem is entirely driven by its low h and its high implicit income tax τ. In other words, it is an accumulation rather than an innovation problem.

On the other extreme, we find El Salvador: given its low levels of h and K/Y (and hence a very low k equal to only 0.3 relative to the U.S.), one would expect El Salvador to have a low relative A level (38% of the U.S. level), yet one observes a high relative A of 72%, implying a high R&D investment rate of 3.3%. Hence, it must have policies and institutions that favor R&D: the model implies that El Salvador enjoys an R&D subsidy of 53%, significantly higher than the one in the U.S.

To summarize the previous results, the exercise suggests very high R&D taxes in Ecuador, Mexico, Panama and Peru, and medium R&D taxes in Argentina, Bolivia, Brazil, and Venezuela. Chile, Colombia, El Salvador and Uruguay appear to have favorable R&D institutions and regulations. The first group of countries has an innovation problem, whereas the problem in the later group is one of accumulation. The first group of countries would benefit enormously from adopting policies and regulations more favorable to innovation. For example, Panama's R&D investment rate would increase from 0.6% to 2.9% of GDP if it could go from $\phi = 1.17$ to $\phi = -0.2$, leading to an increase in its labor productivity relative to the U.S. from 27% to 63%. Of course, this is not to say that this is a simple matter of innovation or tax policy; as we discuss below, the institutions and regulations that determine the effective R&D implicit tax are much more complex. For the group of countries with favorable innovation institutions and regulations, there is little to gain from additional efforts in this dimension.[5]

The next subsection explains columns 15-17 of Table 1. The last column of the table shows the *measured* R&D investment rate. All the implied R&D investment rates of column 12 are higher than the measured ones in column 18. This reveals that measured R&D is significantly lower than the model's implied R&D including technology adoption efforts. This should not be surprising: measured R&D only considers a small portion of overall innovative and technology adoption efforts, since the formal definition of R&D excludes investments that one would normally want to include as technology adoption.[6]

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[5] Of course, this doesn't mean that these countries should not continue to improve their innovation policies. Even with a 20% R&D subsidy, the social rate of return is relatively high. For example, the implied rate of return to R&D in Chile is 26%, just as in the U.S., and considerably higher than the private rate of return. Clearly, it makes sense to provide even stronger support to R&D. The point is that this is no longer the source of divergence from U.S. productivity levels.

[6] One complication that arises here is that although we have a broad definition of R&D, we nevertheless use the measured 2.5% R&D investment rate in the U.S., as well as the official R&D subsidy in the calibration. There are two reasons why we believe this not to be a serious problem. First, because the bias in the measurement of R&D must be much stronger in LDCs than in the U.S., since the main problem arises from the lack of measurement of technology adoption as opposed to innovative efforts. Second,

Indeed, one advantage of the approach taken here is that the "R&D" measure we back out is really a more general measure of innovative effort that is mapped to the TFP measures plugged into the model. In this way, we avoid some issues complicating innovation diagnostics mentioned earlier. First, as mentioned earlier, we include technology adoption efforts that are likely to be left out of the formal measurement of R&D. Second, we implicitly take into account international differences in effectiveness with which R&D is turned into useful knowledge, resulting – among other factors – from differences in the fraction of R&D that is financed by governments across countries.

The role of distortions

The model we have used so far assumes that all TFP differences across countries result from differences in R&D or technology adoption. Thus, it leaves no room for distortions acting through other channels, such as trade barriers that decrease efficiency directly or regulations that leads firms to adopt suboptimal combinations of inputs. We believe that an interesting area for future research is precisely to explore ways to identify the relevance of barriers to technology adoption and direct distortions for international TFP differences. For now, we undertake a simple exercise: we want to know the distortions that would be necessary to account for observed productivity levels if countries had the same R&D policy and institutions as the U.S. (i.e., $\phi = -0.2$).

We model distortions as a factor z that directly reduces output: $Y = K^{\alpha}(zAhL)^{1-\alpha}$. Everything else is as in the model presented above. The analysis of steady state equilibrium is exactly as above as if human capital per worker was zh, instead of h. This implies that now $k \equiv zh(K/Y)^{\alpha/(1-\alpha)}$. For any particular country we can then ask: what is the value of the distortions variable z such that the data and the model are consistent if we also impose $\phi = -0.2$. The result is presented in column 15, whereas

because it is likely that the results would not change much if we instead calibrated the model to a broader concept of R&D in the U.S.

columns 16 and 17 present the implied R&D investment rate and the associated social rate of return to R&D.

Consider Peru again. Instead of being a case of failed development due to perverse innovation policies and institutions, it is now seen as an economy plagued by distortions that by themselves explain a labor productivity level of 30% of the U.S. level.[7] More generally, the countries that in the previous exercise (column 13) were classified as having the highest levels of ϕ, are now portrayed as having the lowest levels of z (i.e., highest distortions). The problem with this analysis is that it is hard to know what specific distortions, and through what channels, would generate such enormous static productivity losses. Moreover, it is hard to compare this to the result that – in the opposite extreme, without distortions – a "barriers to technology adoption" explanation of Peru's low productivity would entail $\phi = 1.55$, which implies firms face a cost of R&D in terms of output that is approximately three times higher than in the U.S. This is because although the distortions analysis only tells us the overall productivity loss resulting from unknown distortions, the barriers to technology adoption analysis tells us the specific "wedge" needed to create the technological backwardness consistent with that productivity loss.

In summary, although the model without distortions used for the analysis of the previous subsection suggests that some Latin American countries suffer true innovation problems, an alternative explanation is that rather than lack of innovation, these economies suffer from severe distortions that directly lower TFP. More research is necessary to understand how to disentangle static distortions from barriers to technology adoption. For now, we proceed (mostly) under the assumption that distortions play no role in explaining low productivity levels.

[7] This effect of distortions takes into account its total effect, both the direct effect through a lower TFP, and the indirect effect through a lower capital stock given a constant capital-output ratio (and constant rate of return to capital).

Potential pitfalls of using international databases and common parameters: the case of Chile

One limitation of the analysis we have conducted so far is that it relies on international databases and assumed common parameters. Although this is fine for the purpose of establishing stylized facts, it is not satisfactory when analyzing a particular country. We now consider two specific issues. First, some countries may exhibit a high measured TFP as result of their large endowment of natural resources. Ideally, one would correct for this to make the results comparable across countries. Second, although the assumption of a constant Mincer coefficient may be a good approximation when studying broad regularities in the data, this is no longer the case when one is interested in a particular country. In that case, it is much better to use the particular Mincer coefficient for the country in question. In this section, we explore these two issues for the case of Chile, assuming first that there are no distortions (i.e., $z = 1$).

First consider the impact of natural resources. In the case of Chile, it is clear that a significant part of its GDP is not so much the result of using human and physical capital according to the production function above but rather the result of "using" its large endowment of mineral resources. According to the Central Bank, mining contributed 6.7% of GDP in 1999, whereas according to the 1998 Household Survey employment in this sector accounted for 1.6% of total employment. Assuming that the physical and human capital stocks per worker were the same in mining as in the rest of the economy, then this implies that pure natural resources in mining account for approximately 5% of GDP.

Table 2 shows the results of this adjustment. The first row replicates the exercise above, while the second row shows the adjusted results. We see that the implied capital-output ratio increases, implying a drop in the implicit income tax from 37% to 34%. Also, there is a small increase in k, and a small decrease in the relative technology index. For this new relative technology index to be consistent with the model above, it is necessary to have a smaller R&D subsidy, calculated now to be 9%. Thus, Chile's "problem" remains one of accumulation and not one of innovation.

The third row of Table 2 turns to the second adjustment mentioned above. We consider Chile's estimated Mincer coefficient rather than the common coefficient imposed for the exercise in Table 1. The estimated TFP (and hence the estimated technology index A) is quite sensitive to the Mincer coefficient. For example, according to Arellano and Brunner (1999) the Mincer coefficient in Chile is close to 0.12. If we use this coefficient, then h increases from 1.85 to 2.39, which by itself would imply a decline in A of 23%. Together with the mining adjustment above, a falls to 51% of the U.S. level. The R&D investment rate and R&D implicit tax that go with this (according to the model) are 0.8% and 50%.[8] Chile now appears to have an innovation problem.

Is the upward adjustment to the Mincer parameter driving these results reasonable? Theory offers little advice: on the one hand, educational quality is likely to be lower in Chile than in the OECD; on the other hand, education stock is lower and hence, ceteris paribus, the return should be higher. What we can say is that the finding has empirical precedent. The adjusted rate is the same as the one Bils and Klenow (2000) and borrowed from Psacharopoulos (1994) and substantially below Lam and Schoeni's (1993) estimate for Brazil.

What would be the required distortions to explain Chile's low TFP after the previous adjustments? Row 4 of Table 2 presents an exercise similar to the one performed in the previous section, to determine the distortions that would be necessary to explain Chile's lower TFP level given an R&D subsidy of 20%. The result is that distortions would have to be such as to reduce Chile's labor productivity by 27%.

In summary, adjusting for the impact of natural-resource abundance and a higher than average return on schooling, the analysis for Chile changes radically: these adjustments lead to a lower TFP, a lower implied R&D investment rate, and a higher "innovation tax." More broadly, the analysis suggests that Chile's low labor productivity is the result of (1) a high income tax that leads to a lower capital-output ratio that by itself would lead to a labor productivity level 16% lower than the U.S. level, (2) a lower average mean years of schooling of the adult population that by itself would lead to 11% lower labor productivity than in the U.S., and a combination of (3) distortions that would cause a decline in labor productivity of 27%, and (4) unfavorable policies and institutions for innovation that would lower R&D from 1.9% to 0.8% and labor productivity by 27%.

III. Does composition matter?

The analysis of the previous section was based on a one-sector model. A valid concern is that this may miss an important source of differences in R&D rates across countries that would have very different implications on productivity and wages than revealed in a one-sector model. This is because in a multi-sector economy with international trade, one may have different countries specializing in sectors with differing possibilities for technological change, so that one would observe significant gaps in R&D investment rates that are consistent with factor price equalization and hence similar wage levels (see Grossman and Helpman, 1991). Although income levels would be higher in the economy with higher R&D rates (since it would enjoy a higher stock of knowledge capital per worker), under reasonable conditions it would not be appropriate for countries to encourage the growth of high-R&D sectors. We discuss this point by briefly reviewing the relevant theory in the next subsection. The following subsection looks at the R&D data at the sector level to gauge the extent to which differences in R&D intensities across sectors are an important phenomenon, and whether it explains a significant part of the R&D insufficiency one observes in LDCs such as Chile.

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[8] Interestingly, the 0.8% implied R&D investment rate is now close to the measured rate for Chile, which

R&D rates in a multi-sector economy: implications from trade theory

Although our interest is R&D and knowledge capital, we present this discussion in the more familiar setting of investment and physical capital. The framework we use for this discussion is the Hecksher-Ohlin (HO) model with capital accumulation. We later add Ricardian productivity differences, differences in income taxes, and externalities.

Consider a model of a small open economy, two factors of production (capital and labor), and two goods that differ in their capital intensity. Let the two goods be 1 and 2, with 1 being labor intensive. Also, assume that capital is produced with a technology that is identical as the one to produce good 1, and assume that there is no depreciation, so that the rental rate of capital is equal to the net rate of return to capital (see Findlay, 1995). Technology is identical in the small economy and in the Rest of the World (RW). International prices are determined in the RW. From the Stolper-Samuelson Theorem we know that under certain regularity conditions there is a unique and positive relationship between the rate of return to capital and the relative price of 2. If the instantaneous intertemporal discount rate is ρ, then we know that the long-run equilibrium in the RW is such that the rate of return to capital is ρ, which pins down the relative price of 2.

Coming now to our small open economy, Figure 3 illustrates the equilibrium analysis. The horizontal axis measures k, the capital-labor ratio, and the vertical axis measures r, the rate of return to capital (note that we change terminology relative to the previous section, where k was a composite capital-output ratio). Curve $r_i(k)$ denotes the equilibrium rate of return to capital given an economy-wide capital-labor endowment of k if there is complete specialization in sector i. Decreasing marginal returns to capital imply that the curves $r_i(k)$ are downward sloping. Let k_i be defined implicitly by $r_i(k) = \rho$. Standard HO analysis tells us that if k was exogenous, then the allocation of resources between sectors 1 and 2 is determined by k: if k is equal to k_1 or lower there would be complete specialization in good 1, whereas if k is equal to k_2 or higher there would be

averaged 0.6% for 1990-2000 (see Lederman and Saenz, 2003).

complete specialization in good 2. There is factor price equalization if k is in between these two extremes, whereas the rate of return is higher (lower) than the world's rate of return if k is lower than k_1 (higher than k_2). For any level of k between the two extremes, the allocation of capital between sectors 1 and 2 is just such that the equilibrium rate of return is equal to ρ. Hence, the equilibrium rate of return as a function of the capital-labor ratio endowment is given by the fat line in the figure.

When there is endogenous capital accumulation in the small open economy, we see that if the rate of discount is the same as in the RW, then there is indeterminacy in the steady-state capital-labor ratio, and the economy is indifferent among all these points. On the other hand, if the economy has a discount rate higher than ρ, meaning it is more impatient than the RW, then it will have a capital-labor ratio lower than k_1, it will be specialized in the labor intensive good, and it will have a higher equilibrium rate of return to capital. The same would occur if the small economy has an income tax that is higher than in the RW. Thus, the first result we derive here is that comparative advantage in a long run HO model is determined from the policies and preferences that affect capital accumulation. Translated to R&D terminology, countries with more favorable policies towards innovation would be specialized in R&D intensive sectors, have higher R&D investment rates and higher income levels. This is line with the results of the previous section.

But consider now what happens if there are Ricardian productivity differences. This is relevant because, as has been pointed out in the literature, when the capital stock is endogenous, then the long-run Production Possibilities Frontier becomes flat. Hence, just as in the Ricardian model, sector-specific productivity differences would completely determine comparative advantage and the pattern of specialization. To see this, imagine that our small economy has a Ricardian productivity that is lower in sector 2 relative to the RW. The analysis for the small economy is exactly as above, but "as if" the international price of good 2 was lower. A lower international price for good w implies that the curve $r_2(k)$ is shifted downward relative to the original curve where the flat segment coincides with to ρ, and the points k_1 and k_2 move to the right, so that the new equilibrium returns as a function of k has the same shape as above, but moved South East. This implies that if the small economy has the same discount rate as the RW, it will specialize in good 1.

In sum, an economy can specialize in good 1 either because it has a higher discount rate, a higher income tax, or a Ricardian comparative advantage in good 1. The only case where it could make sense to do something about the fact that the economy is specialized in a low R&D sector is if this is caused by a higher income tax, otherwise, no intervention is justified.

Externalities

Now imagine that there are sector-specific (Marshallian) externalities. As shown in Rodríguez-Clare (2005), the problem that may arise in this case is that the economy may have a comparative advantage in good 2 and experience a coordination failure that keeps it specialized in sector 1. This is of course the classic analysis of sector-specific externalities and trade, where an economy may be in a bad equilibrium, specialized in a sector where it doesn't have a comparative advantage. If this were the case, then a policy inducing specialization in sector 2 would lead to higher investment rates, a higher steady state capital-labor ratio, and a higher TFP arising from specialization in the sector with comparative advantage.

What does this tell us for the case of an LDC? Translating again to R&D terminology, if the LDC has a Ricardian comparative advantage in R&D intensive sectors, but there are sector specific and local spillovers, then it would make sense to think of a policy to induce a reallocation of resources towards the more R&D intensive sectors. This would lead to an increasing equilibrium R&D investment rate. But does it make sense to think that Chile, for example, has a Ricardian comparative advantage in more R&D sectors? Probably not!

There is a case that can be made for a policy to induce specialization in high R&D sectors. The previous argument applies to the case where externalities or R&D spillovers are entirely within industry. A different result emerges if R&D generates positive economy-wide (i.e., inter-industry) spillovers. In that case, it is easy to show that an economy could be justified in sacrificing efficiency through specialization in sectors where it doesn't have a comparative advantage, to attain higher R&D investment rates and enjoy the associated spillovers. In fact, some of the discussion that took place in the U.S. when it was feared that it was losing its edge in semiconductors was strongly related to this, with commentators like Laura Tyson arguing that semiconductors generate strong inter-industry externalities, and that therefore it is important to have a domestic semiconductor industry even if this runs against comparative advantage (Borrus, Tyson and Zysman, 1986).

For this to be a valid argument, however, it would be necessary that knowledge spillovers associated with R&D be stronger across domestic firms than across firms in different countries. Indeed, if spillovers are international, then it would clearly not make sense for a country to intervene, for any market failures would be *international* in scope, and hence *national* economy policy is clearly not the correct type of intervention. Although there is some controversy on this matter, with – for instance – Irwin and Klenow (1994) finding that learning-by-doing spillovers in the semiconductor industry are as strong internationally as domestically, our reading of the more general evidence leads us to think that domestic spillovers are stronger, since knowledge spillovers are clearly attenuated by distance (Audretsch and Feldman, 2003).

Ultimately, then, this is an empirical matter. If R&D spillovers go beyond sectors but stay mostly within borders, one cannot easily discard policies to push resources towards high R&D sectors. Of course, favoring high-R&D sectors may not be the most standard way to encourage R&D; a more conventional approach would be simply to subsidize R&D. But if for practical reasons this later approach is not advisable, then perhaps a sectoral approach is a relevant approach. As with any policy option, however, there are significant costs and risks that would have to be carefully considered.

Before going any further with policy discussions, however, it is necessary first to explore whether in fact there are significant systematic differences in R&D intensities across sectors, and whether this can explain a significant part of LDCs' (and Chile's, in particular) shortfalls in R&D.

A look at sector level R&D data

We first examine how R&D investment varies across sectors for the OECD since LDC data do not yet permit this kind of exercise. Table 3 reveals several important stylized facts. First, there is a wide range of average R&D investment rates by sector from around .1% in Services, apparel or publishing to almost 30% in pharmaceuticals; office, accounting and computing equipment; and air and spacecraft. Second, there is tremendous variation of investment rates within sectors In manufacturing in the aggregate, for example, Spain holds up the bottom with 2% while Sweden tops the list at close to 12%. Looking within one sector, pharmaceuticals, Spain invests under 10% of value added while Sweden invest more than 40%. Third, overall, individual sectoral investment rates have tended to rise suggesting an increasing intensity in the use of knowledge in the production of these products. Fourth, sectoral composition matters appears to matter. The declining aggregate R&D investment rates across this period, partially a phenomenon of this particular sample cut, is driven by the fact that OECD countries have moved heavily into services-over 6 percentage points in the UK, Japan and more than 4 percentage points in Australia, Belgium, Spain, France and Italy.[9] Hence, as a first pass, increases in aggregate R&D investment rates occur both from increasing R&D investment in existing sectors and shifting into more intensive sectors.

A more careful decomposition of differences in aggregate RDI within the OECD suggests a combination of both elements with wide variations across countries. (see figures 4 and 5). The RDIs in the US and France are higher than the mean largely due to higher investment rates within the mean set of sectors, while Finland and Korea's high RDI, and Canada's, Australia, Netherlands and Norway's lower RDIs are due largely to compositional effects—electronics in the former, perhaps natural resources in the latter. Among the newly emerging eastern European countries, countries, Poland, Spain, Czech Republic, the deficit is due almost entirely to low investment rates within sectors. Within the manufacturing sector (not shown), the story is again mixed. Again, the deficits of the younger countries are due largely to low within-sector investment rates. Among the wealthier countries there is a mix with Germany's superiority and to a lesser extent Japan's due largely to within sector rates while others, again, Finland, Belgium Canada and the US, being driven more prominently by sectoral composition.

To get a feel for what is happening in Chile, for which we lack comparable rates of investment, we take an indirect route. The first column of Table 4 applies Chile's industrial structure to the sectoral investment rates in each country in the OECD. Column 3 relates this simulated value to the actual. It is first clear that structure is not everything. Norway's predicted level is within 10% of it's actual suggesting that the fact that its RDI is double that of Chile is significantly due to low investment rates within existing sectors. However, it is also clear that structure matters. On average, simulated OECD aggregate investment rates are just under 60% of those observed and Finland and Germany, are roughly 30% of their actual.

Table 5 asks which sectors are most responsible for these very large disparities by applying the average OECD sectoral investment rates to the difference between Chile's and the aggregate OECD sectoral participation rates. Virtually the entire difference can be accounted for by Chile's very low participation in the electronics and transport sectors, both of which show very high average investment rates. The fact that Chile has not

[9] See Maloney, 2005. This trend represents a continuation of that identified by Bernard and Jones (1996)

added Nokia to its forestry industry the way Finland did explains the vast difference in the two countries simulated rates.

In summary, Chile's low R&D comes in part from its specialization in sectors with low R&D intensity, but this is not the whole explanation, as there is also a significant gap that comes from lower R&D investment rates at the sector level. The following section turns to possible explanations for this phenomenon.

IV – Explaining Innovation Problems

The previous sections have explored the idea that LDCs suffer from policies and institutions that adversely affect innovation and technology adoption, resulting in lower TFP relative to richer countries. We applied the developed framework to Chile and found that, after some adjustments – and assuming that distortions are not unusually large –, this country appears to suffer from this country as well. What might be the market, government or other failures that make it somehow more difficult in Chile to accumulate the factors that would lead to higher TFP than either educational or physical capital?

Four broad categories come to mind: labor market rigidities, lack of human resources, lack of credit, and absence of policies to internalize externalities. We discuss these in turn.

Labor market rigidities. The recent theoretical literature on explaining international TFP differences has pointed to "barriers to technology adoption," by which it is usually meant labor market rigidities that prevent firms from adopting new technologies that would negatively affect particular groups of workers (see, for example, Parente and Prescott 1994). Indeed, in a recent survey in Chile, firms cited resistance to change and costs of reducing employment as barriers to adopting technologies (Benevente 2004). This is also consistent with studies showing that Chile's costs of severance are substantially above the

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from 1970-1990.

OECD (Heckman and Pages-Serra 2004), although they are substantially below much of the rest of Latin America. Recent empirical work on the impact of the rigidities is somewhat mixed. Caballero, Cowan, Engel and Micco (2004) finds that job security hampers the creative destruction process and that moving from the 20th to 80 percentile in job security cuts one percent from annual productivity growth. For Chile, they calculate that raising flexibility to US levels would lead to an initial gain between 2 and 4% and permanent gains in the structural rate of growth of .3%. On the other hand, working at the firm level in Argentina, Galiani (2005) somewhat surprisingly finds no relationship between the degree of rigidity in union contracts and innovative behavior by firms. Nor can Europe's labor legislation be termed flexible. A fair reading probably suggests continuing agnosticism on the true magnitude of these effects.

Credit markets. According to the recent survey mentioned earlier, firms do not undertake more innovation because of the associated high technical risk and long gestation periods. This could be seen as broadly mapping into the market failures standard in the literature: individual firms cannot handle the lumpiness, risk and long gestation periods of innovation projects. This points clearly to credit market failures.

Recent micro-estimates for Chile by Benevente, de Gregorio and Nuñez (2005) suggest that own rates of return to R&D are high. In particular, they estimate rates of around 30% to R&D, whereas the (gross) returns to physical capital are 16%, borrowing costs of 7.3%. The higher private rates of return to R&D may be due to this activities' higher risk, but it may also be associated with the fact that it is harder to finance, both because of higher risk together with absence of venture capital, and because of the fact that these activities relate to assets that are harder to use as collateral.

Implicit in concerns about longer gestation periods and higher risk of many innovation related projects may be especially difficult access to financial markets. Innovation surveys again suggest that the vast majority of financing of innovative activities is internal suggesting potentially an inability to share risk. That said, there is no consensus on why specialized institutions, such as venture capital, have not taken hold in Chile. Some VC firms have folded allegedly for lack of "deal flow" suggesting that there is inadequate financing at the early stages of idea development that would generate demand downstream. However, recent entrants into the market suggest that deal flow is adequate, but that the design of previous VC operations focused inadequately on the provision of complementary management and mentoring services that are generally part of VC packages. [10] Further, legislation has tied the development of specific institutions to the intermediation of pension funds assets and hence burdened them with inappropriate regulation on risk taking (Arrau 2002). This said, it is worth highlighting that VC is virtually absent in Spain and Italy so it is difficult to assert that this missing market is an insuperable barrier to gains in TFP.

Lack of human resources: Ideally, one could simply look at wages and their distribution according to levels of schooling and professions to see whether there is a scarcity of human resources crucial to innovation and technology adoption. The problem is that this presumes that demand and supply are independent, whereas in this case it is likely that – at least to some extent – supply creates its own demand, and demand depends on the supply of human resources. Very innovative firms are often spinoffs of university research. Managers in firms with a taste for innovation are likely too have an academic background. In Finland, the most important dimension of U-private sector linkages are reported to be masters students doing their theses in the firms. We may imagine that it helps define the frontier of the field and possible areas for innovation investment. We can easily imagine a country where entrepreneurs have little idea of where the frontier is and thus available investment opportunities and as a result, have no demand for the products of the science establishment. In this case, no excess demand for the products of a scientific establishment will appear. Multiple equilibrium models consistent with this type of idea have been elaborated by Howitt and Mayer (2005).

[10] Discussions with Eduardo Bitran and Patricio Arrau respectively

Policies and institutions. A critical problem in the area of innovation is the existence of externalities. This implies that policies and institutions that internalize such externalities are crucial. Perhaps LDCs, and Chile in particular, suffer from policies and institutions that do not perform this function. Although Fundación Chile and CORFO are recognized for work in this area, the overall effort may be insufficient.

An important area is that of collaboration and linkages between universities and the private sector. University private – sector collaboration is a common way of shifting the long term risk of basic science or difficult to appropriate investments from the individual firm. Clearly, universities are also the source of qualified personnel, the lack of which is also cited as a barrier to innovation. In an inversion of what is found in the OECD, in Chile most research is done by, and most researchers are found in, universities rather than the private sector and there is evidence that firms have difficulty accessing either. In theory, skills shortages would be revealed by a high wage premium for scientists and engineers although analysis to date has only identified the general rising premium to tertiary education found globally. However, surveys of private firms suggest, for example, that Chile ranks globally very low on collaboration of the private and university sectors.[11] Though most major universities have offices to promote linkages, only the Universidad de Concepción has any incentives for faculty to collaborate with the private sector in promotion criteria.[12]

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[11] World Economic Forum (various). Only 12% of Chilean firms have signed agreements with universities compared to for instance, 40% in Finland (de Ferranti et al 2003).
[12] Mullin (2005)

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Table 1: A new growth accounting exercise

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Country	**h**	**p**	**K/Y**	**tau**	**k**	**A (1)**	**sR (1)**	**y (1)**	**SRR (1)**	**y (D)**	**A (D)**	**sR (2)**	**Phi (2)**	**SRR (2)**	**z**	**Imp. sR (z)**	**SRR (z)**	**sR (D)**
Argentina	2.1	1.2	1.5	11%	0.7	94%	3.0%	66%	21%	44%	63%	1.2%	61%	37%	0.5	2.4%	19%	0.4%
Bolivia	1.6	1.8	0.8	28%	0.4	57%	1.9%	22%	23%	12%	30%	0.7%	18%	30%	0.7	1.1%	21%	0.4%
Brazil	1.5	1.3	1.7	-7%	0.5	90%	3.5%	47%	17%	33%	64%	1.7%	41%	27%	0.6	2.9%	16%	0.9%
Chile	1.9	1.1	1.1	37%	0.5	69%	1.8%	38%	27%	39%	72%	2.0%	-24%	26%	1.1	1.9%	27%	0.6%
Colombia	1.5	1.6	0.9	23%	0.4	63%	2.1%	26%	22%	22%	53%	1.5%	-4%	25%	0.8	1.9%	21%	0.3%
Ecuador	1.7	1.1	1.6	12%	0.6	87%	2.9%	51%	20%	23%	39%	0.7%	91%	41%	0.4	1.6%	18%	0.1%
Mexico	1.8	1.4	1.7	-19%	0.7	101%	4.0%	67%	16%	37%	57%	1.1%	125%	38%	0.4	3.0%	14%	0.3%
Panama	2.0	1.2	1.5	14%	0.7	92%	2.9%	63%	21%	27%	39%	0.6%	118%	47%	0.4	1.6%	18%	0.4%
Peru	1.9	1.1	1.6	10%	0.7	93%	3.0%	61%	20%	18%	28%	0.4%	155%	51%	0.3	1.3%	17%	0.1%
El Salvador	1.5	2.0	0.7	36%	0.3	38%	1.2%	13%	24%	24%	72%	3.3%	-53%	16%	1.7	1.9%	26%	0.3%
Uruguay	1.9	1.0	1.1	44%	0.5	61%	1.5%	33%	29%	35%	65%	1.7%	-25%	28%	1.1	1.6%	30%	0.3%
Venezuela	1.8	1.3	1.5	4%	0.6	91%	3.2%	55%	19%	36%	61%	1.3%	53%	32%	0.5	2.6%	17%	0.5%
USA	2.7	0.9	1.7	25%	1.0	100%	2.5%	100%	26%	100%	100%	2.5%	-20%	26%	1.0	2.5%	26%	2.5%

(1) These are calculations assuming that all countries have the same R&D subsidy as the U.S.

(2) These are calculations using the data and the model to obtain the implied R&D investment rate, the implied R&D tax and the associated social rate of return to R&D.

(z) These are calculations where all countries have the same R&D subsidy as the U.S. but have distortions that yield their measured income and TFP levels.

(D) These are calculations based directly on the data.

Source: Klenow and Rodríguez-Clare (2004) and own calculations

Table 2: Exploring limitations of international databases and common parameters, the case of Chile

	1	2	3	3	4	5	6	7	8	9
	K/Y	τ	*z*	*k*	Rel. *k*	Data rel. Y/L	Data rel. a	Implied s_R	ϕ	SRR
Chile (1)	1.15	37%	1	1.98	0.55	39%	72%	2%	-24%	26%
Chile (2)	1.21	34%	1	2.04	0.56	37%	66%	1.7%	-9%	28%
Chile (3)	1.21	34%	1	2.62	0.72	37%	51%	0.8%	50%	44%
Chile (4)	1.21	34%	0.73	1.93	0.53	37%	70%	1.9%	-20%	25%

Source: Klenow and Rodríguez-Clare (2004) and authors calculations

Table 3: R&D investment rates by sector and standard deviation

Sector	Median R&D investment rate		Standard Deviation	
	1985	2000	1985	2000
Manufacturing, Utilities, Construction and Services	0.014	0.013	0.005	0.007
TOTAL MANUFACTURING	0.060	0.067	0.025	0.035
Food products, beverages and tobacco	0.012	0.013	0.007	0.007
Food products and beverages	0.005	0.012	0.002	0.008
Tobacco products	0.004	0.004	0.004	0.000
Textiles, textile products, leather and footwear	0.007	0.011	0.005	0.010
Textiles	0.009	0.016	0.005	0.012
Wearing apparel, dressing and dyeing of fur	0.001	0.010	0.000	0.022
Leather, leather products and footwear	0.003	0.004	0.003	0.022
Wood, paper, printing, publishing	0.006	0.007	0.005	0.006
Wood and products of wood and cork	0.003	0.005	0.006	0.011
Pulp, paper, paper products, printing and publishing	0.006	0.007	0.006	0.007
Paper and paper products	0.007	0.008	0.013	0.012
Publishing, printing and reproduction of recorded media	0.001	0.002	0.001	0.005
Chemical, rubber, plastics and fuel products	0.101	0.103	0.033	0.055
Coke, refined petroleum products and nuclear fuel	0.057	0.027	0.042	0.023
Chemicals and chemical products	0.130	0.147	0.045	0.074
Chemicals excluding phamaceuticals	0.098	0.067	0.038	0.039
Pharmaceuticals	0.248	0.251	0.103	0.158
Rubber and plastics products	0.023	0.028	0.044	0.060
Other nonmetallic mineral products	0.016	0.015	0.015	0.014
Basic metals and fabricated metal products	0.015	0.016	0.009	0.010
Basic metals	0.026	0.029	0.012	0.016
Iron and steel	0.024	0.022	0.012	0.020
Nonferrous metals	0.047	0.028	0.040	0.023
Fabricated metal products, except machinery and equipment	0.011	0.009	0.006	0.011
Machinery and equipment, instruments and transport equipment	0.119	0.145	0.048	0.062
Machinery and equipment, n.e.c.	0.043	0.067	0.030	0.028
Electrical and optical equipment	0.178	0.242	0.066	0.153
Office, accounting and computing machinery	0.243	0.274	0.089	0.783
Electrical machinery and apparatus, nec	0.091	0.080	0.239	0.053
Radio, television and communication equipment	0.231	0.186	0.094	0.438
Medical, precision and optical instruments, watches and clocks	0.119	0.154	0.083	0.101
Transport vehicles	0.103	0.085	0.094	0.067
Motor vehicles, trailers and semitrailers	0.104	0.101	0.068	0.070
Other transport equipment	0.160	0.124	0.177	0.072
Building and repairing of ships and boats	0.022	0.025	0.012	0.027
Aircraft and spacecraft	0.289	0.212	0.287	0.079
Railroad equipment and transport equipment n.e.c.	0.042	0.094	0.049	0.076
Furniture; manufacturing n.e.c.	0.005	0.025	0.000	0.007
ELECTRICITY, GAS AND WATER SUPPLY	0.006	0.006	0.007	0.005
CONSTRUCTION	0.001	0.002	0.002	0.002
TOTAL SERVICES	0.002	0.003	0.001	0.002

Simple Correlation 0.9539
Spearman Correlation test. Prob > |t| = 0.0000

Source: OECD Structural Analysis Data Base

Table 4: European R&D investment rates with Chile's economic structure (1995-1990 average)

Country	Estimated RDI using Chilean shares	Observed	Estimated/ Observed
Australia	0.007	0.008	0.886
Belgium	0.007	0.014	0.471
Canada	0.007	0.011	0.645
Czech Republic	0.005	0.008	0.550
Germany	0.004	0.017	0.259
Denmark	0.011	0.015	0.750
Spain	0.002	0.005	0.509
Finland	0.008	0.021	0.365
France	0.007	0.015	0.433
United Kingdom	0.010	0.014	0.724
Italy	0.005	0.006	0.846
Japan	0.010	0.020	0.531
Korea	0.006	0.019	0.329
Netherlands	0.006	0.012	0.507
Norway	0.011	0.012	0.929
Poland	0.002	0.003	0.486
Sweden	0.014	0.030	0.475
United States	0.011	0.019	0.567

Note: Applies Chile's sectoral shares in value added to OECD Country's R&D investment rates (RDI).
Source: UNCTAD, Central Bank of Chile

Table 5: Sectors responsible for difference in aggregate R&D investment in Chile vs. OECD

sector	Shares in Chile (a)	Mean Shares in OECD (b)	Mean RDI in OECD (c)	Mean Shares- Chile's Shares (b-a)	c*(b-a)	Share of difference
Food products and beverages	0.059	0.028	0.009	-0.031	-0.029	-0.06
Tobacco products	0.008	0.002	0.010	-0.006	-0.006	-0.01
Textiles	0.007	0.007	0.013	0.000	-0.001	0.00
Wearing apparel, dressing and dying of fur	0.006	0.005	0.004	-0.001	0.000	0.00
Leather, leather products and footwear	0.005	0.002	0.006	-0.003	-0.002	0.00
Pulp, paper and paper products	0.013	0.008	0.028	-0.005	-0.015	-0.03
Printing and publishing	0.012	0.012	0.002	0.000	0.000	0.00
Wood and products of wood and cork	0.012	0.006	0.004	-0.006	-0.003	-0.01
Chemicals and chemical products	0.019	0.020	0.109	0.001	0.007	0.01
Coke, refined petroleum products and nuclear fuel	0.017	0.006	0.029	-0.010	-0.029	-0.06
Rubber and plastics products	0.007	0.008	0.034	0.002	0.006	0.01
Iron and steel	0.005	0.007	0.022	0.003	0.006	0.01
Nonferrous metals	0.003	0.003	0.025	0.000	0.000	0.00
Other non-metallic mineral products	0.012	0.010	0.015	-0.002	-0.002	0.00
Fabricated metal products, except machinery and equipment	0.013	0.015	0.011	0.002	0.003	0.01
Machinery and equipment, n.e.c.	0.003	0.018	0.052	0.015	0.077	0.16
Electrical machinery and apparatus, n.e.c.	0.002	0.024	0.153	0.022	0.341	0.71
Transport Equipment	0.006	0.018	0.099	0.012	0.118	0.25
Furniture; manufacturing n.e.c.	0.006	0.008	0.014	0.002	0.003	0.01
Recycling	0.000	0.001	0.016	0.001	0.001	0.00
Construction	0.114	0.063	0.002	-0.052	-0.011	-0.02
Utilities	0.035	0.028	0.006	-0.007	-0.004	-0.01
Services	0.636	0.702	0.003	0.066	0.022	0.05
Total	1.000	1.003		0.003	0.481	1.000

Notes: Sectors selection is based on the highest possible level of desegregation for Chile. n.e.c.: not elsewhere classified
Source: UNCTAD, Central Bank of Chile

Figure 1: TFP and capital-labor ratios

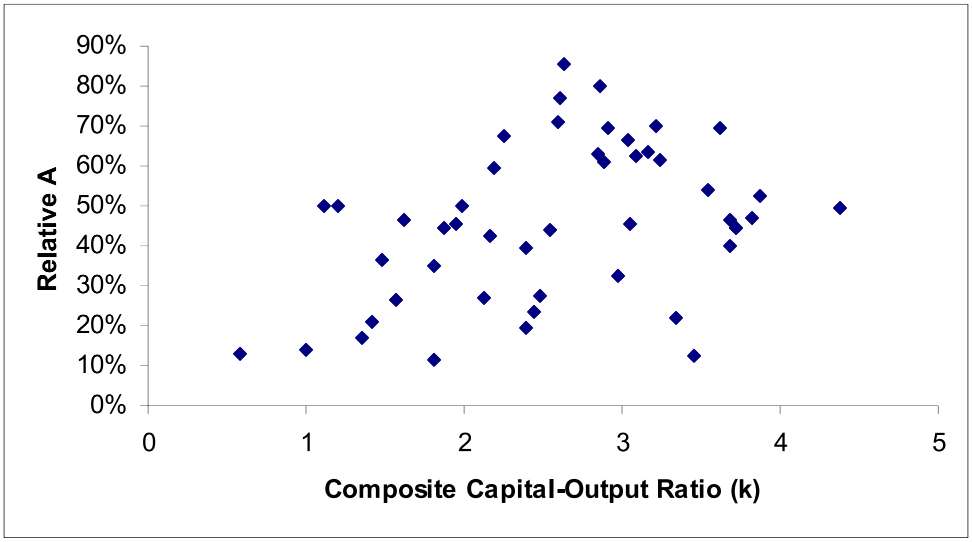

Figure 2: R&D investment and labor productivity

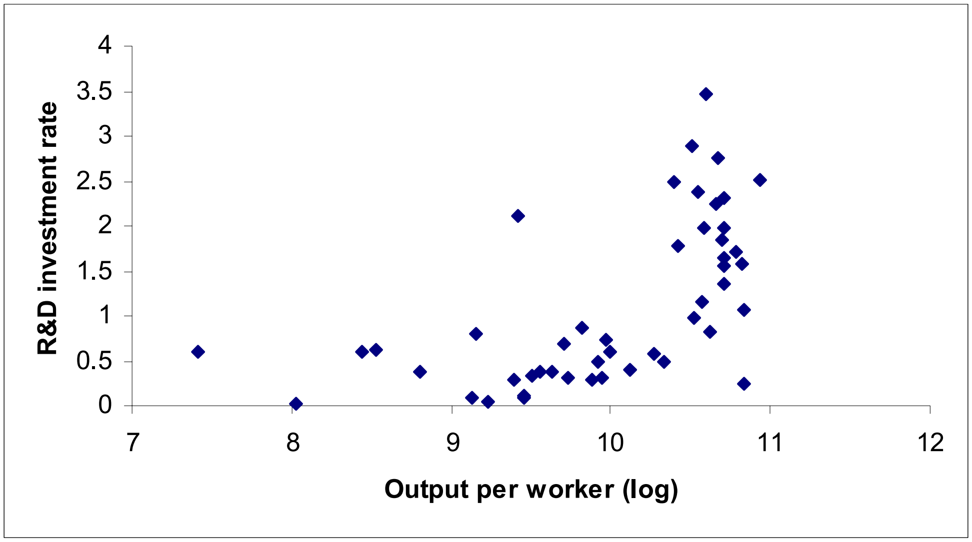

Figure 3

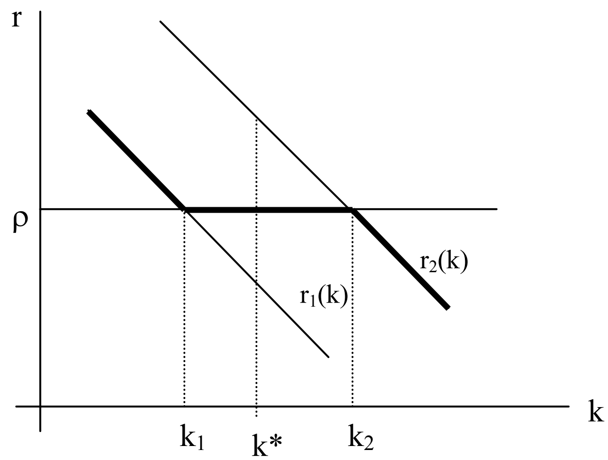

Figure 4: Differences in aggregate R&D investment rates (RDI) from OECD mean

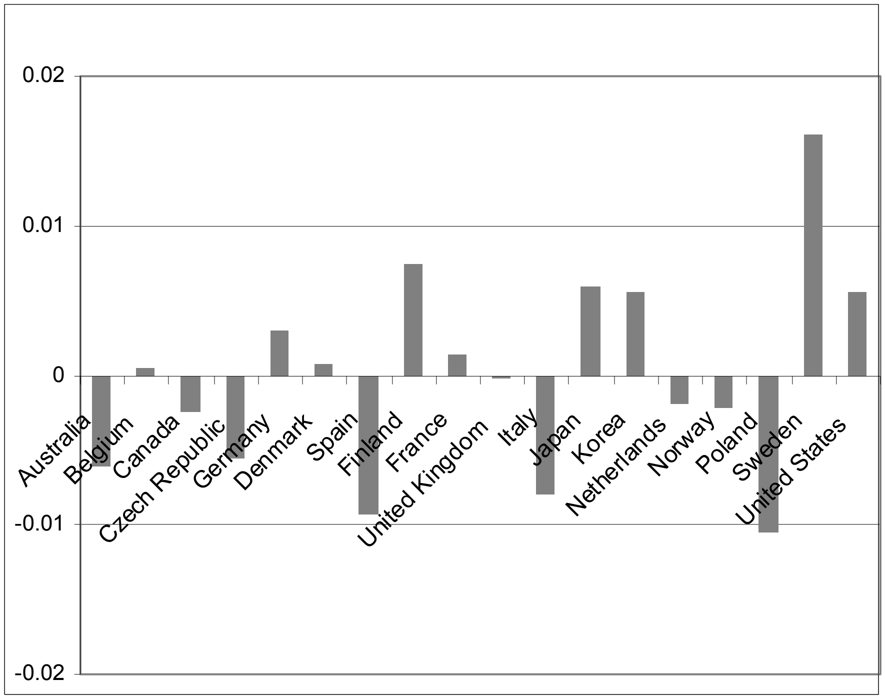

Figure 5: Contribution of economic structure vs sectoral RDI to deviations from OECD mean aggregate RDI