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DO POOR COUNTRIES REALLY NEED MORE IT? THE ROLE OF RELATIVE PRICES AND INDUSTRIAL COMPOSITION

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ABSTRACT

Within 70 countries at various levels of development, we document a positive correlation between income and capital that embodies Information and Communication Technology (ICT). This pattern cannot be fully attributed to cross-country differences in capital stocks. While this regularity is consistent with explanations based on technology adoption lags and ICT-labor substitutability, we find little empirical support for these hypotheses. Instead, we show that (a) relatively higher ICT prices and (b) specialization in less ICT intensive industries fully account for the relative scarcity of ICT in poor countries.

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JEL: O14, O33, O57, E22 Keywords: ICT adoption, industrial composition, ICT capital stocks

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1. Introduction

In 2013, the per-capita number of broadband internet subscriptions in the US was 0.3. In India, the corresponding number was 0.01. In high income countries, over 75% of households owned a computer; in low and middle income countries, the corresponding number was only 27.6%.¹ These disparities suggest that the proliferation of information and communication technologies (ICT) has been vastly different in rich and poor countries. At the same time, a substantial literature documents that ICT was one of the key drivers of growth in advanced economies (e.g., Colecchia and Schreyer, 2002; Basu, Fernald, Oulton and Srinivasan, 2003; Bloom, Sadun and Van Reenen, 2012). In light of this, the dramatic cross-country differences in ICT abundance across countries may seem alarming.

Motivated by these observations we address two important questions: first, is ICT capital truly scarce in low income countries relative to other capital? And second, if so, what can explain this? Notice that our emphasis on the ICT stock *relative to other capital* is important, since poor countries not only have fewer internet subscriptions and PCs but also fewer refrigerators and cars.

We begin our analysis by compiling a new dataset that allows us to measure ICT and non-ICT (henceforth NICT) capital stocks for a sample of 70 countries at various levels of economic development.² Using these data we document that, in low income countries, the value of ICT capital indeed represents a smaller share of the aggregate capital stock. In fact, the differences are even larger in real terms, as we document that ICT capital goods are relatively more expensive in low income countries. This suggests that the scarcity of ICT in developing countries is likely not explained simply by lower capital-labor ratios.

What else can explain the relationship between income per capita and the abundance of ICT capital? One potential mechanism relates to delayed technology adoption. Due to frictions in learning and adopting new technologies, low income countries may be slower to accumulate ICT capital (e.g., Comin and Hobijn, 2010; Gust and Marquez, 2004). A second explanation relates to

¹These numbers are based on the World Telecommunication/ICT Indicators database provided by the International Telecommunication Union (ITU). For more information on this datasource see Appendix A.

²To the best of our knowledge, our dataset is the most comprehensive account of ICT *stocks* around the world to this date. See Section 2.3 for a comparison with other international datasets containing information on ICT.

the relative prices of capital and labor. If labor is to some degree substitutable with ICT capital (e.g., Autor and Dorn, 2013; Karabarbounis and Neiman, 2014), then low-income countries will likely opt for lower ICT capital stocks, as labor is relatively cheaper in these countries.

While these mechanisms are plausible, we find evidence in support of a much simpler explanation based on cross-country differences in industrial composition. Heterogeneity in industrial composition may imply that production in developing countries is relatively less intensive in ICT capital. For example, if agriculture has a larger share in output in developing countries and agriculture is inherently less ICT-intensive than other industries, one would expect there to be relatively less ICT in developing countries. While the first two explanations would imply that, in a given industry, production in developing countries relies less on ICT, our findings suggest that, after controlling for industrial composition, the strong association between income per capita and relative ICT abundance breaks down.

To illustrate this point, we use a simple theoretical framework in which ICT and non-ICT capital intensities differ by industry. Since we are interested in gauging the degree to which industrial composition alone can explain differences in ICT abundance, we assume that sector specific ICT intensities are the same across countries and calibrate these based on data from the US. We then use sector-specific value added for a wide range of countries to predict the aggregate ICT capital share. The exercise suggests that after accounting for the portion of relative ICT abundance that is predicted by cross-country heterogeneity in industrial composition, there is no longer a systematic relationship between GDP per capita and the share of ICT out of total capital. This implies that differences in specialization can fully account for the strong correlation between income per capita and relative ICT abundance.

As an additional piece of evidence for this result, we further document that there is no systematic relationship between a proxy for ICT abundance and income per capita *within* industries. More precisely, while it is well documented that capital labor ratios within the same industry vary widely across countries (e.g., Davis and Weinstein, 2001), we do not find a systematic relationship between income per capita and ICT spending as a fraction of the capital stock.

In sum, our results suggest that the variation across countries in ICT abundance is predomi-

nantly between-industry variation rather than within-industry variation. This suggests that any frictions associated with the accumulation of ICT are reflected in changes in industrial composition, rather than in changes in the production structure within industries. This reasoning is consistent with a Heckscher-Ohlin model of trade specialization. Despite this potential source of endogeneity, we find similar results when using predicted values based on industrial composition in 1980, which is at the beginning of the ICT revolution and therefore less likely endogenous to ICT adoption. However, the extent to which industrial composition is endogenously determined by ICT adoption remains an open question, which is beyond the scope of this paper. While industrial composition may be, to some degree, endogenous to ICT accumulation, it is also likely that a number of other factors determine industrial composition, such as the level of development, comparative advantage, and path dependence.

The remainder of this paper is organized as follows: we begin with empirical evidence on the distribution of ICT capital around the world in Section 2, together with the details of the construction of our dataset. Section 3 presents several possible explanations for the observed correlation between ICT abundance and income per capita. In Section 4 we present a simple model that highlights the relationship between ICT abundance and industrial composition and we provide empirical evidence consistent with its predictions. Section 5 illustrates a benchmarking procedure implied by our analysis, which can be used to assess whether ICT is over- or underabundant in a given country. We offer some concluding remarks in Section 6.

2. Measuring ICT Capital Around the World

We begin our analysis by estimating the stock of ICT and NICT capital for 70 countries at various levels of development. To accomplish this, we use data on ICT spending from the World Information Technology and Services Alliance (WITSA) as well as the International Telecommunication Union (ITU).³ WITSA is currently the most widely used source for data on ICT spending on a global scale and is assembled using a combination of various surveys, vendor supply analysis

³These two datasources are described in detail in Appendix A. We keep the description of our measurement exercise brief in the text, however, Appendix A lays out our procedure in more detail.

and other statistics.⁴ Specifically, WITSA reports ICT spending for four categories: (1) computer hardware, (2) computer software, (3) computer services, and (4) communications. The sum of these four categories gives a fairly comprehensive picture of ICT *expenditure* around the world. However, as we are interested in constructing measures of the physical *stock* of ICT capital, it is important to notice that, conceptually, some of these WITSA spending measures represent investment spending but others consist primarily of rental fees. For example, while spending on internet subscriptions or telecommunication fees may comprise a substantial amount of ICT spending, it does not constitute investment: from a macro perspective, these are transfers between users of ICT capital and owners of ICT capital, more appropriately viewed as rental fees. From an aggregate perspective, an internet subscription does not require the sacrifice of resources today for the purpose of increasing aggregate production capacity tomorrow, which is the defining characteristic of investment.

More specifically, of the four WITSA spending categories, computer services is in fact the only category that consists primarily of true aggregate investment spending, taking the form of custom software development and equipment maintenance. This category also includes some services that may be more appropriately viewed as rental payments, such as web hosting, but these likely represent a small share of spending in this category.

The categories of computer hardware and computer software include the total value of purchases and leases. Ideally, one would like to count hardware and software investment as the purchase of new machinery or software. However, the WITSA measure includes secondary markets as well, as it takes into account the value of leases. Bluntly, if a computer is purchased and then leased, it is double counted. We therefore adopt an approach similar to Vu (2005) and assume that hardware investment is 0.57 times computer hardware spending, which is roughly the coefficient of proportionality in US data.⁵ The coefficient of proportionality for software is greater than one, suggesting that software spending is lower than software investment in the United States. This is probably due to the omission of computer services spending, which includes some forms

⁴For instance, both the Penn World Table and the Conference Board's Total Economy Database use WITSA as the main source for information on ICT spending.

⁵See the Appendix of Vu (2005) for year-by-year estimates of this factor of proportionality.

of software investment. Since we include computer services in our ICT investment measure, we assume that the remaining software investment is equal to WITSA software spending.

It is perhaps worth noting that the distinction between software leases and software investment is somewhat blurred. The software spending category consists of the total value of purchased or leased packaged software. While purchasing software is investment from the firm's perspective, from a macro perspective this is perhaps more appropriately viewed as a rental fee. The creation of new software is similar to investment in research and development (R&D). The returns to writing new software are the dividends from selling or leasing the rights to use that software. From a timing perspective, the value of the initial investment is the costs of programmers and associated capital costs for producing new software. The returns to the investment are the sales of software licenses, either permanent (purchases) or temporary (leases). From a macroeconomic perspective, software investment should be counted as the costs associated with developing new software (similar to R&D investment). However, given that this data is not available, we stick with the commonly adopted micro perspective and assume that software investment is software purchases and leases.⁶

The fourth WITSA category, communication technology (CT), is defined as the total value of voice and data communication services and equipment. Conceptually, communication services (such as internet subscriptions or payments for phone usage) represent rental fees for communication infrastructure, rather than investment. Since we are interested in a pure investment measure, we substitute this category with a direct measure of CT investment from ITU.

Taken together, our final measure of nominal (current USD) ICT investment is the sum of TC investment (ITU), computer services spending (WITSA), adjusted computer hardware spending (WITSA), and computer software spending (WITSA). Ideally, we would like to use these investment series to construct the number of internationally comparable ICT units within each country, and compare these across countries. However, to construct a chain weighted ICT index that is

⁶Note that the high depreciation rate of software implies that there is no big difference between permanent purchases and temporary leases. Generally, most attempts to construct capital stocks take this perspective. The BEA's computations for the NIPA tables are one example. See the official NIPA documentation for details: http://www.bea.gov/national/pdf/chapter6.pdf.

comparable across countries, we would need country and time specific prices for ICT goods. Unfortunately, we do not have access to such data for a representative sample of countries at all levels of development.⁷

We do, however, have access to two waves of item-level price data from the World Bank's International Comparison Program (ICP, 2005 and 2011), which allow us to construct countrylevel measures for the relative price of ICT and NICT capital goods in those two years. We then follow a two-step procedure for constructing a measure of physical ICT stocks that is comparable both across countries and across time: first, we estimate nominal ICT values within each country, under the assumption that the worldwide *trend* in ICT is uniform (i.e., we deflate using the US ICT deflator). Second, we use our ICP price data to re-normalize the reference period, such that cross-country differences in the relative price of ICT are properly reflected.

This procedure will produce accurate measures of physical ICT abundance around the world, as long as the world wide *trend* in ICT prices is approximately uniform. While we do not have the necessary price data to formally test this assumption, we will utilize our two waves of ICP data to provide suggestive evidence in favor of our approximation.

2.1. ICT and NICT Values in Constant USD

As a first step, we construct constant USD stocks using the perpetual inventory method (PIM) within each country. To do so, we start with deflating each nominal investment series described in the previous section with the ICT price deflator for the US, estimated by Eden and Gaggl (2015) based on the BEA's fixed asset accounts.⁸

We note at this point that a substantial body of literature has documented a precipitous decline

⁷While the construction of the PWT aggregate capital stock in part builds on such data (Feenstra, Inklaar and Timmer, 2015; Inklaar and Timmer, 2013), we were not able to obtain access to the detailed unlerving micro data.

⁸Note that we chose to use a single price index to deflate all four investment series, even though we could in principle estimate the disaggregated price indexes from the BEA's fixed asset accounts (e.g., Figure 1). We do so for two reasons: first, it allows us to aggregate the four categories simply by adding the four resulting constant dollar stocks within each category. With time varying investment-type specific price indexes aggregation would be less straight forward. Moreover, while Figure 1 shows that there were some differences in the trends of price indexes for different ICT categories, the general trend is relatively uniform. Second, and probably more importantly, it is not clear how representative the differential trends between detailed investment categories in the US are for other (especially poor) countries.





Notes: Panel A illustrates the price if ICT and NICT based on Eden and Gaggl (2015). Panel B disaggregates ICT into software, hardware, and R&D based on the same data and procedures as in Eden and Gaggl (2015).

in the relative price of ICT and commonly interprets this decline as reflective of technological progress that reduces the costs of computations and communication (e.g., Autor and Dorn, 2013, and references therein). Figure 1 illustrates these patterns for the US based on estimates by Eden and Gaggl (2015) using the BEA's detailed fixed asset accounts. The Figure clearly illustrates the dramatic fall in ICT prices relative to NICT prices over the past 30 years. Our construction of the constant USD ICT investment series assumes that this trend is shared by all countries in our sample—an assumption that is commonly applied in this context, and follows the procedure in the Penn World Table (PWT, Feenstra et al., 2015; Inklaar and Timmer, 2013), among others. While plausible, data limitations prevent direct assessment of this hypothesis. However, we will present some evidence based on our ICP price data suggesting that there is no strong relationship between the relative price of ICT and income per-capita in Section 2.2.

Following the methodology in the PWT starting with version 8.0 (Feenstra et al., 2015; Inklaar and Timmer, 2013), we use constant depreciation rates that differ for telecommunication (TC, 11.5% p.a.) and other information technology (IT, 31.5% p.a.). Accordingly, we apply the PIM separately for TC and IT, summing the respective estimates to construct our baseline measure of



Notes: The figures illustrate the relationship between measures of constnat 2005 USD ICT and NICT values per capita and log output per capita for a sample of 70 countries at all levels of development. Panel A illustrates this relationship for ICT per capita values; panel B for NICT values per capita; and panel C pots ICT per capita against NICT per capita. The reported confidence intervals are based on standard errors that are clustered on country. Column 1 shows this relationship in 1995 and column 2 in 2011.

country-level ICT stocks, measured in constant USD, for a balanced sample of 70 countries over the period 1993-2011. For further details see Appendix A.

Panel A of Figure 2 presents the resulting estimates of ICT capital per capita in constant USD, plotted against GDP per capita. Note that these estimates reflect the dollar values of ICT stocks in different countries, rather than PPP adjusted stocks: if the price of computers is higher in developing countries, 100 dollars-worth of ICT capital in developing countries translates into fewer computers than in advanced economies. Nonetheless, as we will show below, this turns out to be the measure of ICT stocks which will be relevant for most of our analysis. It is further worth noting that, under the assumption that the trend in ICT prices is uniform across countries (as we assumed in this construction), the resulting capital stocks are comparable within countries across time, and can be interpreted as some constant times the number of ICT units. Not surprisingly, panel A of Figure 2 illustrates an upward sloping relationship between income per-capita and the nominal value of ICT per capita, both at the beginning (1995) and the end (2011) of our sample.

To gauge the extent to which this pattern is driven by cross-country differences in capitallabor ratios we construct an analogous constant USD series for NICT. Specifically, we estimate NICT investment by subtracting nominal (current USD) ICT investment from aggregate nominal (current USD) investment measured in the PWT. Similar to the procedure for ICT, we deflate the resulting investment series using the BEA-based NICT price index from Eden and Gaggl (2015) and compute constant USD NICT capital stocks using the PIM, with a depreciation rate of 6% p.a., as estimated by Eden and Gaggl (2015) for the US. Again, see Appendix A for further details.

Panel B of Figure 2 plots the relationship between NICT stocks per capita and income percapita, while Panel C of Figure 2 plots estimated ICT capital stocks per capita against estimated NICT stocks per capita (both in constant USD). The figures illustrate that a large part of the relationship between ICT and income per-capita reflects the general reality that capital-abundance is increasing with income. However, lower ICT abundance in developing countries is not fully accounted for by this relationship, as the fitted regression lines in Panel C of Figure 2 suggest a slope of greater than unity. In fact, a regression using our full sample, spanning the years 1993-2011 and controlling for a complete set of time fixed effects, suggests a coefficient of 1.152 with an

	Year	Obs.	Mean.	Std. Dev.	Min.	Max.		
/	A. The va	lue of IC	T as a Fra	action of Tota	l Capital	Value (%)		
	1995	70	3.95	2.65	0.17	12.40		
	2011	70	3.88	1.56	1.60	8.92		
E	3. The va	lue of IC	T relative	to NICT (%)				
	1995	70	4.19	2.95	0.17	14.16		
	2011	70	4.07	1.73	1.63	9.80		
(C. PPP U	nits of IC	CT per Un	it of NICT (%	, only co	untries with I	CP data in	2011)
	1995	68	0.89	0.70	0.10	3.13		
	2011	68	5.43	2.86	1.46	14.96		
L	D. Log Re	al GDP	Per Perso	n				
	1995	70	-4.76	1.04	-8.41	-3.38		
	2011	70	-4.28	0.96	-6.42	-2.61		

Table 1: Summary Statistics

Notes: The table reports raw sample summary statistics for 70 countries (and 68 for the real ratios) in 1995 and 2011. Panels A and B are based on the current USD values constructed as described in the text. The real ratios are based on our computations described in Section 2.2, in which we construct a country-specific relative price of ICT based on detailed product level price data from the World Bank's International Comparison Program (ICP).

associated 95% confidence interval of [1.065, 1.24].9

Given the importance of capital labor ratios in explaining cross-country variation in ICT, we will focus the rest of our analyses on measures of *relative* ICT abundance. That is, ICT relative to NICT (or alternatively the aggregate capital stock). Panels A and B of Table 1 provide some descriptive statistics for these ratios based on our estimated ICT and NICT stocks for 1995 and 2011, which suggest a number of interesting conclusions. First, in most countries, ICT capital constitutes a small fraction of the aggregate value of the capital stock. In our sample of countries, the value of ICT capital out of total reproducible capital is on average around 3.88% in 2011 (see panel A of Table 1). Second, the summary statistics reported in panel A of Table 1 show that this range is relatively stable throughout our sample, with a mean of 3.95% in 1995, only marginally higher than in 2011. Panel B of Table 1 illustrates a similar picture for the value of ICT as a fraction of NICT.

⁹While we do not show the full regression results here, we note that the confidence interval is based on standard errors that are clustered on country.



Figure 3: ICT Abundance and Income Per Person

Notes: The figures plot measures of ICT abundance across countries in relation to log output per capita. Panel A illustrates ICT values as a fraciton of NICT capital values (see Section 2.1 for details); panel B shows units of ICT per unit of Non-ICT (ratio of quantity indexes; see Section 2.2 for details). Column 1 shows this relationship in 1995 and column 2 in 2011.

Most importantly for the purposes of our study, plotting this measure against real income per capita reveals that, in relatively poorer countries, the value of ICT is smaller relative to NICT (Panel A of Figure 3). To assess this observation more formally, we run regressions of our relative ICT abundance measure on log real GDP per capita and a complete set of time effects. Panel A of Table 2 shows the point estimates for the full sample of 1993-2011 as well as broken down into three sub periods: 1993-2000, 2001-2005, and 2006-2011. These estimates convey the patterns observed in Figure 3 and suggest two main insights: (a) there is a significantly positive relationship

		A. % \$ICT/	\$NICT		B. % Units of ICT per Unit of NICT				
	1993-2011	1993-2000	2001-05	2006-11	1993-2011	1993-2000	2001-05	2006-11	
Log Real GDP/L	0.870***	1.331***	0.759***	0.279	0.680***	0.499***	0.764***	0.876**	
	(0.239)	(0.286)	(0.259)	(0.281)	(0.174)	(0.0832)	(0.181)	(0.365)	
Obs.	1292	544	340	408	1292	544	340	408	
F-Stat.	32.3	37.7	74.1	67.8	22.7	28.3	51.0	49.9	
Time Effects	yes	yes	yes	yes	yes	yes	yes	yes	

Table 2: ICT Abundance: Values & Quantities

Notes: The table reports coefficient estimates from linear regressions of our ICT abundance measures on log GDP per captia and time effects. Panel A reports regressions for the ratio of current USD ICT values relative to NICT values (see Section 2.1 for details) and panel B reports units of ICT per unit of NICT (ratio of quantity indexes; see Section 2.2 for details). Each regression includes a complete set of time effects within the respective time period. Standard errors are clustered on country and reported in parentheses below each coefficient. Significance levels are indicated by * p < 0.1, ** p < 0.05, and *** p < 0.01.

between income per capita and ICT abundance and (b) this relationship is becoming weaker over time, perhaps suggesting that developing countries are catching up in terms of ICT accumulation.

2.2. The Relative Price of ICT & Physical ICT Abundance

While we have so far focused on the value of ICT relative to NICT, it is perhaps more instructive to compare the *physical* abundance of ICT, that accounts for cross country differences in the relative price of ICT. This exercise is especially important as a number of studies have shown that the relative price of investment goods varies dramatically across countries and is significantly higher in poor countries (e.g., Hsieh and Klenow, 2007). Since ICT is likely imported to a large degree in many poor countries, it is natural to expect that ICT is more expensive in these countries relative to other, domestically produced capital goods.

This section lays out a simple strategy for translating the nominal shares reported in panel A of Figure 3 and Table 2 into measures of ICT units per NICT units—more precisely, a ratio of index numbers—that is comparable across countries. Specifically, we seek to compute the ratio

$$\frac{K(ICT, j, t)}{K(NICT, j, t)} = \left[\frac{p(ICT, j, t) \cdot K(ICT, j, t)}{p(NICT, j, t) \cdot K(NICT, j, t)}\right] \cdot \frac{p(NICT, j, t)}{p(ICT, j, t)},\tag{1}$$

where K(ICT, j, t) and K(NICT, j, t) denote physical units of ICT and NICT, respectively. Recall that our construction of the nominal ICT/NICT ratios in Section 2.1 implicitly made the assump-

tion that ICT and NICT prices can be written as

$$p(ICT, j, t) = p(ICT, us, t) \cdot p(j, t) \cdot p(ICT, j)$$
(2)

$$p(NICT, j, t) = p(NICT, us, t) \cdot p(j, t) \cdot p(NICT, j),$$
(3)

where p(j,t) is some relative price of capital in country j (with j = us indicating the US) at time t, which may vary over time, while p(ICT, j) and p(NICT, j) are country-specific ICT and NICT components that are time invariant. The relative price of ICT can therefore be written as

$$\frac{p(ICT, j, t)}{p(NICT, j, t)} = \frac{p(ICT, us, t) \cdot p(j, t) \cdot p(ICT, j)}{p(NICT, us, t) \cdot p(j, t) \cdot p(NICT, j)} \\
= \frac{p(ICT, us, t)}{p(NICT, us, t)} \cdot \frac{p(ICT, j)}{p(NICT, j)},$$
(4)

which allows us to re-write (1) as

$$\frac{K(ICT, j, t)}{K(NICT, j, t)} = \left[\frac{p(ICT, us, t)}{p(NICT, us, t)} \cdot \frac{p(ICT, j)}{p(NICT, j)} \cdot \frac{K(ICT, j, t)}{K(NICT, j, t)} \right] \cdot \frac{p(NICT, us, t)}{p(ICT, us, t)} \cdot \frac{p(NICT, j)}{p(ICT, j)} \\
= \left[\frac{p(ICT, j)}{p(NICT, j)} \cdot \frac{K(ICT, j, t)}{K(NICT, j, t)} \right] \cdot \left[\frac{p(ICT, j)}{p(NICT, j)} \right]^{-1},$$
(5)

where the expression in the first bracket of (5) is the constant USD ratio from Section 2.1 and $\frac{p(ICT,j)}{p(NICT,j)} \equiv rp_j$ is a time invariant measure of the country specific relative price of ICT.

Thus, to translate the constant USD ratios from Section 2.1 into "real" ratios, we devote the rest of this section to lay out our strategy to measure rp_j based on two waves of item level price data from the ICP (2005 and 2011).¹⁰ Unfortunately, these data are only available for a small number of countries in 2005 and even in 2011 there are many missing observations for prices at the item level. Nevertheless, we are able to construct a fairly comprehensive country specific measure for

¹⁰Note that we manually classify items as ICT and non-ICT investment goods. Our classification is in line with the usual definitions of ICT and details are available upon request.

the price of ICT relative to that of NICT, defined as

$$rp_j = \frac{E_{i \in ICT} \frac{p_{i,j}}{p_{i,us}}}{E_{i \in NICT} \frac{p_{i,j}}{p_{i,us}}}$$
(6)

where $p_{i,j}$ denotes the price of item *i* in country *j* and *j* = *us* indicates the US.

This measure uses US prices as a benchmark, and compares prices of ICT and non-ICT items relative to the US. We use the US as a benchmark because, due to limited data availability, we cannot construct ICT and non-ICT investment bundles that are comparable across countries. The role of the comparison with the US is to remove item fixed effects. To see the importance of this, consider a hypothetical scenario in which there are two countries. In country 1, we have data on the price of computers (an ICT item) and a sewing machine (a non-ICT item). In country 2, we have data on the price of computers but we do not have data on the price of a sewing machine; instead, we have data on the price of a vehicle (a larger non-ICT item). It would be meaningless to compare the ratio of the computer price to the non-ICT item, because the vehicle represents a more expensive item. However, if we compare the price of computers relative to a benchmark country to the price of the non-ICT item relative to a benchmark country (where we use the US as a benchmark), we are capturing some notion of whether there is a premium associated with ICT items, on average.¹¹

Panel A of Figure 4 documents a negative correlation between rp_j and log real GDP per capita. This suggests that, relative to non-ICT capital goods, ICT capital goods are relatively more expensive in low income countries. We further compute the growth rate in rp_j between 2005 and 2011 for a small number of countries for which item level data is available in both ICP waves.¹² Using this measure, Panel B of Figure 4 suggests that, while there is a weak negative correlation between the change in rp_j and log income per-capita, the relationship is not statistically significant. Note that the confidence intervals do not reflect the uncertainty regarding the estimation of rp_j , which is usually constructed based on a small set of items. Thus, we cannot reject the common working

¹¹We have also experimented with alternative reference countries and find similar results. We report the US here because most of the extant research on ICT prices has thus far focused on the US and it therefore serves as a natural benchmark.

¹²Since data is not available for the US in 2005, we use the UK as a benchmark for this exercise.



Figure 4: The Price of ICT relative to NICT and Income Per Person

Notes: Panel A illustrates the relationship between rp_j as defined in equation (6) for 160 countries based on ICP price data from 2011. Panel B illustrates the change in the relative price if ICT. Panel A uses the USA as the benchmark country. In panel panel B we use the UK as the benchmark country because we do not have ICP price data for the US in 2005.

assumption that the dynamics of the price of ICT relative to NICT are uniform across countries at different levels of development. Moreover, it is perhaps worth noting that we show price dynamics between 2005 and 2011 here—a period in which relative ICT prices weren't falling dramatically even in the U.S. (see Figure 1). Thus, our finding of no systematic worldwide decline in ICT prices between 2005 and 2011 is perfectly consistent with the assertion that the US price trend is relevant more globally.

Our resulting estimates of "real" ICT abundance are summarized in panel B of Figure 3 and Table 2, suggesting the following insights: first, the ratio of ICT capital goods to non-ICT capital goods is significantly higher in richer countries. Second, the difference in this measure between the poorest and the richest countries has increased significantly between 1993 - 2011. This is reflected both in the significantly steeper slope of our fitted regression line during the later periods in our sample (see panel B of Table 2) as well as the comparison of the maximum and minimum values in panel C of Table 1. These observations are also visually apparent in panel B of Figure 3 as well as Figure 5, which plots the time effects for three alternative versions of the full-sample regressions reported in Panels A and B of Table 2: ones in which income per capita is respectively normalized





Notes: The figure shows a comparison of the nominal (see Section 2.1 for details) and real (ratio of quantity indexes; see Section 2.2 for details) share of ICT over time. The lines are plots of the time effects from regressions analogous to the ones in the first columns in panels A and B of Table 2. These time effects are normalized so that they reflect countries at the 25-th percentile (panel A), the median (panel B), and the 75-th percentile of log real GDP per capita in our sample. That is, for each panel we run a separate log linear regression in which we re-center log real GDP per capita such that it is zero at the respective percentile cutoff.

to zero for the country at the 25-th, 50-th, and 75-th percentile of the real income distribution. This final figure particularly highlights that, while the nominal value of ICT as a fraction of NICT has remained roughly constant (or if anything declined mildly), the physical abundance of ICT has increased significantly around the world. Moreover, this pattern is relatively uniform across different levels of development.

In sum, these findings suggest that lower physical abundance of ICT capital in developing countries may partly be accounted for by its higher relative price. Similar to the argument laid out by Hsieh and Klenow (2007), lower labor costs will tend to imply higher costs of imported goods. Since ICT capital goods are likely to have a larger imported component than NICT capital goods, the higher relative price may contribute to the lower physical abundance of ICT. However, the implications for the relative value of ICT capital are, in principle, ambiguous, and depend on the elasticity of substitution between ICT and NICT capital.

2.3. Comparison With Existing Datasets

At this point, it is perhaps useful to compare our measurement strategy with existing datasets that include measures of ICT capital. There are two main datasets containing ICT capital measures: (a) the Groningen Growth and Development Center's KLEMS datasets, and (b) the Conference Board's Total Economy Database (TED).

The key difference with the KLEMS datasets is country coverage. The EU KLEMS covers 27 high income countries between 1970-2013 (O'Mahony and Timmer, 2009) and the WORLD KLEMS database provides additional ICT/NICT data for Canada (Gu, 2012) and Russia (Voskoboynikov, 2012). In contrast, our dataset on ICT/NICT capital stocks covers 70 countries at various levels of development (see Panel D of Table 1) and is—to the best of our knowledge—the most comprehensive account of ICT and NICT stocks at this point. That said, there are currently numerous WORLD KLEMS projects under construction to expand converge. The TED, on the other hand, has very comprehensive country coverage, yet it only contains measures of the growth in ICT capital services for the period 1990-2014 and does not specifically attempt to measure ICT capital stocks.

While our measurement efforts are clearly complementary to Jorgenson and Vu (2005), who also use WITSA and ITU data to estimate ICT, there are some differences. Specifically, they assume that ICT investment is proportional to ICT spending, while we try to construct an investment measure directly. Furthermore, most previous work does not count the category of "capital services" as an investment category, and rather focuses on projected values of hardware, software and telecommunications spending on hardware, software and telecommunications investment. Since the services category consists of some software investment (such as custom software or website design), the ratio of software spending and software investment in the US is above two (Vu, 2005). Our view is that the category "ICT services" represents pure investment spending and should be counted as such. Another important difference is that the data provided in his paper is data on ICT capital growth rather than on the stock of ICT.

Finally, we keep our methodology conceptually close to that of the PWT (Feenstra et al., 2015; Inklaar and Timmer, 2013). Note that, starting with version 8.0, the PWT constructs aggregate capital stocks by adding estimated capital stocks of six different asset types, among them computers, communication equipment and software.¹³ These are also based on the PIM, run separately for

¹³Note that, unfortunately, PWT does not make their disaggregated investment series publicly available and we were not able to gain access to these data.

these categories, with depreciation rates that are similar for computers and software (31.5%) but substantially lower for communications (11.5%). As mentioned in the previous section, we also adopt these assumptions.

3. Why is ICT Capital Relatively Less Abundant in Poor Countries?

There are several potential explanations for the relatively lower ICT abundance in low-income countries. In Section 4, we will present evidence relating this correlation to systematic differences in industrial composition between rich and poor countries. However, before proceeding, it is useful to illustrate that there are a variety of plausible mechanisms consistent with this correlation, all of which would also imply a systematic correlation between income per-capita and ICT abundance *within* industry—a prediction we reject in Section 4.

To illustrate, it is useful to consider a production framework that utilizes ICT and NICT capital, denoted k_i and k_n respectively, as well as labor (l). We will interpret l as consisting either of total labor or more specifically of labor performing automizable tasks which are substitutable with ICT (commonly referred to as "routine labor"). In the spirit of Autor and Dorn (2013), Krusell, Ohanian, Ríos-Rull and Violante (2000), or Eden and Gaggl (2015) we assume that the production function is given by:

$$y = k_n^{\alpha} (Ak_i^{\sigma} + l^{\sigma})^{\frac{1-\alpha}{\sigma}}$$
⁽⁷⁾

where $\alpha, \sigma \in (0, 1)$. The above production function is a Cobb-Douglas in NICT capital and a constant elasticity of substitution (CES) aggregate of ICT capital and labor. The assumption that $\sigma \in (0, 1)$ implies that ICT and labor are more substitutable than Cobb-Douglas. The parameter *A* captures the relative productivity of ICT capital. If the efficient utilization of ICT capital requires some know-how, a higher *A* captures better technology adoption.

Assuming that the interest rate is close to 0 (for expositional purposes), the producer's problem

can compactly be written as follows:¹⁴

$$\max_{k_i,k_n,l} k_n^{\alpha} (Ak_i^{\sigma} + l^{\sigma})^{\frac{1-\alpha}{\sigma}} - \delta_n p_n k_n - \delta_i p_i k_i - wl$$
(8)

where δ_n , δ_i are depreciation rates and p_n and p_i are the prices of capital relative to output. Let k_i^* and k_n^* be the ICT and NICT capital levels that solve the above optimization problems.

The following lemma establishes that, under realistic assumptions regarding the relationship between ICT productivity, relative input prices and income per-capita, this production framework implies a positive relationship between ICT abundance and income per-capita:

Lemma 1. Let h = 1, ..., n be a set of countries, ordered by income per-capita (where h = 1 is the country with the lowest income per-capita). Let A_h , $p_{i,h}$, $p_{n,h}$ and w_h denote the ICT productivity, ICT capital price, NICT capital price and wage in country h, and let $k_{i,h}$ and $k_{n,h}$ denote the solution to the producer's optimization problem in country h. Assume that:

- (a) The ratio $\frac{p_{i,h}}{A_h p_{n,h}}$ is decreasing in h
- (b) The ratio $\frac{p_{i,h}}{A_h w_h}$ is decreasing in h

Then,

- 1. The ratio $\frac{p_{i,h}k_{i,h}}{p_{n,h}k_{n,h}}$ is increasing in h.
- 2. The labor share $\left(\frac{wl}{y}\right)$ is decreasing in h.

The proof is provided in Appendix B. Note that the conditions of this lemma are satisfied if (a) ICT is more expensive in low income countries relative to both labor and NICT capital, and if (b) ICT productivity is relatively lower in low-income countries. The first condition is consistent with the empirical evidence that we document regarding the relative prices of ICT and NICT capital goods, as well as with well-known evidence regarding the higher relative price of capital in low income countries (e.g., Hsieh and Klenow, 2007, and references therein). The second condition is consistent with the view of technology adoption lags: if low-income countries are slower in adopting new technologies, we would expect *A* to be relatively lower in low-income countries (e.g., Comin and Hobijn, 2010).

¹⁴More elaborately, assuming that capital is purchased a period in advance and must be financed by borrowing at an interest rate r, capital enters the producer's maximization problem as $(1 - \delta)pk - pk * (1 + r)$ (if changes in the price of capital are ignored). The above is equal $-\delta pk$ if we assume that r = 0. These assumptions are not crucial and are made merely for expositional purposes.

The second part of the lemma establishes an additional testable prediction regarding the relationship between income per-capita and the labor income share. We directly test this prediction, and establish no strong relationship between the labor income share and income per capita. An even more generous interpretation of the model, that restricts attention to labor in occupations that are relatively more substitutable with ICT, is also not supported by the data. We show in Appendix C how we reach these conclusions.

Finally, note that the above model assumes a single final good and an aggregate production technology. It can also be interpreted as a production technology for a particular industry. Thus, this model implies a positive correlation between ICT abundance and income per-capita at the industry level—a prediction we reject based on empirical evidence provided in Section 4.

4. ICT Abundance and Industrial Composition

To provide another alternative to the explanations discussed above, we devote this section to present a simple quantifiable model that illustrates the relationship between industrial composition and the relative values of ICT and NICT capital stocks. Based on the predictions of this model we then evaluate the degree to which the cross-country differences in ICT abundance are accounted for by variation in industrial composition.

To motivate the analysis, Figure 6 documents that low-income countries produce disproportionately in sectors that utilize ICT less intensively. Panel A is based on country- and industryspecific value added as reported in the Groningen Growth and Development Center's 10 sector database (GGDC10, Vries, Vries and Timmer, 2014). While this measure provides a relatively high level of disaggregation, it is available only for a relatively small number of countries. As an alternative, we consider a more coarse measure of industrial composition by using data on the value added in agriculture, industry excluding manufacturing, manufacturing and services, based on the World Bank's World Development Indicators (WDI) for a wider set of countries. Panel B of Figure 6 illustrates a similar distribution of industrial composition based on this alternative data source. To highlight differences between high and low income countries we illustrate the value added shares of countries in the lowest (first) and highest (fourth) quartile of the per-capita income



Figure 6: Industrial Composition & Income

Notes: Panel A shows the industrial composition for the top and bottom income quartile in 2000 based on he GGDC10 Database. Industry shares are averaged over 2000 and 2010 and industries are orderd by their ICT Share in the US in 2000. Panel B shows an analogous graph based on WDI sector data.

distribution within our sample.

Most notably, agriculture, wholesale, retail and hospitality constitute the largest sectors in low income countries. Even in the US, these sectors do not use ICT intensely. In contrast, services and manufacturing constitute the largest sectors in high income countries, and the ICT intensity of these sectors is substantially higher. This suggests that perhaps one reason for lower ICT stocks in low income countries is lower demand for ICT in production.

To set ideas, consider the following simple model. Economies are indexed h = 1, ..., H. There are *n* industries indexed j = 1, ..., n. Output in industry *j* in country *h* is given by

$$Y_{h,j} = A_{h,j} k_{h,j,i}^{\alpha_{j,i}} k_{h,j,n}^{\alpha_{j,n}} l_{h,j}^{1-\alpha_{j,i}-\alpha_{j,n}},$$
(9)

where $A_{h,j}$ is normalized such that the output price of industry j in country h is 1. This specification assumes that ICT and NICT capital intensities are common across countries within the same industry. The rationale behind this assumption is that we wish to fix the intensity with which a given industry uses ICT and ask to what extent the industrial composition alone affects ICT abundance in the aggregate. The first order conditions with respect to ICT and NICT capital in sector j yield

$$MPK_{h,j,i} = p_{h,i}(r+\delta_i) \text{ and } MPK_{h,j,n} = p_{h,n}(r+\delta_n),$$
(10)

where MPK here denotes the physical marginal product of each type of capital. Using the assumption of a Cobb-Douglas production technology (equation (9)) and multiplying the above relations by the appropriate capital stocks yields

$$\alpha_{j,i}Y_{h,j} = p_{h,i}k_{h,j,i}(r+\delta_i) \text{ and } \alpha_{j,n}Y_{h,j} = p_{h,n}k_{h,j,n}(r+\delta_n).$$
(11)

Using $k_{h,i}$ and $k_{h,n}$ to denote aggregate ICT and NICT capital stocks and summing the above relations across industries delivers

$$\sum_{j=1}^{n} \alpha_{j,i} Y_{h,j} = p_{h,i} k_{h,i} (r+\delta_i) \text{ and } \sum_{j=1}^{n} \alpha_{j,n} Y_{h,j} = p_{h,n} k_{h,n} (r+\delta_n).$$
(12)

Dividing the two expressions yields predicted values for $\frac{p_{h,i}k_{h,i}}{p_{h,n}k_{h,n}}$ as a function of $\frac{r+\delta_n}{r+\delta_i}$ and the industrial composition as reflected by the country and industry specific levels of output, $Y_{h,j}$:

$$\frac{p_{h,i}k_{h,i}}{p_{h,n}k_{h,n}} = \left(\frac{r+\delta_n}{r+\delta_i}\right) \left(\frac{\sum_{j=1}^n \alpha_{j,i}Y_{h,j}}{\sum_{j=1}^n \alpha_{j,n}Y_{h,j}}\right)$$
(13)

Equation (13) allows us to conduct a simple test for the hypothesis that cross-country heterogeneity in the industrial composition may play an important role in explaining the cross-country differences in ICT abundance. Specifically, we use equation (13) to compute predicted values for ICT abundance that vary across countries exclusively because of differences in industrial composition. To accomplish this we first estimate industry specific capital income shares for the US based on the BEA's fixed asset accounts to proxy $\alpha_{j,i}$ and $\alpha_{j,n}$. These estimates are constructed based on the aggregate estimates by Eden and Gaggl (2015). Specifically, we use estimates of the aggregate marginal products of ICT and NICT and multiply them by the industry specific ICT and NICT capital output ratios. We then assume that $\delta_n = 0.06$ and $\delta_i = 0.2$, the average values observed in the US over the period 1993-2011, again based on Eden and Gaggl (2015). Finally we assume r = 0.03, which resembles the average real return consistent with equation (10). As described



Figure 7: ICT Abundance and Industrial Composition



(B.2) Ind. Pred. and Real Income: WDI



Notes: Panel A displays the observed ratios against the ones predicted by equation (13). Panel B plots the industry predictions against log real GDP per capita. Column 1 is based on GGDC10 data while column 2 is based on WDI data, respectively.

above, we consider two alternative measures for $Y_{h,j}$, one based on the GGDC10 database and one based on the WDI. Again, it is worth emphasizing that, by construction, the only source of cross-country variation in these predicted values is due to heterogeneity in industrial composition measured by value added.

Panel A of Figure 7 illustrates the "fit" of these predictions based on industrial composition. Since our estimates for ICT start in 1993 and the GGDC10 database reports values every 10 years, we can only use the years 2000 and 2010 to conduct our cross country analysis for this data source. Panel A.1 suggests a remarkably close fit of our predicted values for both years. Likewise, Panel A.2 reveals a similar fit based on the much coarser WDI sectors, yet for a much larger number of

	A. 2000				B. 2010			C. 1994 & 2011			$\ln(\frac{Obs.}{Pred.})$
	(A.1)	(A.2)	(A.3)	(B.1)	(B.2)	(B.3)	(C.1)	(C.2)	(C.3)	(D)	(E)
In(GDP/L)	0.32***		0.034	0.029		-0.088	0.19**		-0.0081	-0.048 (0.11)	-0.037
Ind. Pred.	(0.070)	1.16***	1.06**	(0111)	0.48** (0.18)	0.64**	(0.07.1)	0.86*** (0.17)	0.88***	0.79***	(0.000)
t=2000		(0.20)	(0.12)		(0.10)	(0.27)	-2.23*** (0.35)	-0.80*	-0.79	-1.33***	-0.58** (0.29)
t=2010							-2.41*** (0.31)	-0.81	-0.78	-1.41***	-0.55**
Constant	-1.66*** (0.35)	0.025 (0.57)	-0.093 (0.66)	-3.13*** (0.45)	-1.88*** (0.54)	-1.80*** (0.56)	(0.0.1)	(0)	()	(0)	()
Obs. F-Stat. R ²	32 17.9 0.4	32 33.3 0.4	32 17.2 0.4	32 0.1 -0.0	32 7.1 0.1	32 3.9 0.1	64 984.6 1.0	64 1116.7 1.0	64 827.3 1.0	62 764.7 1.0	64 17.2 0.4

Table 3: GGDC10: ICT Abundance and Industrial Composition

Notes: The table reports coefficient estimates from linear regressions of $\ln\left(\frac{p_{h,i}k_{h,i}}{p_{h,n}k_{h,n}}\right)$ on log real GDP per capita and predicted values based on country specific industrial composition, both separately and jointly. Predictions based on industrial composition are based on equation (13) and computed as $\ln\left[\frac{r+\delta_n}{r+\delta_i} \cdot \frac{\sum_{j=1}^n \alpha_{j,i}Y_{h,j}}{\sum_{j=1}^n \alpha_{j,n}Y_{h,j}}\right]$, with r = 0.03, $\delta_n = 0.06$, and $\delta_i = 0.2$. Robust standard errors are reported in parentheses below each coefficient. Significance levels are indicated by * p < 0.1, ** p < 0.05, and *** p < 0.01.

countries and reported at an annual frequency for the period 1993-2011. Given this fairly tight fit it is perhaps not surprising that panel B of Figure 7 suggests a strong positive correlation between our predicted values and log income per-capita for both data sources.

Inspired by this graphical illustration we use our predicted values to evaluate the degree to which cross country variation in ICT abundance is accounted for by industrial composition. Table 3 reports a regression of log nominal ICT/NICT on log real GDP per capita and the log of our predicted values from equation (13) based on the GGDC10 database. While this database has fairly detailed information on value added by sector, we only have data for 32 countries in 2000 and 2010 in overlap with our ICT measures.

Panel A displays the results for 2000, panel B for 2010, and panel C pools both years but controls for year effects. Columns (A.1) and (A.2) in panel A indicate that, in 2000, both income and our predictions based on industrial composition were positively correlated with ICT abundance. However, once we include both regressors jointly, only the industrial prediction regressor has any explanatory power. In fact, the point estimate does not significantly differ from the estimate in column (A.2) and is in the neighborhood of one, as our model would predict. The results in panel B mirror those of panel A. The pooled regressions in panel C also confirm the results from panels A and B. Notice further that the time effects in panes C.2 and C.3 are insignificant (i.e. statistically speaking zero on average), directly lending support to our expression derived in equation (13).

While these results provide some evidence for the predictions of our model, there are many potentially omitted regressors that might cause both ICT accumulation and industrial composition (e.g., low skill labor) and therefore bias our results. To address this concern, panel D of Table 3 shows an additional regression in which we proxy the the predicted values based solely on industrial composition in 1980. That is, we "fix" the industrial composition within each country prior to the main thrust of the so-called "ICT revolution". This alternative specification confirms the results from our main estimates in panel C.

Finally, panel E reports one additional specification in which we regress the log ratio of observed and predicted relative ICT/NICT values on log real GDP per capita. Again, this regression also suggests that there is no systematic relation between relative ICT abundance and real income after industrial composition is accounted for. Specifically, notice the substantially lower R^2 (and adjusted R^2) for this final specification.

Given the limited number of countries and years in the GGDC10 database we repeat the above exercise with data from the WDI, which provides many more years and countries but offers a much more coarse classification for the sectors of production. Table 4 shows that our estimates based on WDI data are very close to those based on the GGDC10 database. Specifically, notice that all the time effects in specification (C.1) are highly significant while the bulk of the variation is absorbed by our predictions based on industrial composition in specifications (C.2) - (E). Again, like in our analysis based on GGDC10 data, the coefficient on our industry predictions is close to one in all specifications. Finally, once we divide the observed values of relative ICT abundance by our industry predictions (column E), real income and time effects have virtually no explanatory power, with R^2 substantially lower than in columns (C.1) through (D). Notice, however, that (despite the overall low explanatory power) this is the only specification in which we get a marginally significant coefficient on our industry predictions is slightly above one.

	A. 2000			B. 2010			C. 1994 – 2011			Ind. Pred.	$\ln(\frac{Obs.}{Pred.})$
	(A.1)	(A.2)	(A.3)	(B.1)	(B.2)	(B.3)	(C.1)	(C.2)	(C.3)	(D)	(E)
In(GDP/L)	0.37*** (0.058)		0.15 (0.12)	0.069 (0.061)		0.066 (0.063)	0.27*** (0.061)		0.14* (0.074)	0.037 (0.10)	0.12** (0.058)
Ind. Pred.		1.67*** (0.30)	1.11 [*] (0.60)		0.13 (0.23)	0.047 (0.21)		1.31*** (0.26)	0.88*** (0.30)	0.93*** (0.34)	
Constant	-1.60*** (0.25)	1.48 [*] (0.83)	0.58 (1.24)	-2.98*** (0.25)	-2.89*** (0.68)	-2.85*** (0.62)		()	. ,	、 ,	
Time Effect	ts						yes	yes	yes	yes	yes
Obs.	66	66	66	67	67	67	1226	1226	1226	702	1226
F-Stat.	40.1	31.8	19.3	1.3	0.3	0.7	338.2	416.6	415.4	310.6	151.0
R^2	0.3	0.3	0.4	0.0	0.00	0.0	1.0	1.0	1.0	1.0	0.4
Adj. R ²	0.3	0.3	0.3	0.0	-0.0	-0.001	1.0	1.0	1.0	1.0	0.4

Table 4: WDI: ICT Abundance and Industrial Composition

Notes: The table reports coefficient estimates from linear regressions of $\ln\left(\frac{p_{h,i}k_{h,i}}{p_{h,n}k_{h,n}}\right)$ on log real GDP per capita and predicted values based on country specific industrial composition, both separately and jointly. Data are taken from the WDI. Predictions based on industrial composition are based on equation (13) and computed as $\ln\left[\frac{r+\delta_n}{r+\delta_i}\cdot\frac{\sum_{j=1}^n\alpha_{j,i}Y_{h,j}}{\sum_{j=1}^n\alpha_{j,n}Y_{h,j}}\right]$, with r = 0.03, $\delta_n = 0.06$, and $\delta_i = 0.2$. Panels C, D and E include a complete set of time effects for the relevant time horizon. Standard errors are clustered on country and reported in parentheses below each coefficient. Significance levels are indicated by * p < 0.1, ** p < 0.05, and *** p < 0.01.

4.1. Reduced Form Within Industry Evidence

As a final test of our model's predictions we investigate whether there is a notable within-industry relation between ICT abundance and real income. Note that, if cross-country differences in ICT abundance were truly driven primarily by variation in industrial composition, then we should not expect a strong relationship between ICT abundance and real income per capita *within* a given industry. Due to data limitations we cannot perform a direct test of this prediction but we provide some suggestive evidence using reduced form analysis based on an approximation.

Specifically, we assemble a sector by country by year panel with a proxy for ICT abundance based on WITSA's detailed tables on sector specific total ICT spending and total capital stocks based on the World Input Output Database (WIOD).¹⁵ Note that we would ideally like to construct relative ICT stocks as in Section 2. However, at the sector level, we only have aggregate WITSA ICT spending data. We do not have any data on telecommunication spending from the ITU at

¹⁵This datasource is publicly available at http://www.wiod.org.

		Regre	Regression with time effects					
	ho	β	s.e.	p-value	Ν			
Manufacturing	0.562	0.008	0.002	0.000	195			
Hospitality and Leisure	0.405	0.021	0.006	0.002	195			
Retail Trade	0.261	0.010	0.006	0.111	195			
Financial Services	0.268	0.040	0.028	0.173	195			
Educational Services	0.241	0.003	0.002	0.187	195			
Energy & Utilities	0.223	0.001	0.001	0.223	195			
Healthcare	0.187	0.007	0.006	0.247	195			
Telecommunications	-0.222	-0.061	0.066	0.363	195			
Construction	0.156	0.005	0.006	0.416	195			
Government	0.133	0.004	0.006	0.505	195			
Transportation	-0.096	-0.002	0.005	0.628	195			
Wholesale Trade	0.073	0.002	0.006	0.791	195			
Professional Services	0.042	0.000	0.001	0.806	195			
Natural Resources	0.011	0.000	0.001	0.903	195			

Table 5: Within Sector Correlation of ICT Abundance and Real Income

Notes: For each WITSA sector, the first column reports the within-sector correlation of X_{ict}/K and ln(GDP/L) over the years 2003-2009 based on 32 countries, where X_{ict} represents sector specific WITSA ICT spending and K is the sector specific capital stock reported in the WIOD. The remaining columns report the results from a regression of X_{ict}/K on ln(GDP/L) and a complete set of time effects. Standard errors are clustered on country.

the sector level. Thus, as a crude proxy for ICT abundance we simply divide WITSA's measure of sector-specific nominal ICT spending by the corresponding nominal sector-specific capital stock reported in the WIOD (in current USD).¹⁶ The resulting panel spans the period 2003-2009 for a total of 14 WITSA sectors in 32 countries.

Table 5 summarizes our results. The first column reports the within industry correlation of our relative ICT abundance proxy and log real income per capita. While there is some overall correlation (measured by the correlation coefficient pooled over all years), we only find a statistically significant relationship for two out of fourteen sectors when controlling for time fixed effects. Considering that the dependent variable in this exercise is only a very crude proxy for true ICT abundance, we take this as an additional piece of suggestive evidence in favor of our results from the previous section.

¹⁶Note that we manually build a concordance between the SIC sectors in the WIOD and the sectors reported in WITSA.

5. Does India Have Too Little ICT? An Illustrative Example

We opened this paper with a comparison of the percent of households that subscribe to broadband internet in the United States and in India, suggesting that internet subscriptions are 30 times more abundant in the United States. Is this 30-fold difference too large or too small? In other words, is ICT under-utilized or over-utilized in India?

Assuming that internet subscriptions are proportional to the physical abundance of ICT, we can construct a benchmark level of ICT capital based on the capital labor ratio, the ICT price and industrial composition using the following decomposition:

$$k_i = \left(\frac{p_i k_i}{pk}\right) \cdot k \cdot \left(\frac{p}{p_i}\right),\tag{14}$$

where k_i is the physical stock of ICT capital per-capita; $\frac{p_i k_i}{pk}$ is the nominal share of ICT capital out of total capital; k is the aggregate capital stock per-capita, and $\frac{p}{p_i}$ is the ratio of the capital price and the price of ICT capital. Our model from Section 4 suggests that we can further decompose $\frac{p_i k_i}{pk}$ to arrive at the following expression:

$$k_{i} = k \cdot \left(\frac{p}{p_{i}}\right) \cdot \left(\frac{\sum_{j=1}^{n} \alpha_{i,j} Y_{j}}{\sum_{j=1}^{n} (\alpha_{i,j} + \alpha_{n,j}) Y_{j}}\right) \cdot \frac{r + \delta_{n}}{r + \delta_{i}}$$
(15)

where j = 1, ..., n are industries. Note that the ratio $\frac{r+\delta_n}{r+\delta_i}$ is an approximation, using the fact that ICT represents a relatively small share of capital (otherwise, the numerator is some weighted average of δ_n and δ_i). Applying these expressions to the specific case of India and the United States then gives rise to the following benchmark ratio:

$$BR = \frac{k_{us}}{k_{ind}} \cdot \frac{\left(\frac{p}{p_i}\right)_{us}}{\left(\frac{p}{p_i}\right)_{ind}} \cdot \frac{I_{us}}{I_{ind}}$$
(16)

where *us* and *ind* are subscripts for the US and India, and $I = \frac{\sum_{j=1}^{n} \alpha_{i,j} Y_j}{\sum_{j=1}^{n} (\alpha_{i,j} + \alpha_{n,j}) Y_j}$.

Using estimates from the Penn World Table 8.1, the dollar value of the capital stock per capita is about 28.5 times higher in the United States than in India, explaining a large part of this disparity $(\frac{k_{us}}{k_{ind}} = 28.5)$. The relative price of aggregate capital relative to the price of ICT capital—roughly

	WDI Value Adde	d Share (%)	-		
	United States	India	ICT share (%)	NICT share (%)	
Agriculture	1	18	9	91	
Industry Excluding Manufacturing	8	12	2	98	
Manufacturing	13	15	5	25	
Services	78	55	6	30	

Table 6: Industrial Composition and ICT Intensity: United States & India

Notes: The table reports value added shares and ICT/NICT income shares in the four major WDI sectors, both for India and the United States in 2010. Value added shares are based on WDI data and income shares are approximations based on aggregate estimates of the capital specific marginal product based on Eden and GaggI (2015) and industry specific ICT and NICT output ratios.

equal to the relative price of NICT and ICT capital, given that ICT constitutes a small share of the capital stock—is about 1.6 times higher in the US than in India, i.e. $\frac{(\frac{p}{p_i})_{us}}{(\frac{p}{p_i})_{ind}} = 1.6$.

To compute I, we use the values displayed in Table 6, which presents the value added shares by industry in the United States and in India, together with the breakdown of the ICT and NICT shares by industry in the US. Notice that, while agriculture has the highest ICT share in absolute terms, it also has a substantial NICT share. The same is true for industry excluding manufacturing. Put differently, the relative expenditure share of ICT and NICT is much higher in manufacturing and services than it is in agriculture and industry excluding manufacturing. Since India is producing much more intensively in the latter two sectors (compared to the US) this suggests that India will use less ICT in the aggregate, simply based on its industrial composition. More precisely, to calculate I_{ind} , we compute

$$I_{ind} = \frac{18*9 + 12*2 + 15*5 + 55*6}{18*(9+91) + 12*(2+98) + 15*(5+25) + 55*(6+30)}$$
(17)

We derive I_{us} analogously and arrive at approximately $\frac{I_{us}}{I_{ind}} = 1.4$. The benchmark ratio of ICT in the US relative to ICT in India is then given by BR = $28.5 \cdot 1.6 \cdot 1.4 = 63$.

Thus, for the specific example of India, an observed 30-fold difference in broadband subscriptions relative to the US is actually suggestive of ICT utilization rates that are high compared to our benchmark. Given the capital labor ratios, the price differentials and the industrial composition, India appears to be utilizing ICT beyond what would be expected.

It is worth emphasizing that the above benchmarking procedure does not utilize our estimates

of ICT and NICT capital stocks. The procedure provides a benchmark for ICT prevalence, that requires as inputs only aggregate capital-labor ratios, value added by industry, and estimates of the relative prices of ICT and NICT capital goods. Since capital-labor ratios are available widely from the PWT and industrial composition is available widely from the WDI, the only input that is not readily available is the relative ICT price. Our ICP-based estimates for relative prices are available for a wide variety of countries and can be utilized in this benchmarking procedure.

6. Concluding Remarks

This paper documents a correlation between income per capita and the ICT capital stock. This correlation is not surprising: technology adoption lags would imply that capital that embeds relatively new technologies would be less abundant in low income countries. This is especially the case if the new technology is substitutable with labor (e.g., Autor, Levy and Murnane, 2003), a factor that is relatively abundant in low income countries.

Despite these plausible economic mechanisms, our findings suggest that the correlation between ICT abundance and income per capita is entirely accounted for by differences in industrial composition. Predicted values based on domestic industrial composition and US industry level ICT intensity exhibit the same relationship with income per capita. Moreover, we present evidence suggesting that, within industries, ICT spending is similar across countries of different levels of development.

The suggested implication is that technology adoption lags are not very important for the proliferation of ICT. On average, after controlling for industrial composition, the value of ICT capital per capita is the same as the general capital-labor ratio. A higher relative price of ICT capital in low income countries, which is perhaps reflective of higher costs of tradables, implies that the corresponding quantity of ICT capital goods is lower in low income countries.

Of course, our analysis here "explains" cross country differences in ICT abundance only in an accounting sense. This accounting exercise illustrates that in order to understand the source of the differences, one must look deeper into the fundamental questions of development economics, and understand why the capital-labor ratios are lower in developing countries; why non-tradables

are relatively cheaper; and why production is concentrated disproportionately in agriculture and other industries that do not require much ICT capital.

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Appendix A. Capital Stocks Based on WITSA & ITU

As described in Section 2, we construct nominal ICT investment series based on data from the the World Information Technology and Services Alliance (WITSA) and the International Telecommunication Union (ITU) databases. We then treat NICT investment as the residual between total capital investment in the PWT and our measure of ICT investment.

WITSA produced reports (Digital Planet 1998, 2000, 2002, 2004, 2006, 2008, 2010) that provides data on Information Communication Technology investment from 1993 to 2011. The number of countries varies across the reports (55-75 countries). WITSA uses data provided by International Data Corporation (for reports 1998, 2000, 2004) & Global Insights, Inc. (for reports 2004, 2006, 2008, 2010). For more details please see http://www.witsa.org.

ITU publishes the World Telecommunication/ICT Indicators database covering data on 150 telecommunication/ICT statistics from 1975 to 2013 for over 200 countries. ITU collects it data from annual questionnaire that are sent to official country contacts. For more details please see http://www.itu.int/en/ITU-D/Statistics/Pages/publications/wtid.aspx

Taken together WITSA and ITU provide US with data on IT and TC investment for an unbalanced sample of 70 countries that also appears in the PWT for the period 1993-2011. About 40 countries have have complete data series for all years from all sources but for many countries (especially for poor countries) the data is much more sparse. Therefore, like in the construction of the PWT capital investment series (Inklaar and Timmer, 2013), we employ two layers of interpolation and two layers of extrapolation. First, we interpolate "in sample" (1993-2011) missing values in proportion to total WITSA ICT spending where available, and aggregate PWT capital investment otherwise. To facilitate the construction of starting values for our ICT stocks in 1993 we further extrapolate the "in-sample" investment series backward to 1950 in proportion to aggregate PWT investment and a time trend where PWT investment is available (many countries in PWT only have investment data starting in 1970) and any remaining missing values are extrapolated based purely on a log linear time trend.¹⁷

To compute the stock of ICT and NICT we deflate the resulting investment expenditures (from 1950-2011) using capital specific price indexes as estimated by Eden and Gaggl (2015). We then use a version of the standard (Solow) steady state condition, $K_{c,0} = \frac{I_{c,0}}{\bar{g}_c + \delta_{c,0}}$, to estimate an initial value in 1950, where $I_{c,0}$ is real ICT investment in the first period, \bar{g}_c represents country specific long run growth, and $\delta_{c,0}$ is the depreciation rate in the initial period. We use our extrapolated value in 1950

¹⁷There are three countries for which we use a time trend only to extrapolate backward: Nigeria, Sri Lanka, and Japan. We make this exception because the PWT investment series are poor predictors of ICT investment trends for these countries.

as the initial value for capital specific investment and use the associated implied constant growth rate as a proxy for \bar{g}_c . Based on this initial capital stocks we then use the perpetual inventory method separately for IT, TC, and NICT capital and iterate on the following equation:

$$K_{c,t+1} = I_{c,t} + (1 - \delta_{c,t})K_{c,t}$$
(A.1)

where we assume the following depreciation rates: 31.5% for IT, 11.5% for TC (see Inklaar and Timmer, 2013), and 6% for NICT (as in Eden and Gaggl (2015)).¹⁸ We have experimented with a number of version of this procedure and have found little sensitivity to our results.

Appendix B. Proof of Lemma 1

The standard first order conditions imply that $\frac{\partial y}{\partial k_n} = \delta_n p_n$, $\frac{\partial y}{\partial k_i} = \delta_i p_i$ and $\frac{\partial y}{\partial l} = w$. Given the Cobb-Douglas structure of the production function, NICT capital is paid a fraction α of output:

$$\alpha y = \delta_n p_n k_n \tag{B.1}$$

The first order conditions with respect to ICT capital and labor can be written as:

$$(1-\alpha)k_n^{\alpha}(Ak_i^{\sigma}+l^{\sigma})^{\frac{1-\alpha}{\sigma}-1}Ak_i^{\sigma-1} = \delta_i p_i$$
(B.2)

$$(1 - \alpha)k_n^{\alpha}(Ak_i^{\sigma} + l^{\sigma})^{\frac{1 - \alpha}{\sigma} - 1}l^{\sigma - 1} = w$$
(B.3)

Dividing the two yields:

$$\left(\frac{k_i}{l}\right)^{\sigma-1} = \frac{\delta_i p_i}{Aw} \Rightarrow A\left(\frac{k_i}{l}\right)^{\sigma} = \frac{\delta_i p_i k_i}{wl}$$
(B.4)

The first part of the above equation illustrates that if $\frac{p_i}{Aw}$ is higher, the optimal choice of $\frac{k_i}{l}$ is lower (note that $\sigma < 1$). The second part of the above equation illustrates that, if the ratio $\frac{k_i}{l}$ is lower, the

¹⁸Our choice of mapping the NICT depreciation rate to the estimate in Eden and Gaggl (2015) rather than to the PWT is due to aggregation issues, as the PWT distinguishes between several types of NICT assets with different depreciation rates.



Figure B.8: Income Shares: Routine/Non-Routine Labor

Notes: The figures illustrate measures of the routine and non-routine income shares. Earnings shares are taken from the I2D2 database and the aggregate labor share is taken from the PWT 8.1. Self-employed workers are included and the patterns are robust to their exclusion.

relative expenditure on ICT capital $(\frac{\delta_i p_i k_i}{wl})$ is lower.

Given the Cobb-Douglas assumption, it is easy to establish that:

$$\delta_i p_i k_i + w l = (1 - \alpha) y \tag{B.5}$$

Let s_i denote the ICT share. Given that $\frac{p_{i,h}}{A_h w_h}$ is decreasing in h, it follows that $s_{l,h}$ is increasing in h. Thus, the ratio $\frac{s_{l,h}}{\alpha}$ is increasing in h, and therefore (under the assumption that depreciation rates for ICT and NICT are the same across countries) $\frac{p_{i,h}k_{i,h}}{p_{n,h}k_{n,h}}$ is increasing in h.

Appendix C. Disaggregate Labor Shares and Income Per-Capita

To evaluate our model's predictions about the relationship between disaggregate labor shares and income per capita we use data from the World Bank's International Income Distribution Database (I2D2). This database covers a standardized set of demographic, education, labor market, house-hold socioeconomic and income/consumption variables for over 150 countries drawn from more than 1000 nationally representative household surveys, with the earliest data starting in 1960. We use this data source to measure the total annual wage bill by occupation and then classify occu-

pations as performing "routine" and "non-routine" tasks following Acemoglu and Autor (2011). That is, we classify (1) managerial, professional and technical occupations as "non-routine cognitive"; (2) sales, clerical and administrative support occupations as "routine cognitive"; (3) production, craft, repair, and operative occupations as "routine manual"; and (4) service occupations as "non-routine manual". This then allows us to calculate the routine (groups 2 and 3) and nonroutine (groups 1 and 4) wage bill as a percent of the total wage bill within each country. Finally, we obtain routine and non-routine income shares by multiplying the resulting wage bill shares with the aggregate labor income share taken from the PWT.

Figure B.8 illustrates that, if anything, both routine and non-routine labor income shares (and hence the aggregate labor income share) are slightly positively correlated with income per-capita, rejecting part two of Lemma 1.