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Innovation Shortfalls

by

William Maloney*
Andrés Rodríguez-Clare**

*World Bank
**Inter-American Development Bank

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Abstract

There is a common perception that low productivity or low growth is due to what can be called an "innovation shortfall," usually identified as a low rate of investment in research and development (R&D) compared with some high-innovation countries. The usual reaction to this perceived problem is to call for increases in R&D investment rates, usually specifying a target that can be as high as 3 percent of GDP. The problem with this analysis is that it fails to see that a low R&D investment rate may be appropriate given the economy's pattern of specialization, or may be just one manifestation of more general problems that impede accumulation of all kinds of capital. When does a country suffer from an innovation shortfall above and beyond the ones that should be expected given its specialization and accumulation patterns? This is the question tackled in this paper. First, it shows a simple way to estimate the R&D gap that can be explained by a country's specialization pattern, and illustrates this with the case of Chile. The analysis finds that although Chile's specialization in natural-resource-intensive sectors explains part of its R&D gap, a significant shortfall remains. Second, it shows how a calibrated model can be used to determine the R&D gap that should be expected given a country's investment in physical and human capital. If the actual R&D gap is above this expected gap, the country suffers from a true innovation shortfall.

1. Introduction

The common perception is that low productivity or low growth in both developed and developing countries is due to a lack of innovation. Exhibit number one in favor of this argument is a relatively low research and development (R&D) investment rate as a share of gross domestic product (GDP), a common proxy for innovative activity. Some recent publications, for example, have noted with concern that Latin American countries invest an average of roughly 0.4 percent of GDP in R&D, whereas most OECD countries' R&D investment rates hover around 2 percent of GDP.[1]

The reaction to this perceived problem is to recommend increasing R&D spending up to some target rate based on the R&D investment rates of high-innovation countries. Thus, in pursuit of turning the European Union into the most competitive knowledge-based economy in the world, the March 2002 meeting of the European Council in Barcelona announced the goal of increasing average investment in R&D from 1.9 to 3 percent by 2010. The objective is to close the gap with the United States (2.7 percent) and Japan (3.0 percent).[2] In another example, President Ricardo Lagos of Chile recently stated that his country should reach an R&D investment rate of 1.5 percent by 2010.[3]

The problem with these benchmarking exercises and targets is the failure to recognize that R&D investment is just one more activity whose level is determined by the economy's pattern of specialization as well as by overall economic incentives and distortions. Should the natural resource-abundant economies of South America invest as much in R&D as the manufacturing-oriented countries of East Asia do? Are innovation policies crucial for countries whose low R&D investment rates may just be one more manifestation of general problems that impede accumulation of all kinds of capital? What is the level at which a country suffers from an innovation shortfall above and beyond the ones that should be expected given the country's specialization and accumulation patterns? These are the questions this paper tackles. Because of Chile's commitment to

[1] See OECD (2004), World Bank Institute (2005), and De Ferranti et al. (2003).
[2] See OECD (2004).
[3] Ricardo Lagos, Discourse on the State of the Nation, May 21, 2005 (see http://www.gobiernodechile.cl/21 mayo2004/indice_discursos.asp).

the innovation agenda, and its previous far-reaching micro-reforms, it serves as an illustration of the proposed analysis. Thus, the paper provides a general exploration of ways to identify innovation shortfalls and an analysis of whether Chile suffers from one.

The next section explores the relationship between R&D investment rates and specialization patterns. Based on data at the OECD level, R&D investment rates vary tremendously across sectors, from 0.2 percent of value added in publishing, printing, and reproduction of recorded media and construction; to 25 percent in pharmaceuticals; and 27 percent in office, accounting, and computing machinery. Clearly, if for exogenous reasons a country is specialized in sectors characterized by low innovation, then it would not be surprising to find that it spends relatively little on R&D. Ideally, the analysis would directly compare R&D investment rates in the same sector across countries; unfortunately, such data are not available for developing countries. Thus, we perform an indirect analysis, asking how much R&D investment rates would fall in OECD countries if they had the economic structure of a resource rich Latin America country, using Chile as an example. The results suggest that compositional matters are relevant but do not explain a large part of the country's innovation shortfall.

The third section turns to the question of whether low R&D investment rates should be seen as innovation shortfalls caused by environments that adversely affect innovation, or as part of a broader problem of low accumulation in all types of capital. Put differently, the question is whether a country's low R&D investment results from problems common to accumulation overall or the activity of innovation itself is somehow especially impeded. The appropriate policy depends critically on the answer to this question.

For example, Chile had an R&D investment rate of 0.4 percent of GDP in 1995, which was well below the comparable number for the United States (2.5 percent in 1995). It is tempting to conclude that Chile has an innovation shortfall; however, it also has low investment rates in human and physical capital, as reflected in a composite capital-output ratio of 50 percent of the U.S. level.[4] Perhaps whatever leads Chile to have low

[4] The composite capita-output ratio includes both human and physical capital, and is given by $k \equiv h(K/Y)^{\alpha/(1-\alpha)}$, where h is human capital per worker (measured as $h = e^{\gamma s}$, where γ is the Mincer

investment rates in human and physical capital may also explain its low R&D investment rate. Figure 1 extends this analysis to 48 countries for which the required data are available for 1995. The figure shows a positive relationship between R&D investment as a share of GDP and the composite capital-output ratio. Again, the conclusion is that—at least for some countries—low R&D investment rates could be just part of a more general accumulation problem.

The challenge that emerges, then, is to find a way to identify true innovation shortfalls and separate them from cases of low overall accumulation (or accumulation problems).[5] For this purpose, we propose the use of a model developed and calibrated by Klenow and Rodríguez-Clare (2005) 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 explore the model's implications for Latin American countries and find some countries that seem to suffer from true innovation shortfalls. However, the results from this analysis are extremely preliminary because the exercise suffers both from large measurement error intrinsic to the use of international data sets, such as those of Barro and Lee (2000) and the Penn World Tables 6.1, as well as model misspecification for some countries. To explore these issues, the analysis considers the case of Chile and shows that some particular adjustments to the model are necessary for a more appropriate analysis. After such adjustments, the conclusion that emerges is that Chile does indeed suffer from a true innovation shortfall: its R&D investment rate is significantly below what would be expected given its stocks of human and physical capital. Still, the goal here is not so much to reach a solid conclusion for any particular country, but to illustrate how this kind of analysis might be undertaken. Even for the case of Chile, a more careful analysis is called for.

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coefficient and s is the average years of schooling of the adult population), K is the stock of capital, Y is total output, and α is the share of capital in output (see below for a formal derivation).

[5] In part, this paper is inspired by the recent contribution by Hausmann, Rodrik, and Velasco (2004), in which the authors 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 the approach here is that whereas Hausmann, Rodrik, and Velasco argue for looking at shadow prices, this paper instead looks at quantities but uses theory to infer the corresponding shadow prices.

The fourth section briefly discusses possible explanations presented in the literature for true innovation shortfalls, again focusing on the case of Chile. The paper ends by calling for more research both for improving the methodology to identify innovation shortfalls, and for finding the most important determinants of such shortfalls in specific countries.

2. R&D and the Pattern of Specialization

There is enormous variation in R&D investment rates across sectors, reflecting the fact that, just as with physical and human capital, some sectors are more intensive in knowledge capital relative to others. This has important implications for comparisons of R&D investment rates across countries. In a multi-sector economy with international trade, countries specialize in sectors with differing possibilities for technological change, so that significant gaps in R&D investment rates are consistent with factor price equalization and hence similar wage levels (see Grossman and Helpman, 1991). Although income levels would be higher in an 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. The next section discusses this point by briefly reviewing the relevant theory. The following subsection looks at the R&D data at the sector level to gauge the extent to which differences in specialization patterns may explain a significant part of the R&D insufficiency in developing countries such as Chile.

R&D Rates in a Multi-Sector Economy: Implications from Trade Theory

Although the paper focuses on R&D and knowledge capital, this section presents the discussion in the more familiar setting of investment and physical capital based on the Hecksher-Ohlin (HO) model with capital accumulation. Later the analysis includes 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 and serving as the numeraire. Assume that capital is produced with a technology that is identical to the one that produces 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 (ROW). International prices are determined in the ROW. From the Stolper-Samuelson Theorem, under certain regularity conditions there is a unique and positive relationship between the rate of return to capital and the relative price of good 2. If the instantaneous intertemporal discount rate is ρ, then the long-run equilibrium in the ROW is such that the rate of return to capital is ρ, which pins down the relative price of good 2.

Figure 2 illustrates the equilibrium analysis for the small open economy. The horizontal axis measures k, the capital-labor ratio, and the vertical axis measures r, the rate of return to capital. The 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 $r_i(k) = \rho$. According to standard HO analysis, if k is 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 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 bold line in Figure 1 gives the equilibrium rate of return as a function of the capital-labor ratio.

When there is endogenous capital accumulation in the small open economy, if the rate of discount is the same as in the ROW, 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 ROW, then it will have a capital-labor ratio lower than k_1, it will specialize 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 ROW. Thus, the first result is that comparative advantage in a long-run HO model is determined by the policies and preferences that affect capital accumulation. Translated to R&D terminology, countries with more favorable policies toward innovation would specialize in R&D-intensive sectors, have higher R&D investment rates in each sector and for the whole economy, and attain higher income levels.

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, 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 the small economy has a Ricardian productivity that is lower in sector 2 relative to the ROW. The analysis for the small economy is exactly as above, but it is as if the international price of good 2 is lower. A lower international price for good 2 implies that the curve $r_2(k)$ is shifted downward relative to the original curve, with points k_1 and k_2 moved to the right, so that the new equilibrium-returns curve as a function of k has the same shape as above, but moved southeast. This implies that if the small economy has the same discount rate as the ROW, it will specialize in good 1 and use the same capital-labor ratio in the production of this good as the ROW.

The relevance of this finding for understanding the role of specialization patterns in explaining R&D gaps across countries is the following: if a country's lower R&D investment rate is entirely caused by its specialization in low-R&D-intensive sectors, then the whole R&D gap should be explained by the country's sector structure, with the same R&D investment rates across each sector. In other words, if an economy's R&D investment rate is the weighted average of the sector R&D rates with weights given by the shares of each sector in total output, then a Ricardian story would lead to differences in R&D rates entirely driven by differences in the weights but not in the sector R&D rates. The analysis will check whether this is indeed the case.

Summing up, 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. In the first two cases, both sector specific R&D gaps and sector composition differences explain differences in R&D investment rates across countries. In the third case (that is, Ricardian comparative advantage), sector composition would be solely responsible for international differences in R&D spending. Note also that 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 does not 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 higher total factor productivity (TFP) arising from specialization in the sector with comparative advantage.

What does this mean for the case of a developing country? Translating again to R&D terminology, if the developing country has a Ricardian comparative advantage in R&D-intensive sectors with sector specific and local spillovers, then it could make sense to think of a policy to induce a reallocation of resources toward the more R&D-intensive sectors. This would lead to an increasing 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 (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 does not 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 United States when it was feared that it was losing its edge in semiconductors can be interpreted in this way. Commentators such as Laura Tyson argued that semiconductors generate strong inter-industry externalities, and that therefore it is important to have a domestic semiconductor industry even if this runs counter to comparative advantage (Borrus, Tyson, and Zysman 1986).

For this to be a valid argument, however, knowledge spillovers associated with R&D would have to 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 because any market failures would be international in scope, and hence national economy policy is clearly not the correct type of intervention. There is some controversy on this matter. For instance, Irwin and Klenow (1994) find that learning-by-doing spillovers in the semiconductor industry are as strong internationally as domestically, and the more general evidence seems to show 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, policies that push resources toward high-R&D sectors should not be discarded. 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 the latter approach is not advisable, then perhaps a sector approach is relevant. As with any policy option, however, there are significant costs and risks that would have to be carefully considered.

Before going any further with the policy discussion, 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 the shortfalls in R&D in developing countries (and in Chile in particular).

A Look at Sector-Level R&D Data

This section first examines how R&D investment varies across sectors for the OECD since developing country data do not yet permit this kind of exercise. Table 1 reveals several important stylized facts. First, there is a wide range of average R&D investment rates by sector, from around 0.1 percent in services, apparel, or publishing to almost 30 percent 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 percent, while Sweden tops the list at close to 12 percent. Looking at just the pharmaceuticals sector, Spain invests less than 10 percent of value added while Sweden invests more than 40 percent. Third, overall, individual sector investment rates have tended to rise, suggesting an increasing intensity in the use of knowledge in the production of these products. Fourth, sector composition 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, which make up more than 4 percentage points of total nonagricultural value added in many OECD countries.[6] Hence, as a first pass, increases in aggregate R&D investment rates occur both from increasing R&D investment in existing sectors and from shifting into more intensive sectors.

A more careful decomposition of differences in aggregate R&D investment (RDI) rates within the OECD suggests a combination of both elements with wide variations across countries (see Figures 3 and 4). The RDIs in the United States and France are higher than the mean largely due to higher investment rates within the mean set of sectors. Finland and Korea's high RDIs and Canada, Australia, Netherlands, and Norway's lower RDIs are due largely to compositional effects—electronics in the former and perhaps natural resources in the latter. In the newly emerging Eastern European countries and Poland, Spain, and Czech Republic, the deficit is due almost entirely to low investment rates within sectors. In the manufacturing sector (not shown), the story is mixed. Again, the deficits of the younger countries are due largely to low within-sector

[6] This trend represents a continuation of that identified by Bernard and Jones (1996) from 1970 to 1990.

investment rates. In 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, such as Finland, Belgium, Canada, and the United States, are driven more prominently by sector composition.

To get a feel for what is happening in Chile, which lacks comparable rates of R&D investment at the sector level, the analysis takes an indirect route. The first column of Table 2 applies Chile's industrial structure to the sector investment rates in each country in the OECD. Column 3 relates this simulated value to the actual value. It is clear that structure is not everything. Norway's predicted level is within 10 percent of its actual level, suggesting that the fact that its RDI is double Chile's is significantly due to low investment rates in existing sectors. However, it is also clear that structure matters. On average, simulated OECD aggregate investment rates are just under 60 percent of those observed; Finland and Germany, are roughly 30 percent of their actual.

Table 3 looks at which sectors are most responsible for these large disparities by applying the average OECD sector investment rates to the difference between Chile's and the aggregate OECD's sector participation rates. Virtually the entire difference can be accounted for by Chile's low participation in the electronics and transport sectors, both of which show high average investment rates. The fact that Chile did not add Nokia to its forestry industry the way Finland did explains the vast difference in the two countries' simulated rates.

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. There is also a significant gap that comes from lower R&D investment rates at the sector level. The next section explores whether the lower R&D investment rates can be seen as a consequence of a specific innovation shortfall or of a broader problem of low accumulation of all kinds of capital.

3. 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 or 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 (2005) formulate a model in which TFP is the result of accumulation decisions. The authors used the model to explore the relevance and magnitude of international spillovers. They also investigate 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. The authors are interested in whether the analysis should postulate significant differences across countries in the treatment of innovation and technology adoption. They conclude that the latter element is important: to explain differences in labor productivity across countries, it is necessary to assume that there are significant cross-country differences in policies or institutions that affect the cost of technology adoption.

This section applies the framework of Klenow and Rodríguez-Clare to understand the reasons behind a developing country'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, this framework can be used to conduct a sort of R&D diagnostics to determine whether a country suffers from low R&D beyond what would be expected given its low investment in other types of capital. The case of Chile provides an illustration for the methodology and for discussing its advantages and disadvantages, as well as the way in which it is sensitive to different assumptions.

As customary, the model is based on 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. Following the Mincer specification, $h = e^{\gamma s}$, where s is years of schooling and is 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 A evolves. A complete description is beyond the scope of this paper, and the reader is referred to Klenow and Rodríguez-Clare (2005). This section provides 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 is denoted by $a = A / A^*$ —is determined by the country's efforts in technology adoption, which the model equalizes to a broad concept of R&D.[7] Thus, R&D in the 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 (that is, decreasing a). Given that R&D is more effective in increasing the country's A when the country has a lower relative level of A (that is, there are benefits of 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 actual labor productivity in R&D may differ due to differences in the amounts of physical and human capital. This basic productivity in R&D is denoted by λ. Thus,

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

In steady state we have:

$$a = 1 - \frac{g_A}{\lambda s_R k + \varepsilon} \tag{1}$$

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*, taking into account the indirect effect through induced capital accumulation, is a proportional increase in labor productivity (see Klenow and Rodríguez-Clare, 1997). There is an additional interaction between *A* and *k* since *k* positively affects a. 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 the model captures 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, the model allows 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. A parameter μ between zero and one captures 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.

[7] The reader may be concerned that this formulation implies that all TFP differences result from differences in technology adoption. This issue is explored quantitatively below.

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:

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

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. However, the analysis assumes 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:

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

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 thus has two components. The first is generated by taxes and the domestic R&D externality, as captured by the term Ω. The second 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 the assumption that new firms are born with a productivity equal to the average productivity of existing firms. Equation (3) determines a country's relative level of A given the country's measured levels of k and the two tax parameters τ and ϕ.

Calibration

For calibration, the model follows Klenow and Rodríguez-Clare (2005) so that $\alpha = 1/3$, $\gamma = 0.085$, $\delta = 0.08$, $r = 0.086$, $g = \varepsilon = 0.015$, $\lambda = 0.38$, 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 percent in the United States (that is, $\tau = 0.25$) and given data for the capital-output ratio and the relative price of investment in the United States, 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. The analysis assumes 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 to make the social rate of return to R&D in the United States three times the net private rate of return given an R&D subsidy of 20 percent ($\phi = -0.2$), and given an R&D investment rate in the United States of 2.5 percent.[8]

Initial Results

Table 4 presents the results of this exercise for several Latin American countries plus the United States. These results are only suggestive, since they are affected by the measurement error intrinsic to international databases, such as those of Barro and Lee (2000) and the Penn World Table 6.1. Although useful for generating broad international stylized facts, such databases are too noisy to be reliable in undertaking a country-specific analysis. Moreover, although the calibrated model is a good approximation for

[8] The assumption that the United States has a 20 percent subsidy on R&D may be questioned for two reasons. First, although this is the statutory rate (see Hall and Van Reenen 2000), the effective rate is much lower. Second, since this analysis considers a broad concept of R&D, the actual rate would be even lower. It turns out, however, that this is not too relevant for the main conclusions. Recalibrating the model with a U.S. R&D tax of 0 percent does not change the results in any significant way.

broad international patterns, it may be way off for particular countries. A serious analysis for a particular country necessarily entails obtaining better data and adjusting the model for country idiosyncrasies. The relevance of this approach is illustrated below for the case of Chile.

Columns 1-3 in Table 4 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 stock as described in Klenow and Rodríguez-Clare (2005). Column 4 calculates the income tax τ implied by equation (2) above assuming that all countries have the same interest rate as in the United States, calibrated above as r = 8.6 percent. Mexico has the lowest implied income tax and a physical capital-output ratio equal to that of the United States 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 United States.

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 have the same implicit tax on R&D as that in the United States ($\phi = -0.2$) and presents it 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 United States. 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 percent of that of the United States. Column 9 presents the social rate of return to R&D given $\phi = -0.2$.

The exercise continues in columns 10-13 of Table 4. 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.

By way of illustration, consider the case of Peru. According to the model, with $\phi = -0.2$, Peru's labor productivity would be 61 percent of the U.S. level, rather than the 18 percent recorded in the data. The reason for this is that given its (implied) low income tax (τ = 9 percent), a 20 percent R&D subsidy ($\phi = -0.2$) would lead Peru to an R&D investment rate of 3 percent, implying a steady-state technology index equal to 93 percent of the U.S. level. By contrast, Peru's actual R&D rate is only 0.4 percent, implying a level of *A* of only 28 percent of the U.S. level, and hence a labor productivity of only 18 percent of the U.S. level. For this to be an equilibrium phenomenon, the model requires an R&D tax of 154 percent, which implies a social rate of return to R&D of 51 percent. 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 percent R&D subsidy would be 38 percent, which is very similar to what is recorded in the data. In both the hypothetical and actual cases, the implied R&D investment rate is close to 2 percent. In line with this, the model's implied R&D tax for Chile is –24 percent. 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 problem rather than an innovation problem.

The case of El Salvador illustrates the other extreme. The country has low levels of *h* and *K*/*Y* (*k* = 0.3 relative to the United States). Thus, it would be expected that El Salvador would have a low relative *A* level (38 percent of the U.S. level); instead, it has a high relative *A* of 72 percent, implying a high R&D investment rate of 3.3 percent. Hence, it must have policies and institutions that favor R&D: the model implies that El Salvador enjoys an R&D subsidy of 53 percent, which is significantly higher than the one in the United States.

To summarize the previous results, the exercise suggests (again, remember these results are only suggestive; more elaborate country-specific analysis is required to explore individual countries) 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 latter group is one of accumulation. The first group of countries would benefit 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 percent 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 United States from 27 to 63 percent. Of course, this is not to say that this is a simple matter of innovation or tax policy. As discussed 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.[9]

The next subsection explains columns 15-17 of Table 4. 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 would normally be included as technology adoption.[10] Indeed, an advantage of the approach taken here is that the R&D measure is really a more general measure of innovative effort that is mapped to the TFP measures plugged into the model. In this way, the analysis avoids some issues complicating innovation diagnostics mentioned earlier. First, it includes technology adoption efforts that the formal measurement of R&D would likely omit. Second, it implicitly takes into account international differences in the effectiveness with which R&D is turned into useful

[9] Of course, this does not mean that these countries should not continue to improve their innovation policies. Even with a 20 percent 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 percent, just as in the United States, 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.

[10] One complication that arises here is that although the analysis uses a broad definition of R&D, it nevertheless uses the measured 2.5 percent R&D investment rate in the United States, as well as the official R&D subsidy in the calibration. There are two reasons why this is not likely to be a serious problem. First, the bias in the measurement of R&D must be much stronger in developing countries than in the United States because the main problem arises from the lack of measurement of technology adoption as opposed to innovative efforts. Second, the results do not change in a significant way if instead the model is calibrated to a broader concept of R&D in the United States.

knowledge, resulting—among other factors—from differences in the fraction of R&D that is financed by governments across countries.

The Role of Distortions

So far the model has assumed 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 lead firms to adopt suboptimal combinations of inputs. 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. This section undertakes a simple exercise to explore the distortions that would be necessary to account for observed productivity levels if countries had the same R&D policy and institutions as the United States ($\phi = -0.2$).

Here distortions are modeled 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 but human capital per worker is zh instead of h. This implies that now $k \equiv zh(K/Y)^{\alpha/(1-\alpha)}$. For any particular country, what is the value of the distortions variable z such that the data and the model are consistent when $\phi = -0.2$? The result is presented in column 15; 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 percent of the U.S. level.[11] 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 (highest distortions). The problem with this analysis is that it is difficult to know what are the specific distortions and through what channels they would generate such

[11] This effect of distortions takes into account their 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).

enormous static productivity losses. Moreover, it is difficult to compare this with the opposite scenario, in which barriers to technology adoption explain Peru's low productivity. The latter scenario would entail $\phi = 1.55$, which implies that firms face a cost of R&D in terms of output that is approximately three times higher than in the United States. The distortions analysis provides an explanation only for the overall productivity loss resulting from unknown distortions; the barriers to technology adoption analysis reveals the specific wedge needed to create the technological backwardness consistent with that productivity loss.

The model without distortions used for the analysis in 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, the analysis proceeds (mostly) under the assumption that distortions play no role in explaining low productivity levels.

The Case of Chile

One limitation of the analysis so far is that it relies on international databases and assumes common parameters. Although this is fine for establishing stylized facts, it is not satisfactory for analyzing a particular country. This section considers two specific issues. First, some countries may exhibit a high measured TFP as result of their large endowment of natural resources. Ideally, the analysis should 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 for considering a particular country. In that case, it is much better to use the particular Mincer coefficient for the country in question. The exploration of these two issues for the case of Chile starts by assuming that there are no distortions (that is, $z = 1$).

First consider the impact of natural resources. In the case of Chile, a significant part of 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 the country's large endowment of mineral resources. According to the Central Bank, mining contributed 6.7 percent of GDP in 1999, and according to the 1998 Household Survey, employment in this sector accounted for 1.6 percent 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, this implies that pure natural resources in mining account for approximately 5 percent of GDP.

Table 5 shows the results of this adjustment. The first row replicates the exercise above, while the second row shows the adjusted results. The implied capital-output ratio increases, implying a drop in the implicit income tax from 37 to 34 percent. In addition, 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, which is calculated now to be 9 percent. Thus, Chile's problem remains one of accumulation and not one of innovation.

The third row of Table 5 turns to the second adjustment mentioned above: 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 Braun (1999), the Mincer coefficient in Chile is close to 0.12. Using this coefficient, h increases from 1.85 to 2.39, which by itself would imply a decline in A of 23 percent. Together with the mining adjustment above, a falls to 51 percent of the U.S. level. The R&D investment rate and the R&D implicit tax that go with this (according to the model) are 0.8 percent and 50 percent, respectively.[12] 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. However, the finding has empirical precedent. The adjusted rate is the same as the one Bils and Klenow (2000) borrowed

[12] Interestingly, the 0.8 percent implied R&D investment rate is now close to the measured rate for Chile, which averaged 0.6 percent for 1990-2000 (see Lederman and Sáenz, 2002).

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 5 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 percent. The result is that distortions would have to be such as to reduce Chile's labor productivity by 27 percent. Although this analysis cannot say whether this number is reasonable, it seems that it would be difficult to argue that Chile is so much more inefficient than the United States as to generate such a large direct fall in TFP. Still, this clearly remains an open question for research.

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 four factors. First, the country's high income tax leads to a lower capital-output ratio that by itself would lead to a labor productivity level 16 percent lower than the U.S. level. Second, the lower average mean years of schooling of the adult population by itself would lead to 11 percent lower labor productivity than in the United States. Third, distortions would cause a decline in labor productivity of 27 percent. And fourth, unfavorable policies and institutions for innovation would lower R&D from 1.9 to 0.8 percent and reduce labor productivity by 27 percent.

4. Explaining Innovation Problems

The previous sections have explored the idea that some countries suffer from policies and institutions that adversely affect innovation and technology adoption, resulting in lower productivity relative to high-innovation countries. Application of the developed framework to Chile showed that, after some adjustments—and assuming the distortions are not unusually large—the country appears to suffer from this problem. What market, government, or other failures might make it somehow more difficult in Chile to accumulate the factors associated with a higher TFP relative to its accumulation of human and 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.

Labor Market Rigidities

The recent theoretical literature on explaining international TFP differences points to barriers to technology adoption, which usually means 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 consistent with studies showing that Chile's severance costs are substantially above those in the OECD (Heckman and Pagé, 2004), although they are substantially below those in much of the rest of Latin America. Recent empirical work on the impact of the rigidities is somewhat mixed. Caballero, Engel, and Micco (2004) find that job security hampers the creative destruction process and that moving from the 20th to 80th percentile in job security cuts 1 percent from annual productivity growth. For Chile, they calculate that raising flexibility to U.S. levels would lead to an initial gain between 2 and 4 percent and permanent gains in the structural rate of growth of 0.3 percent. On the other hand, working at the firm level in Argentina, Galiani (2005) somewhat surprisingly finds only a fragile relationship between the degree of rigidity in union contracts and firms' innovative behavior. Furthermore, Europe's labor legislation cannot be termed flexible. A fair reading of the limited evidence probably suggests continuing agnosticism on the true magnitude of these effects.

Credit Markets

According to the recent survey mentioned earlier, firms in Chile 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 Núñez (2005) suggest that own rates of return to R&D are high. In particular, they estimate rates of around 30 percent to R&D, whereas the (gross) returns to physical capital are 16 percent. The higher private rates of return to R&D may be due to its higher risk. They may also be associated with the fact that it more difficult to finance, both because of higher risk together with absence of venture capital, and because of the fact that R&D leads to the accumulation of assets that are more difficult to use as collateral.

Innovation surveys again suggest that the vast majority of financing of innovative activities is internal, potentially suggesting 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 venture capital firms have folded allegedly for lack of "deal flow," which might imply 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 venture capital operations failed to pay sufficient attention to the provision of complementary management and mentoring services that are generally part of venture capital packages.[13] Furthermore, legislation has tied the development of specific institutions to the intermediation of pension fund assets and hence burdened them with inappropriate regulation on risk taking (Arrau, 2002). However, it is worth highlighting that venture capital 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, the analysis could simply look at wages and their distribution according to levels of schooling and professions to determine 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

[13] Discussions with Eduardo Bitráan and Patricio Arrau, respectively.

some extent—supply creates its own demand, and demand depends on the supply of human resources. Very innovative firms are often spin-offs of university research. Managers in firms with a taste for innovation are likely to have an academic background. In Finland, the most important dimension of university-private sector linkages is reported to be masters students doing their theses in the firms. It may be that such exchanges help define the frontier of the field and possible areas for innovation investment. For example, it would be easy to imagine a country where entrepreneurs have little idea of the location of the frontier 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 will appear for the products of a scientific establishment. Multiple-equilibrium models consistent with this type of idea have been elaborated by Howitt and Mayer-Foulkes (2005).

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 developing countries, and Chile in particular, suffer from policies and institutions that do not perform this function. Although Fundación Chile and the national Development Corporation (Corporación de Fomento, 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 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 them. 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 between the private and university sectors.[14] Although most major universities have offices to promote linkages, only the Universidad de Concepción has incentives for faculty to collaborate with the private sector in promotion criteria.[15]

5. Conclusion

Countries have innovation shortfalls, but this paper has argued that their diagnosis requires more than simple unconditional comparisons of R&D or other related indicators. Standard issues of comparative advantage influence the optimal level of knowledge accumulation and generation. Furthermore, even if low levels of innovation are conditionally established, it is not immediately clear whether the problem pertains particularly to this factor, or whether there are barriers to accumulation more generally that need to be addressed. This paper offers approaches to both issues and illustrates their application for Chile, a country that is currently thinking seriously about improving its innovation policy. The results that emerge suggest that Chile does indeed suffer from a true innovation shortfall, and the analysis offers some tentative ideas on what may be causing it. Clearly, further refinements would be valuable for both technique and data.

[14] World Economic Forum (various issues). Only 12 percent of Chilean firms have signed agreements with universities, compared with 40 percent in Finland (de Ferranti et al., 2003).
[15] Mullin (2005).

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Table 1. 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	0.012	0.013	0.007	0.007
Food products and	0.005	0.012	0.002	0.008
Tobacco products	0.004	0.004	0.004	0.000
Textiles, textile products, leather and	0.007	0.011	0.005	0.010
Textiles	0.009	0.016	0.005	0.012
Wearing apparel, dressing and dyeing of	0.001	0.010	0.000	0.022
Leather, leather products and	0.003	0.004	0.003	0.022
Wood, paper, printing,	0.006	0.007	0.005	0.006
Wood and products of wood and	0.003	0.005	0.006	0.011
Pulp, paper, paper products, printing and	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	0.001	0.002	0.001	0.005
Chemical, rubber, plastics and fuel	0.101	0.103	0.033	0.055
Coke, refined petroleum products and nuclear	0.057	0.027	0.042	0.023
Chemicals and chemical	0.130	0.147	0.045	0.074
Chemicals excluding	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	0.016	0.015	0.015	0.014
Basic metals and fabricated metal	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	0.011	0.009	0.006	0.011
Machinery and equipment, instruments and transport	0.119	0.145	0.048	0.062
Machinery and equipment,	0.043	0.067	0.030	0.028
Electrical and optical	0.178	0.242	0.066	0.153
Office, accounting and computing	0.243	0.274	0.089	0.783
Electrical machinery and apparatus,	0.091	0.080	0.239	0.053
Radio, television and communication	0.231	0.186	0.094	0.438
Medical, precision and optical instruments, watches and	0.119	0.154	0.083	0.101
Transport vehicles	0.103	0.085	0.094	0.067
Motor vehicles, trailers and	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	0.022	0.025	0.012	0.027
Aircraft and spacecraft	0.289	0.212	0.287	0.079
Railroad equipment and transport equipment	0.042	0.094	0.049	0.076
Furniture; manufacturing	0.005	0.025	0.000	0.007
ELECTRICITY, GAS AND WATER	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| =

Source: OECD Structural Analysis Data Base.

Table 2. European R&D Investment Rates with Chile's Economic Structure, 1995-90 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 sector shares in value added to OECD country's R&D investment rates.
Source: UNCTAD; Central Bank of Chile.

Table 3. Sectors Responsible for the Difference in Aggregate R&D Investment in Chile Compared with the 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

Note: 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.

Table 4. 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%
United States	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 (2005); authors' calculations.

Table 5. Limitations of International Databases and Common Parameters in 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 (2005) and authors' calculations.

Figure 1. R&D Investment Rates versus Capital-Output Ratios

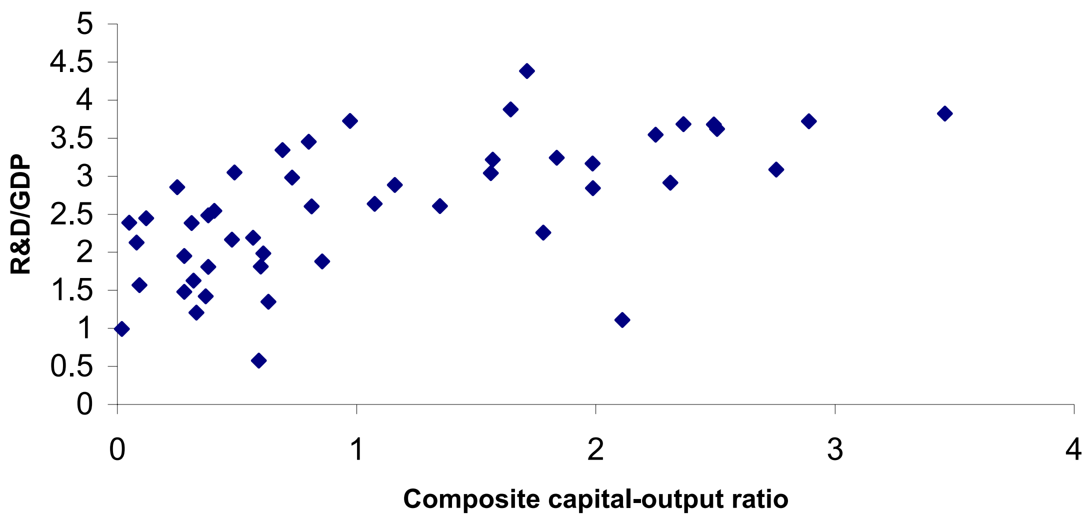

Figure 2. Equilibrium Analysis for a Small, Open Economy

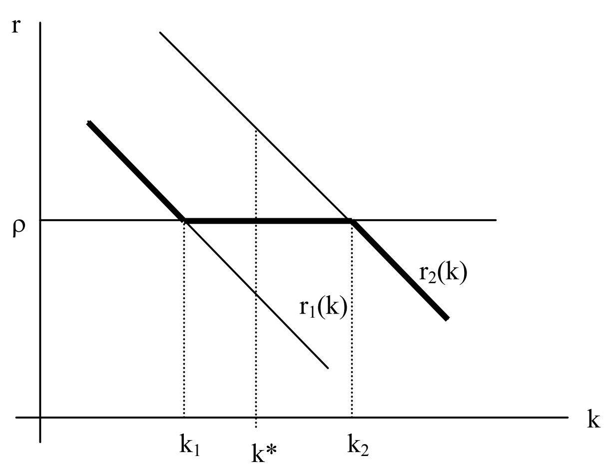

Figure 3. Differences in Aggregate R&D Investment Rates Compared with OECD Mean

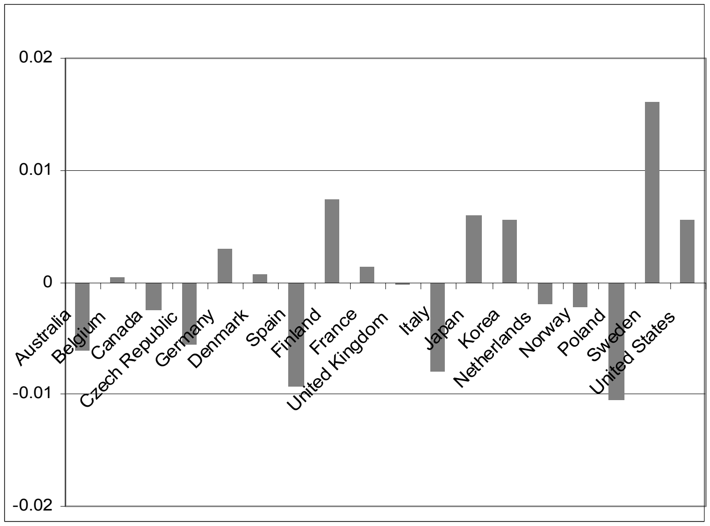

Figure 4. Investment in Research and Development: Contribution of Economic Structure Compared with Deviations from OECD Mean Aggregate Value