International Medical Technology Diffusion*

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Abstract

Does medical technology generated in frontier countries have a significant impact on health outcomes in the rest of the world? This paper considers a framework where non-frontier countries may benefit from medical innovation that is embodied in medical imports or diffuses in the form of ideas. Using a novel dataset from a cross-section of 63 technology-importing countries, we show that medical technology diffusion is an important contributor to improved health status, as measured by life expectancy and mortality rates.

Keywords: International technology diffusion, life expectancy, medical imports, medical students.

JEL Classification: O30, O40

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1 Introduction

One of the most fundamental aspects of economic development and a nation's welfare is the population's health status as manifested by a variety of indicators, such as life expectancy at birth or mortality rates. Understanding the main forces contributing to the marked improvement in health during the second half of the 20^{th} century is an important research and policy question. Along with the general improvement in health status, this period also witnessed a narrowing of differences between rich and poor nations, as improvements in life expectancy accelerated in the developing world. Over the period 1950-2000, life expectancy increased by 3.7 years per decade in Latin America, by 6 years in East Asia, by 4.5 in South Asia, and by 3.4 years in Sub-Saharan Africa (prior to the reversal due to AIDS since 1990). The corresponding figure for the high-income economies was 2.5 years per decade.[1] Bourguignon and Morrisson (2002, p.741) report that "... unlike income, world inequality in life expectancy fell considerably after 1930, as improvement in world mean life expectancy accelerated."[2]

A lively debate on the sources of the observed improvement in health centers on whether it has proceeded in tandem with general increases in the standard of living or whether 'exogenous' sources, that is sources other than income, are responsible. While the earlier literature favored the former explanation, recent research has focused on the latter. In a series of papers Preston (1975, 1980, 1996) and more recently Soares (2005) have argued that increases in life expectancy have occurred independently of increases in per capita income. While not denying the importance of other factors, Soares (2005, p.581) places emphasis "... on changes in mortality determined from technological innovations in medical and biological sciences." Both authors have shown evidence that the positive cross-sectional relationship between life expectancy and per capita income has shifted upward steadily over time.

There are numerous other references in the literature to potentially exogenous sources of increase in life expectancy. Kremer (2002, p.67) emphasizes the importance of modern medical technologies in allowing "... tremendous improvements in health even at low income levels."[3] Jamison, Sandbu,

[1] The estimates are population weighted averages for each region, based on data from Bourguignon and Morrisson (2002) and the World Development Indicators (2002).

[2] These authors calculate that the Theil index of life expectancy inequality rose throughout the 19^{th} century and the first part of 20^{th} century to reach 0.046 by 1930 and then declined steadily to reach 0.013 by 1992.

[3] Kremer (2002) offers an illuminating observation on the importance of technology diffusion in boosting life expectancy in the case of Vietnam where at the end of the 20th century life expectancy stood at "... 69 years despite a per capita income that according to official statistics is less than one-tenth that of the United States in 1900, which

and Wang (2001) document the importance of different rates of technological progress across countries for the declining cross-country variation in infant mortality rates. Becker, Philipson and Soares (2005) argue that "... in the last 50 years, countries starting with modest longevity levels experienced life expectancy gains significantly larger than countries starting with high longevity levels." They attribute the convergence in life expectancy in large part to the diffusion of existing knowledge that has helped reduce mortality from major diseases. Fogel (1994, p.388) points to a potential explanation for the acceleration of life expectancy improvements in "... the huge social investments made between 1870 and 1930, whose payoffs were not counted as part of national income during the 1920's and 1930's even though they produced a large stream of benefits during these decades" and adds that he "... refer[s], of course, to the social investment in biomedical research." Finally, Preston (1996, p.533) suggests that mortality changes in developing countries came about through the provision of public programs and the dissemination of knowledge especially about the role played by parasites and germs in disease transmission and the corresponding changes in personal hygiene habits, concluding that "... at certain times and in different places government intervention may have been less important than the spread of information and behavior through informal channels."

In this paper we take a careful look at the role of exogenous forces in the improvement of health status in the second half of the 20th century. We argue that medical innovation diffuses steadily across the world contributing to significant improvements in life expectancy. International medical diffusion occurs through two distinct channels. First, imports of medical goods, such as drugs, vaccines and medical equipment. Second, the direct flow of medical knowledge from a few frontier countries to the rest of the world, a flow that is facilitated by information *networks* created by medical students from non-frontier countries who study in frontier countries.

No study has considered the global diffusion of medical technology and the potential welfare-enhancing benefits of medical R&D by technologically-advanced countries in terms of health improvements in less advanced economies. This should stand as a surprise because the pharmaceutical industry is the single most R&D-intensive industry, no less so than capital goods production.[4] In this paper, we propose that, similar to capital goods in manufacturing, medical goods such us pharmaceuticals (e.g. vaccines and antibiotics) or medical equipment (e.g. surgical instruments) embody R&D-induced technology. Moreover, R&D in the pharmaceutical industry is highly con-

had a 47-year life expectancy."

[4]Lichtenberg and Virabhak (2002) also emphasize that pharmaceuticals are more R&D intensive than capital equipment imports, and Lichtenberg (2003) considers the impact of new drugs on longevity across 52 countries.

centrated in a small group of ten countries which are also the main exporters of these goods. In sum, it is reasonable to expect that advances in medical technology occurring in a small group of developed economies diffuse to the rest of the world either embodied in medical exports or "dis-embodied" in the form of flow of ideas and may, potentially, have a significant impact on health status in the rest of the world.

The remainder of the paper is organized as follows. Section 2 describes in detail our dataset with particular emphasis on the construction of data on medical imports, medical R&D and medical students trained abroad. Section 3 presents a brief discussion that motivates our basic empirical specification, followed by estimation results and evaluation of the impact of medical technology diffusion on health status. Section 4 discusses our findings and concludes.

2 Data description

We start by describing the dataset we have assembled to test our main hypothesis regarding the relationship between health status and medical technology diffusion. Health status is measured by three alternative variables: life expectancy at birth, the rate of male mortality and the rate of infant mortality.

We have employed a variety of sources to obtain the necessary data. First, the OECD *International Trade by Commodity Statistics* (ITCS) database contains medical-related exports (in current US dollars) from each of ten leading exporters of medical technology (Belgium, France, Germany, Italy, Japan, Netherlands, Sweden, Switzerland, U.K., and U.S.A.) to each importing country. These ten countries supply the bulk of medical products and carry out the vast majority of medical R&D. We use this dataset to measure a country's imports of medical goods because it is the only consistent source of medically-related trade. The ITCS database includes annual bilateral flows across 269 international locations for 2581 goods categories (albeit with a great deal of empty cells) for the period 1960-2000. We studied carefully these traded goods categories and consulted with bio-specialists to arrive at a list of thirteen health-related traded goods sub-categories. We excluded four of these categories for which data availability was a serious concern[5] and were left with the nine categories reported in Table 1 (with *SITC Revision 2* codes in parentheses). Our

[5]These categories were: Soap, organic surface-active products and preparations (5541), Sinks, wash basins, bidets, water closet pans, etc (8122), Disinfectants packed for sale etc. (59141), and Preparations culture media for development of micro-organisms (59893).

Table 1: Categories of imported medical products used in estimation

Medicinal & Pharmaceutical Products (54)	Hyg. & Pharm. Articles of Rubber (6281)
Electric Apparatus for Medical Purposes (774)	Orthopedic Appl., Surg. Belts & the like (8996)
Medical Instruments & Appliances (872)	Optical Goods (884)
Medical, Dental, Surg. or Vet. Furniture (82121)	Insecticides (5911)
Laboratory, Hyg. & Pharm. Glassware (66581)	

Notes: Medicinal and Pharmaceutical Products include, among others, the following sub-categories: Antibiotics (5413), Antisera and Microbial Vaccines (54164), and Medicaments containing Antibiotics and derivatives thereof (54171).

final trade dataset contains exports of each of the nine categories from each of the ten "medical frontier" countries to each of sixty-three "non-frontier" countries.

Initially, we consider an aggregate measure of a country's medical imports ($MEDIM$) as the sum of all the pharmaceutical, medical, and health-related categories reported in Table 1. In addition to our aggregate measure, we also consider two other measures of medical imports: (i) medical capital and equipment ($MCAPIM$) which is the sum of two categories, Electric Apparatus for Medical Purposes (SITC code 774) and Medical Instruments & Appliances (SITC code 872) and (ii) medicinal and pharmaceutical imports alone ($PHAIM$ or SITC code 54). To convert figures from current to constant (1990) dollars, we use the manufacturing and chemicals industry price deflator (for each of the ten providers of medical goods) extracted from the 1998 OECD *Intersectoral Database* (ISDB, 1998).[6] Finally, our measure of real medical imports is converted to a per capita basis by dividing by each recipient country's total population.

Second, to construct our measure of foreign medical innovation and the spillover effect we use the *ANBERD* 2001 database for pharmaceutical R&D in nine technologically advanced countries[7] from 1973 to 1997. These nine countries account for the vast majority of OECD (and thus global) medical R&D: they accounted for more than 96 percent of all medical R&D expenditures reported to the OECD in 1973 and over 94 percent in 1995. The Commission on Macroeconomics and Health (2001, p.79) notes the so called *90/10 disequilibrium* in medical R&D spending: only 10 percent of R&D spending is directed at diseases pertinent to 90 percent of the global population. It would

[6]We use the chemical industry price deflator for pharmaceuticals imports and the manufacturing sector price deflator for other types of medical imports.

[7]The ten major medical exporters listed above minus Belgium and Switzerland for which no R&D data exist in the OECD ANBERD data, plus Canada that was ranked tenth in medical R&D in 1973 among countries included in the OECD database. In terms of medical exports, Canada ranks just below the ten major exporters listed above.

seem, *a priori*, that most R&D spending in the leading economies ought not have an impact on health in non leading economies. Two points are worth noting here. While the disequilibrium may exist so that most medical R&D is directed at Type I diseases (incident in both rich and poor countries e.g. measles, hepatitis B, diabetes tobacco-related illnesses) or Type II diseases (incident in both rich and poor but prevalent in poor, e.g. HIV/AIDS and tuberculosis), such R&D may have an impact on health in lower income economies, an empirical issue that our paper addresses. Second, the significant estimates of medical R&D on health in less advanced economies uncovered by our empirical estimates (see next section) should be seen as 'lower bounds' on the effects of medical R&D: any reallocation of R&D resources (as urged by the Commission) will likely bring substantially greater health benefits to non-leading economies.

In order to construct a measure of medical R&D flow for each non-frontier country, we make use of an estimate of R&D expenditures from the current PPP dollars series for (SIC Revision 2) category "Drugs and Medicines" for each of these nine leading economies.[8] We deflate these by the chemical industry price deflators from the *ISDB* database. Finally, we multiply the constructed R&D in constant US dollars of each of the nine source countries by inverse physical distance (proximity) of that source country to the recipient country as a share of total inverse distance from all source countries. This is similar to the measure used in Xu and Wang (1999) and in the spirit of Keller (2002). Specifically, country i's medical R&D flow is:

$$RD_i = \sum_{c=1}^{9} \frac{1/\ln DIST_{ci}}{\sum_{c=1}^{9} 1/\ln DIST_{ci}} \times CRD_c,$$

where $DIST_{ci}$ is physical distance of country i from source country c, and CRD_c is constant dollar pharmaceutical R&D expenditures by source country c.[9] Subsequently, we will refer to RD_i as the distance-weighted implied R&D stock for each country. In the empirical analysis we include medical imports as a separate variable along with RD in all estimated models. This helps isolate the effects of foreign medical R&D from potential trade-related effects. The fact that both variables

[8] R&D spending on other medical products is only available at an aggregate level that includes a broad set of non-medical categories such as Electric Machinery excluding Communications Equipment, and Professional Goods, which would be rather imperfect matches for R&D on Electric apparatus for medical purposes and for Medical instruments and appliances, respectively.

[9] In the cross-sectional empirical application of next section, we use the average of this variable over the period, a measure closely connected to the level of the medical R&D stock of each country. It varies across different countries to the degree that one country is physically close to a more R&D-intensive source country rather than a less R&D-intensive country.

appear to be independently significant determinants of health status (see next section) suggests that the weights employed to construct RD capture 'non-trade' factors (e.g. institutional, cultural, and linguistic) that enhance the flow of ideas from one location to another.

In addition to medical imports and foreign R&D, we construct a third measure of international medical technology diffusion, the number of foreign-trained medical students. It is intended to capture informal medical information links between each non-frontier country and four countries on or relatively close to the medical frontier: Canada, Germany, United Kingdom and the United States. The choice of these four frontier countries was based on their relative importance and data availability constraints. Our empirical measure is the number of students from each country that are enrolled in medical studies in these four countries, relative to each country's population. We conjecture that foreign-trained medical students provide valuable information flows between countries away from the medical technology frontier and each of the four frontier countries. These information flows exist irrespective of the country in which the medical students choose to practice. If they relocate in their home countries they bring information gained from abroad, information that is not available to locally-trained physicians. If they choose to practice in these four countries or other medically-advanced countries they may still provide important information links through personal or professional networks.[10]

To construct the number of foreign medical students trained in these four countries (per thousand population) we obtained information separately from local statistical and medical offices in each of the four countries. Our data come from four separate institutions: Canadian Medical Education Statistics at the *Association of Faculties of Medicine of Canada*, Statistics of Higher Education of the *Federal Statistics Office of Germany,* the *U.K. Higher Education Statistics Agency* and the Data Warehouse at the *Association of American Medical Colleges.*[11] The data for Canada and the U.S. are in the form of flows of foreign medical students enrolled by citizenship: the available data extend from 1978 to 2000 for the U.S. and 1986 to 2000 for Canada. We utilize these data up to

[10]The information flows we consider here are very similar to the network effects for international trade in goods that are not traded on organized exchanges and have no reference price, described by Rauch (1999). In empirical applications, he uses physical distance between nations and the existence of common language or colonial ties as proxies to measure these network effects. We incorporate physical distance in our measure of RD and the number of foreign-trained physicians is intended as another proxy for the role of personal/kinship ties in the diffusion of medical technology.

[11]We acknowledge the following persons for their help in collecting these data: Dr. Gwen Garrison, at the Division of Medical School Services and Studies, *Association of American Medical Colleges*, Dale Yeatman at the *Association of Faculties of Medicine of Canada*, Ilka Willand at *Federal Statistics Office of Germany* and Tanya Biryukova at the *U.K. Higher Education Statistics Agency.*

2000 in order to minimize the impact of year-to-year measurement error, shocks, or cyclicalities to the extent possible. The German and U.K. data are available for a shorter period: 1997-2004 for Germany and 1994-2004 for the U.K. The statistical offices of these two countries provide medical student data in the form of stocks (total number of students enrolled irrespective of year of study) rather than flows. Thus, we divide stocks for 2000 by the number of years of medical study (5 years for the U.K. and 6 for Germany) to construct the annual flow of medical students. The number of foreign medical students for each country is the sum of the annual flow figures for Canada, Germany, U.K. and the U.S. We divide this by each country's total population to obtain the per capita variable (*MEDS*) we use for estimation purposes.[12]

We also use a number of health output and health input variables from various sources. The *World Development Indicators* (WDI) 2002 database provides data on life expectancy at birth, infant mortality per thousand live births, male mortality per thousand male adults, physicians per thousand people, the female illiteracy rate, the percentage of population with access to an improved water source and the percentage of the population with access to improved sanitation facilities.[13] The WDI also provides data on total population and GDP per capita in PPP dollars. We also obtained data on daily calorie intake from the *Food Balance Sheets* database of the Food and Agriculture Organization (FAO). We construct total daily calorie intake per person as the sum of calorie intake from both vegetable and animal sources.[14] We use also a measure of the incidence of AIDS (defined as number of cases per thousand persons) from Papageorgiou and Stoytcheva (2006) in an effort to control for the adverse effects of the AIDS epidemic on health status[15] and an

[12]We repeated the above exercise using data for the period 1978 to 1995 for the US, 1986 to 1995 for Canada, and the 1995 stock for the UK and 1997 stock available for Germany. The estimates for the impact of the foreign medical students variable obtained using this definition were very close to those reported in the text.

[13]The female illiteracy rate is the percentage of females ages 15-24 who cannot, with understanding, read and write a short simple statement on their everyday life. Access to an improved water source refers to the percentage of the population with reasonable access to an adequate amount of water from an improved source, such as a household connection, public stand-pipe, borehole, protected well or spring, and rainwater collection. Reasonable access is defined as the availability of at least 20 liters per person a day from a source within one kilometer of the dwelling. Access to improved sanitation facilities refers to the percentage of the population with at least adequate access to excreta disposal facilities that can effectively prevent human, animal, and insect contact with excreta. Improved facilities range from simple but protected pit latrines to flush toilets with a sewerage connection.

[14]We recognize that food is of dual usage, i.e. both a consumption and health good. We allow calorie intake to enter as a regressor in our empirical specification of health status to capture the marginal impact of food consumption on health. This should be positive for countries below the top income percentiles since over-consumption of food (which can have a negative marginal impact on health in the richer countries) is less likely to be a problem for the 63 countries studied here. Over-consumption of food will be relevant for the richer countries, excluded for the most part from our sample. This non-linearity of the marginal impact of calorie-intake on health is thus left unexplored in the current study.

[15]We thank Petia Stoytcheva for providing these data to us.

indicator of the general degree of openness, the Frankel and Romer (1999) trade share computed from a gravity model based only on population and geography.

Finally, we use a measure for the proportion of a country's land area that is subject to a tropical climate from Sachs and Warner (1997) (*TROPIC*), and an index of malaria ecology (*MALECO*) built upon climatological and vector conditions from Sachs (2003). *TROPIC* is a variable that has been used quite extensively in the empirical growth literature to capture the idea that economic development may depend on geographic endowments like temperate instead of tropical location.[16] *MALECO* is an bio-geographic index that combines temperature, species abundance, and vector type. It is an index that measures the suitability of a country's climate to mosquito breeding as well as the prevalence of mosquito species that feed only on humans. The underlying index is measured at a highly disaggregated sub-national level and then averaged to arrive at an index for the entire country. It is predictive of malaria risk, but also captures the incidence of other tropical infectious diseases.[17] We view the index of malaria ecology as a proxy for those characteristics of tropical climate most closely related to a variety of infectious diseases inimical to health.

We were able to put together the above series for 63 countries (excluding the countries listed previously that are the leading source of pharmaceutical production and R&D) during the period 1961-1995. Excluding the medically advanced countries with a substantial domestic pharmaceutical sector allows us to focus on health status in countries that are dependent to a large (in most cases exclusive) degree on the import of foreign medical technology. It should be noted that the vast majority of these series are not available annually; in some cases the data are exceedingly sparse in the time dimension.[18] Because the cross-sectional dimension of the dataset is more complete and because of the inherent long-run nature of the relation under study, we chose to explore empirically the cross-sectional dimension of our dataset. The cross sectional variables are measured as long-run averages of the available data.

Scatter plots between aggregate per capita medical imports (*MEDIM*) and the three indicators

[16] See e.g., Kamarck (1976) and Sachs (2001) that strongly advocate the potential relationship between tropical location and development.

[17] Sachs (2003, p. 6) explains that "*m*alaria is intrinsically a disease of warm environment..." and that "*t*his is, in essence, why malaria is a disease of the tropics and the sub-tropics." Gallup and Sachs (2001 p.93) go on to suggest that "*m*alaria could be a proxy for a range of tropical diseases", and Gallup, Sachs, and Mellinger (1998, pp. 34 and 41), argue that malaria measures "may be picking up the incidence of other tropical diseases" since "the pattern of malaria is common for a range of infectious diseases whose vectors of transmission depend on the tropical climate."

[18] Life expectancy and infant mortality rates are available about every other year, male mortality rates are available about once per decade and physicians about a third of the time. Moreover, water and sanitation are available only once during the period for a lot of the countries, and the openness measure only once per country during this period.

of health status are in Figure 1. The first panel shows a positive correlation between *MEDIM* (the measure that includes, pharmaceuticals, imports of medical equipment and other broadly defined medical imports) and life expectancy (the correlation coefficient is 0.79). The correlation between medical imports and health is robust to the choice of health indicator: the other two panels show scatter plots between *MEDIM*, on the one hand, and male and infant mortality rates, on the other (the correlation coefficients are -0.77 and -0.84, respectively). While these correlations may be suggestive, in the following section we examine systematically the health-medical imports relationship.

3 Empirical Estimation, and Results

3.1 Motivation of Empirical Specification

As mentioned previously, in this paper we look systematically into the role of exogenous (non-income) forces in the improvement of health status in the second half of the 20th century. Specifically, we argue that R&D-induced advances in medical technology by a few industrialized countries diffuse systematically across the world contributing to significant improvements in health status. Thus, countries receive substantial benefits from foreign medical R&D even in the absence of domestic medical R&D, and even at low per capita income levels.

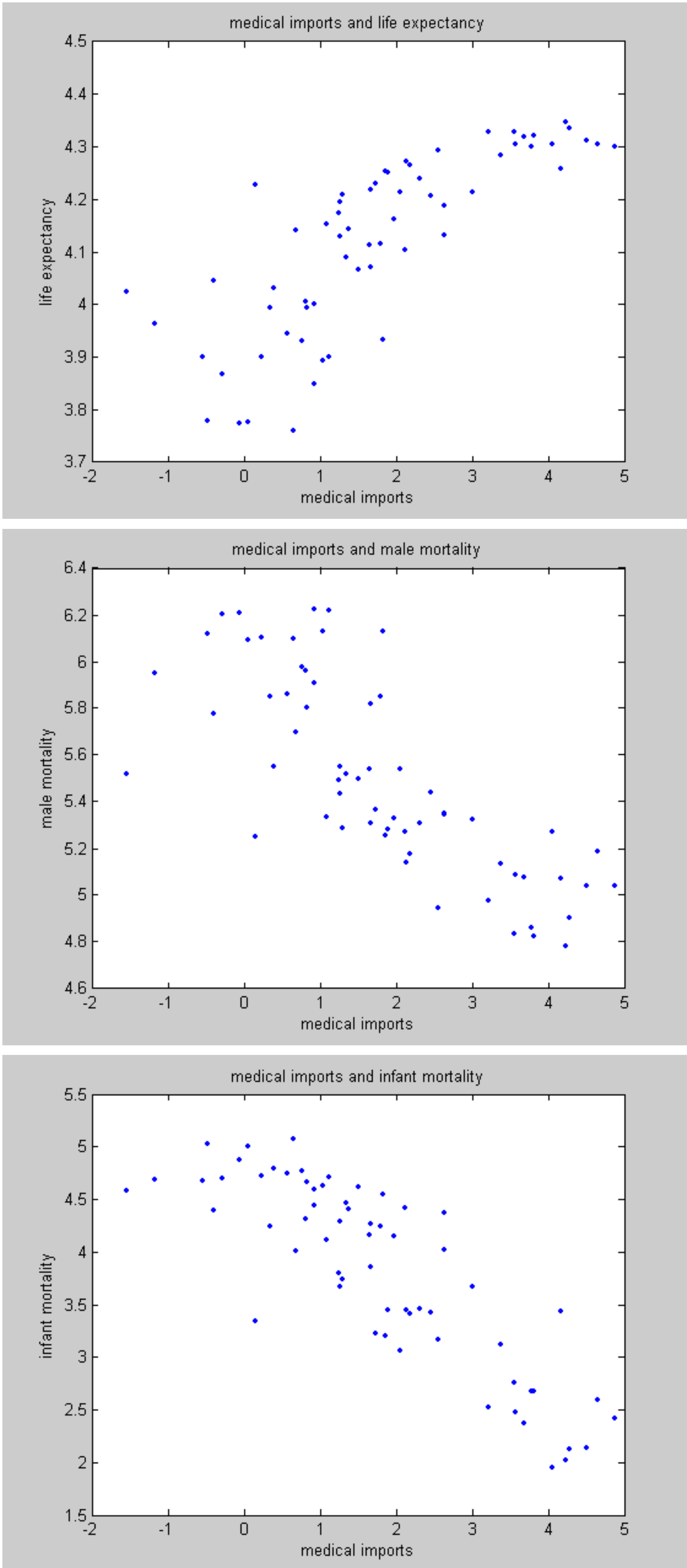
Figure 2 summarizes our testable hypotheses regarding medical technology diffusion. The dissemination of medical advancement is channelled to developing countries in two distinct ways.[19] First, medical technology is embodied in medical exports from frontier economies to the rest of the world. Second, it occurs via the direct transfer of medical knowledge and ideas, a channel that depends on geographic distance from frontier R&D economies and the number of foreign medical students studying in the frontier countries.

As for the first channel, medical imports, we follow Caselli and Wilson (2004) and Eaton and Kortum (2001), and consider that production of goods embodying medical technology is concentrated in a small number of R&D-intensive countries while the rest of the world typically imports these goods. Thus, these imports capture adequately the impact of new embodied medical technology on the overall health level in these countries.[20]

[19] In a previous version of the paper we constructed a simple dynamic model of health status that provided theoretical justification for the channels illustrated in Figure 2. This is available from the authors upon request.

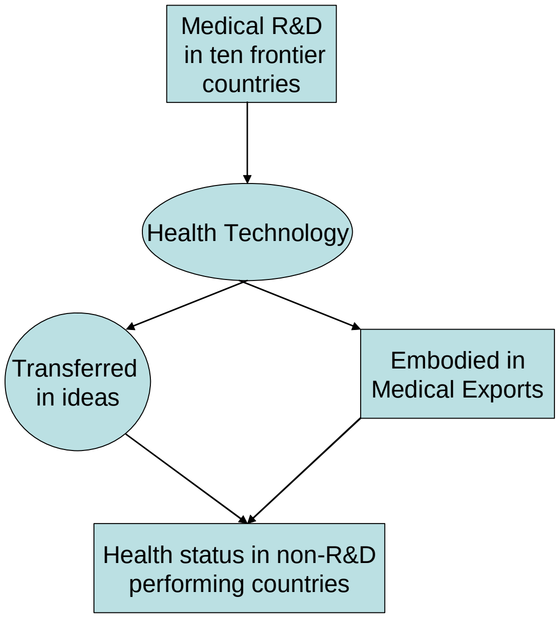
[20] There is a lengthy literature on the diffusion of technology embodied in capital goods (and used by the manufacturing sector) from advanced R&D performing economies to the rest of the world. Spending on R&D by capital

Figure 1: Scatter plots between measures of health and medical imports



Notes: The correlation between medical imports and life expectancy, male mortality and infant mortality are, 0.79, -0.77 and -0.84, respectively. All variables are in logs.

Figure 2: Illustration of baseline theoretical relationship



Direct dissemination of ideas, the second channel of medical diffusion, is consistent with the common belief that R&D carried out in advanced economies diffuses globally in terms of knowledge and ideas that can be used (as in the case of capital goods) by producers other than those carrying out the R&D. These producers may be located within or across the country's borders. This is particularly important in the case of providers of medical services (say physicians) who are likely to improve their practice by utilizing ideas developed in frontier countries.

Although the 'ideas' channel has been studied in the literature on technology diffusion (albeit not medical technology diffusion) the transfer of medical know how via information networks formed as a result of foreign medical students studying in frontier economies (some of whom may return to their home countries or remain in practice in frontier economies) has been overlooked. The extent to which medical students from non-frontier countries study in advanced countries on or close to the medical frontier could facilitate knowledge flows via information networks created between these

goods producers has been shown to boost productivity and growth not only in economies carrying out the R&D but also other economies; for the importance of international R&D spillovers for capital goods see Xu and Wang (1999), Keller (2000), and Savvides and Zachariadis (2005).

two sets of countries.

3.2 Measurement and estimation

We measure health status by three indicators: average life expectancy at birth (*LIFE*), infant mortality (*INFANT*) and male mortality (*MALE*). Our explanatory variables include the three alternative measures of medical goods imports. In addition the distance-weighted foreign R&D (*RD*) and the number of foreign students enrolled in medical studies in four frontier countries (*MEDS*) are also included. The implicit assumption, in the first instance, is that a non-R&D performing country's health knowledge is influenced by the health technology of the countries physically closer to it; consequently, greater proximity with countries that perform large amounts of medical R&D will increase a country's health knowledge. The distance weights used in the construction of *RD* capture physical, and possibly cultural and institutional proximity between countries, all of which would enhance technology flows, independently of the effect of medical imports through the embodied technology channel (for which we control separately in each estimated model). In addition, ideas and knowledge may flow through informal networks as a result of medical training received by foreign students in countries at or close to the frontier.

We examine the relationship between health status and medical technology diffusion by controlling for a variety of determinants of health. In order to isolate the effects of our proposed channels of technology diffusion on health status, one certainly needs to account for various other factors important in determining health outcomes. To begin with, it is widely accepted that a wealthier individual who can afford more medical goods, is generally healthier and more productive.[21] Therefore, we would expect health status and per capita income to be closely interconnected (indeed the correlation coefficient between per capita income and life expectancy in our data is 0.72). Our empirical strategy takes account of this possible endogeneity problem, first, by including the exogenous component of income per capita as a determinant of life expectancy and, second, by including a variety of health inputs through which income per capita might indirectly affect life expectancy (e.g. calorie intake, the number of physicians, female illiteracy rates, access to clean water, and sanitation).

We obtain the exogenous component of income as that part of income per capita explained

[21] Kalemli-Ozcan (2002) presents a formal model that links health outcomes to economic growth. Specifically, in her theoretical framework a decline in mortality increases economic growth through the fertility and education channels.

by social infrastructure (*GADP*). Social infrastructure is the measure assumed by Hall and Jones (1999) to be the main determinant of per capita income across a wide cross section of economies.[22] This is an index of government anti-diversion policies and measures the role of the government in preventing rent-seeking and other non-wealth creating activities, as well as the role of government as a possible diverter of private wealth. It is calculated as the simple average of the scores provided by Political Risk Services (a firm that specializes in assessing country risk) in five categories: (i) law and order, (ii) bureaucratic quality, (iii) corruption, (iv) risk of expropriation and (v) government repudiation of contracts.

In addition, we control for the adverse effects of HIV/AIDS that had devastating repercussions for global health during the second half of our sample period, especially in sub-Saharan Africa. We also use a measure for the proportion of a country's land area that is subject to tropical climate and a measure of malaria ecology built upon climatological and vector conditions, predictive of malaria risk but also capturing the incidence of other tropical diseases. We use this *bio-geographic* variable in addition to the purely geographic *TROPIC* variable in order to best capture the effect of tropical ecology on health. Finally, we show that our results regarding the importance of technology flows for health status do not merely capture a broad "trade openness" effect, but instead depend on the degree to which a given import type embodies R&D-induced technology.

Our main hypothesis relates to embodied technology diffusion in the form of medical imports. A possibly serious concern is endogeneity, insofar as medical imports tend to increase after adverse health shocks are experienced and, generally, in the presence of adverse health outcomes. In order to explore this we test the null hypothesis of exogeneity of medical imports and conclude that medical imports are not likely to be exogenous. The null of exogeneity is rejected with a p-value of 0.072 for *MEDIM* and a p-value of 0.049 for *PHAIM*.[23] On the other hand, with a p-value of 0.229 the hypothesis of exogeneity of imports of medical capital and equipment (*MCAPIM*) is rejected marginally. As the evidence for endogeneity appears strong (at least for two of our three measures of medical imports), we use an instrumental variables approach to address this issue.

The estimates reported in Table 2 are obtained by instrumenting average medical imports over the period 1971-1995 by their predetermined values at the beginning of the period, 1961-1970, in

[22] In our sample of countries, *GADP* is a positive and significant determinant of per capita income that explains about fifty percent of the cross-country variation in per capita income.

[23] The exogeneity test is a Hausman-test type comparison of the coefficient estimate for the potentially endogenous variable using IV relative to OLS estimation; the test is conducted for each regression specification we report in the next section.

order to explain average health status over the 1971-1995 period. Even though the average value of medical imports may be endogenous to health outcomes during the entire period, this approach could alleviate the endogeneity problem to the extent that future health status does not affect previous values of medical imports, so that the initial value of medical imports could be used as a predetermined instrument for medical imports during 1971-1995. Medical imports during 1961-1970 is a strongly significant determinant of medical imports during 1971-1995 in a regression on all predetermined or exogenous variables, with p-values much lower than the 0.01 level. Although it is not possible to test for identification, strong rejection of the null that our instruments have no impact on medical imports is important for the finite sample properties of the IV estimator, as explained in Wooldridge (2002, p.86) and elsewhere.

3.3 Results

Our principal indicator of health status is *life expectancy* and is the measure used by most studies.[24] All variables are considered in natural logarithms so our estimates can be interpreted as elasticities. Model 1 in Table 2 excludes the three measures of medical technology diffusion (medical imports, foreign medical students, and distance-weighted foreign R&D). Models 2-4 include the three measures of technology diffusion. Model 2 includes *MEDIM* as an indicator of medical technology imports. In addition to this aggregate measure, we also consider two alternatives: medical capital and equipment (*MCAPIM*) in Model 3 and pharmaceutical imports (*PHAIM*) in Model 4. All specifications include the exogenous component of per capita income (*INC*) to allow for general level of development effects on life expectancy, and a variety of other additional potential determinants of life expectancy to gauge the robustness of our estimates. Potential explanatory variables of health status include the prevalence of AIDS in the population (*AIDS*), daily calorie intake (*CAL*), availability of physicians (*PHYSI*), female illiteracy (*ILLIT*), access to water (*WATER*), sanitation (*SANI*), the proportion of a country's area subject to a tropical climate (*TROPIC*), malaria ecology (*MALECO*), and a measure of overall trade openness (*TRADE*) to determine whether medical imports in and of themselves have an effect on life expectancy over and above the general effect of openness on life expectancy.

[24] We note that the correlation between the three indicators of health status is high. Life expectancy has a correlation of -0.89 with infant mortality and 0.94 with male mortality. While we focus on life expectancy, we will also discuss the implications of medical imports on the other two indicators of health status and highlight possible differences between the three measures.

Estimated coefficients for Model 1 suggest that physician availability is a significant correlate of life expectancy. The results for Models 2-4 support the existence of an embodied and a disembodied medical technology diffusion link, both statistically and economically significant: the estimate of medical imports is positive and significant in all specifications, and so is that of *RD*. Moreover, the estimate for *MEDS* proxying for network links between medically advanced and non-frontier countries, is positive and significant across all models.

The estimate of the elasticity of life expectancy with respect to aggregate medical imports is 0.031 for Model 2, 0.045 for medical capital and equipment imports in Model 3, and 0.027 for pharmaceutical imports in Model 4. If we compare the country at the 25^{th} percentile (Kenya) in terms of per capita expenditures on medical imports with that at the 75^{th} percentile (Tunisia), the difference is 11.81 constant 1990 US dollars ($2.27 compared to $14.08). The estimates of Model 2 predict that life expectancy would be about 3.5 years higher for the country at the 75^{th} percentile than that at the 25^{th} percentile, holding the effect of all other variables constant. It is interesting to note that imports of medical capital and equipment (*MCAPIM*) have an even stronger positive impact on life expectancy than aggregate medical imports (*MEDIM)*. Using Model 3 and comparing again the country at the 25^{th} percentile (Kenya) with the country at the 75^{th} percentile (Costa Rica) in terms of medical capital and equipment imports, our estimates would imply a life expectancy that is greater by 6.7 years. This suggests that our estimates do not merely capture a broad "trade openness" effect but instead depend on the degree to which a given import type embodies R&D-induced technology. This conclusion is reinforced by the inclusion of a general measure of trade openness (*TRADE*). While estimates of medical imports always retain their economic and statistical significance, the estimated coefficients for *TRADE* are statistically insignificant.

The elasticity of medical students with respect to life expectancy is about 0.013 in all specifications. Comparing the country at the 25^{th} percentile (Algeria) in terms of the number of foreign medical students to the one at the 75^{th} percentile (Denmark) involves an increase of 0.0022 students per thousand population (from 0.0003 to 0.0025). Using the estimates of Model 2, this translates into an increase in life expectancy by 1.6 years.

Finally, the elasticity of life expectancy with respect to foreign R&D ranges from 1.1 in Model 3 to 1.5 in Model 4. The estimate of 1.4 obtained for Model 2 suggests that the average person in the country at the 75^{th} relative to the 25^{th} percentile (in terms of foreign R&D) would face a

Table 2: Cross-country life expectancy regressions

	Life Expectancy			
	Model 1	Model 2	Model 3	Model 4
MEDIM	—	0.0314** (2.18)	—	—
MCAPIM	—	—	0.0448* (1.88)	—
PHAIM	—	—	—	0.0271** (2.18)
RD	—	1.3812** (2.21)	1.1425* (1.81)	1.4887** (2.32)
MEDS	—	0.0126** (2.27)	0.0136** (2.44)	0.0127** (2.28)
INC	0.0309 (0.94)	0.0276 (0.84)	0.0148 (0.43)	0.0310 (0.95)
AIDS	−0.0050 (−1.14)	−0.0079** (−2.12)	−0.0083** (−2.15)	−0.0081** (−2.18)
CAL	−0.0066 (−0.05)	0.0659 (0.58)	0.0468 (0.41)	0.0706 (0.62)
PHYSI	0.0741*** (3.52)	0.0491*** (3.17)	0.0433** (2.52)	0.0515*** (3.37)
ILLIT	−0.0152 (−1.55)	−0.0089 (−1.02)	−0.0080 (−0.89)	−0.0093 (−1.09)
WATER	−0.0145 (−0.31)	−0.0259 (−0.69)	−0.0400 (−1.07)	−0.0238 (−0.62)
SANI	0.0336 (1.22)	0.0146 (0.58)	0.0104 (0.43)	0.0148 (0.59)
TRADE	0.0126 (1.37)	−0.0160 (−0.98)	−0.0155 (−0.89)	−0.0144 (−0.92)
TROPIC	0.0487 (1.27)	0.0392 (1.19)	0.0414 (1.27)	0.0374 (1.13)
MALECO	−0.0266 (−1.32)	−0.0308* (−1.93)	−0.0259 (−1.61)	−0.0299* (−1.87)
Adj. R^2	85.5	86.1	86.4	86.1
Obs.	63	63	63	63

Notes: * p-value < 0.01, ** p-value < 0.05, *** p-value < 0.10. Heteroskedasticity-consistent finite sample standard errors are used in constructing t-statistics. All variables are in natural logarithms. MEDIM is aggregate medical imports in constant US dollars per person, MCAPIM is imports of medical machinery and equipment in constant US dollars per person, PHAIM is pharmaceutical imports in constant US dollars per person, RD is distance-weighted implied R&D stock for each country, MEDS is the number of medical students in medically advanced countries per thousand population of the source country, INC is the exogenous component of initial GDP per capita in constant US dollars, AIDS is AIDS cases per thousand people, CAL is total daily calorie intake per person, PHYSI is number of physicians per thousand people, ILLIT is illiteracy rate as a percentage for females ages 15 to 24, WATER is percentage of population with access to improved water source, SANI is percentage of population with access to improved sanitation facilities, TRADE is the Frankel and Romer (1999) measure of openness, TROPIC is the proportion of a country's land area that is subject to a tropical climate from Sachs and Warner (1997), and MALECO is an index of malaria ecology built upon climatological and vector conditions from Sachs (2003).

life expectancy that is greater by 1.9 years.[25] We note that the impact of *RD* on life expectancy falls in magnitude in Model 3 where we account for medical capital and equipment imports. If *MCAPIM* embodies foreign R&D induced medical technologies to a greater degree than other import categories included in the more aggregate measure, this should reduce the potential of attributing what is, in effect, embodied technology diffusion to the flow of ideas as measured by the foreign R&D stock variable. Overall, the gain for a country that finds itself on the 75^{th} relative to the 25^{th} percentile in terms of all three technology diffusion measures (medical imports, *RD*, and *MEDS*) is 7.03 additional life-years for Model 2, 6.98 for Model 4 and 9.98 years for Model 3.[26]

The exogenous component of per capita income has no significant impact on life expectancy in any of the four models considered in Table 2. Improvements in per capita income was the most commonly cited explanation for differences in health status across countries in some of the earlier literature. Indeed this variable is strongly significant with an elasticity of 0.09 in a regression (not shown here) that includes the three diffusion measures, total calories, and AIDS prevalence. In this sense, our results suggest that per capita income may be a main determinant of health but the effect operates primarily via various health inputs that a larger level of per capita income enables; once these are accounted for, the impact of income is statistically insignificant. On the other hand, the significant effect of medical imports is robust to the inclusion of additional health inputs.

Medical care availability, as measured by the number of physicians per thousand population, has a relatively strong and significant positive impact on life expectancy: the elasticity is in the range 0.04 to 0.05 in models 2-4. It should be noted that physicians play a dual role: first, as a direct input into the health production function and second, as facilitators of technology diffusion. Ideally, one would like to decompose the impact of physicians into its direct and indirect roles, and attribute the latter to the overall impact of medical technology diffusion on health status. This decomposition, however, is far from straightforward. Instead, we include physician availability in all specifications to estimate what is, effectively, a lower bound for the impact of technology diffusion. In doing so, we attribute all the impact of physicians to its direct role in the health production function, understating the overall effect of medical technology diffusion. Alternatively, excluding physicians, leads to a considerable increase in the magnitude for the estimates of medical imports

[25] This involves a comparison of 1,146.97 million constant 1990 US dollars (Korea) relative to 1,121.54 (Iran).

[26] Since the test for the exogeneity of medical and capital equipment imports (*MCAPIM*) could not reject the null at the 0.2 level, we considered *MCAPIM* as an alternative instrument for total and for pharmaceutical medical imports. The estimates for our technology diffusion measures are qualitatively similar to those in Table 2.

and the distance-weighted R&D effect.[27]

The prevalence of AIDS has an adverse and consistently significant impact on life expectancy. The appearance of the pandemic has been the strongest viral shock on the global health scene during the last two decades of the 20^{th} century. The results in Table 2 confirm a negative significant effect of AIDS incidence on life expectancy with an elasticity of just below one percent for all models that include technology diffusion. The index of malaria ecology has a negative and significant, in Models 2 and 4, effect on life expectancy: a one percent increase reduces life expectancy by about three percent. All remaining variables do not enter significantly in any of the specifications of Table 2. Female illiteracy appears to have a negative impact on life expectancy but an effect that is statistically insignificant across all specifications. Calorie intake, sanitation, access to safe water, and the percentage of tropical land in a country are insignificant in the complete model.[28] These variables are significant and of the expected sign in partial regression specifications where one or more of the other inputs are excluded.[29]

The results in Table 2 are robust to excluding potential outliers from the sample.[30] Madagascar is identified as the most influential outlier. Removing this from the sample, our coefficient estimates for the three technology diffusion measures are qualitatively unchanged. The coefficient estimates in Model 2 are 0.033 (p-value=0.032) for $MEDIM$, 1.44 (p-value=0.027) for *RD*, and 0.011 (p-value=0.097) for *MEDS*. India is also identified as a potential outlier for some specifications, perhaps due to the fact that it has an important domestic pharmaceutical sector for which we cannot control given data availability. Removing India, our coefficient estimates for the three technology diffusion measures in Model 2 are 0.031 (p-value=0.083) for $MEDIM$, 1.379 (p-value=0.031) for *RD*, and

[27]Excluding *PHYSI* from Model 2, the coefficient estimate for *MEDIM* nearly doubles to 0.057 (p-value=.007) while that of *RD* increases to 2.11 (p-value=.003) and for *MEDS* to 0.0133 (p-value=.056), suggesting *PHYSI* in part captures technology diffusion, in addition to its direct role in determining health status. The impact of our measures of technology diffusion when excluding *PHYSI* can be viewed as an upper bound of their effect on health status.

[28]The insignificance of *TROPIC* remains when we exclude *MALECO* from the model but the estimates of our three medical technology diffusion measures remain significant. This coclusion is unchanged if we include a measure of proximity to the equator (from Hall and Jones, 1999) in place of the percentage of a country's tropical land, regardless of inclusion or exclusion of *MALECO*. Finally, the latter index has a negative and usually significant impact on health when excluding the TROPIC variable while the estimates of the medical technology diffusion measures are unchanged.

[29]In regressions not reported, calorie intake has a significant impact on life expectancy if physicians and female illiteracy are excluded. Access to improved water source is significant in a specification with only *MEDIM* and per capita income. The same goes for sanitation. *TROPIC* has a highly significant negative impact on life expectancy in a specification that includes income and the three technology diffusion measures.

[30]We determine outliers by checking whether the diagonal of the matrix $X(X'X)^{-1}X'$, where X is the vector of observable explanatory variables, exceeds two times the number of coefficients over the number of observations. This procedure is suggested by Belsley, Kuh and Welsch (1980) to identify influential observations and to rank them in terms of potential influence.

0.013 (p-value = 0.028) for *MEDS*. Removing both countries, the coefficient estimates in Model 2 are 0.032 (p-value=0.082) for $MEDIM$, 1.271 (p-value=0.057) for *RD*, and 0.009 (p-value=0.215) for *MEDS*. In sum, removing potential outlier countries one at a time or both together, does not alter the conclusions regarding the estimates for technology diffusion.

We explore further the relation between medical technology diffusion and health status by considering the rate of male mortality or infant mortality as alternative indicators of health status. We report the results in Table 3. Compared to the estimates for life expectancy, the results for mortality rates present both similarities and some interesting differences.

Model 1a suggests that physician availability, malaria ecology, and income are significant determinants of male mortality. The elasticity of male mortality with respect to medical imports is significant and more than twice that of life expectancy in magnitude and ranges from -0.08 in Model 4a to -0.011 in Model 3a. When we compare the countries at the 75^{th} and the 25^{th} percentile in terms of medical imports, male mortality would be lower by about 41 deaths per $1,000$ adults using the estimates of baseline Model 2a.[31] The estimate for network information flows (*MEDS*) is significant with elasticities ranging between -0.039 (Models 2a and 4a) and -0.041 (Model 3a): comparing the 75^{th} to the 25^{th} percentile country in terms of medical students these estimates imply a lower mortality by between 19.3 to 20.5 deaths per $1,000$ adults. Distance-weighted R&D has negative but statistically insignificant elasticities in the range -1.9 to -2.8.

The availability of physicians has a consistently significant and negative impact on male mortality. The incidence of AIDS is, as expected, a significant determinant of male mortality with an estimated elasticity twice as large as that of life expectancy. Similarly, the estimate of the malaria ecology index is positive and highly significant. Per capita income has a negative effect that is significant in some specifications. Finally, the estimated elasticities with respect to general trade openness are not statistically different from zero and so are the estimates for our measures of calorie intake, illiteracy, sanitation, access to safe water, and percentage of land with tropical climate.

Table 3 also reports estimates for the determinants of *infant mortality*. The estimates for Model 1b suggest that income per capita, physician availability, female illiteracy, and openness to trade are significant determinants of infant mortality. When we include the three measures of international

[31] Excluding *PHYSI*, the estimated coefficient for medical imports increases (in absolute value) to -0.139 (p-value= 0.002) while that of *RD* also increases to -3.9 (p-value=0.072), and that for *MEDS* rises slightly to -0.0399 (p-value=0.03). Again, the increase in the coefficient estimates is likely due to the dual role of physicians: its coefficient estimate captures in part technology diffusion, thus diminishing the impact of technology diffusion when included in the empirical specification.

Table 3: Cross-country male and infant mortality regressions

	Male Mortality				**Infant Mortality**			
	Model 1a	Model 2a	Model 3a	Model 4a	Model 1b	Model 2b	Model 3b	Model 4b
MEDIM	—	−0.0899** (−2.36)	—	—	—	−0.0277 (−0.57)	—	—
MCAPIM	—	—	−0.1089* (−1.92)	—	—	—	−0.0819 (−1.01)	—
PHAIM	—	—	—	−0.0782** (−2.36)	—	—	—	−0.0178 (−0.42)
RD	—	−2.5253 (−1.23)	−1.9115 (−0.88)	−2.8276 (−1.39)	—	−2.4105 (−0.87)	−2.0040 (−0.75)	−2.4738 (−.88)
MEDS	—	−0.0388** (−2.34)	−0.0412** (−2.49)	−0.0389** (−2.37)	—	−0.0609*** (−2.89)	−0.0622*** (−2.91)	−0.0611*** (−2.91)
INC	−0.1734** (−2.11)	−0.1496* (−1.75)	−0.1184 (−1.39)	−0.1581* (−1.87)	−0.2971** (−2.50)	−0.2529** (−2.49)	−0.2236** (−2.12)	−0.2566** (−2.52)
AIDS	0.0105 (0.91)	0.0167* (1.69)	0.0172* (1.66)	0.0173* (1.78)	−0.0001 (−.01)	0.0040 (0.28)	0.0058 (0.39)	0.0039 (0.27)
CAL	−0.0633 (−0.19)	−0.1335 (−0.52)	−0.1017 (−0.38)	−0.1503 (−0.59)	−0.1843 (−0.31)	−0.3459 (−0.72)	−0.3128 (−0.66)	−0.3485 (−0.73)
PHYSI	−0.1551*** (−3.17)	−0.0955** (−2.49)	−0.0873** (−2.20)	−0.1019*** (−2.67)	−0.1461** (−2.56)	−0.1114* (−1.79)	−0.0864 (−1.21)	−0.1165* (−1.95)
ILLIT	−0.0123 (−.58)	−0.0261 (−1.32)	−0.0262 (−1.25)	−0.0247 (−1.30)	0.2417*** (6.51)	0.2360*** (7.60)	0.2302*** (7.19)	0.2373*** (7.67)
WATER	−0.0215 (−.017)	0.0203 (0.19)	0.0458 (0.45)	0.0139 (0.13)	0.0374 (0.28)	0.0430 (0.38)	0.0865 (0.75)	0.0374 (0.33)
SANI	−0.0539 (−0.76)	−0.0085 (−0.13)	0.0040 (0.07)	−0.0074 (−0.12)	−0.0421 (−0.41)	0.0240 (0.30)	0.0317 (0.39)	0.0239 (0.30)
TRADE	−0.0387 (−1.29)	0.0564 (1.09)	0.0456 (0.90)	0.0523 (1.03)	−0.1831*** (−4.56)	−0.1031** (−1.98)	−0.0827 (−1.53)	−0.1092** (−2.11)
TROPIC	−0.0329 (−0.35)	−0.0258 (−0.29)	−0.0279 (−0.29)	−0.0213 (−0.24)	−0.1584 (−0.95)	−0.1367 (−0.92)	−0.1503 (−1.04)	−0.1333 (−0.89)
MALECO	0.1115** (2.45)	0.1292*** (3.13)	0.1149*** (2.88)	0.1267*** (3.09)	0.0245 (0.46)	0.0373 (0.75)	0.0343 (0.71)	0.0352 (0.71)
Adj. R^2	82.1	82.3	82.6	82.5	92.0	92.5	92.6	92.5
Obs.	61	61	61	61	63	63	63	63

Notes: *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.10. Heteroskedasticity-consistent finite sample standard errors are used in constructing t-statistics. All variables are in natural logarithms. MEDIM is aggregate medical imports in constant US dollars per person, MCAPIM is imports of medical machinery and equipment in constant US dollars per person, PHAIM is pharmaceutical imports in constant US dollars per person, RD is distance-weighted implied R&D stock for each country, MEDS is the number of medical students in medically advanced countries per thousand population of the source country, INC is the exogenous component of initial GDP per capita in constant US dollars, AIDS is AIDS cases per thousand people, CAL is total daily calorie intake per person, PHYSI is number of physicians per thousand people, ILLIT is illiteracy rate as a percentage for females ages 15 to 24, WATER is percentage of population with access to improved water source, SANI is percentage of population with access to improved sanitation facilities, TRADE is the Frankel and Romer (1999) measure of openness, TROPIC is the proportion of a country's land area that is subject to a tropical climate from Sachs and Warner (1997), and MALECO is an index of malaria ecology built upon climatological and vector conditions from Sachs (2003). Male mortality rates are not available for Turkey and the Congo, reducing the sample to 61 observations.

technology diffusion, only the network effect via the training of medical students abroad is highly significant, with an estimated elasticity of about -0.06. In terms of the economic effect of this channel, an increase in the number of medical students from the country at the 25^{th} percentile to the 75^{th} percentile would be associated with a reduction in infant mortality of 5.6 deaths per $1,000$ live births for the baseline Model 2b. Higher medical imports and foreign R&D also reduce infant mortality, but the effect is not statistically significant. Given these estimates, the effect of medical imports on life expectancy does not appear to be driven by its impact on infant mortality.[32]

Illiteracy among young women has a negative and highly significant effect on infant mortality in all specifications (in contrast to its insignificant effect on life expectancy and male mortality). The incidence of AIDS has no statistically significant effect on infant mortality, in contrast to its consistently detrimental and significant impact on life expectancy and male mortality. Similarly, the percentage of land with tropical climate and malaria ecology have no impact on infant mortality. Of the three indicators of health status, increases in the exogenous component of per capita income have the largest (in terms of elasticity) impact on infant mortality. This variable is significant in contrast to its zero impact on life expectancy, suggesting that income per capita has a separate impact on infant mortality that is not due to its impact on the control variables included in the model. Finally, overall trade openness is an important determinant of infant mortality in Models 1b, 2b, and 4b, even though it is not a significant determinant of male mortality rates.[33]

4 Conclusion

While much has been written about the beneficial effects of the diffusion of technology embodied in capital goods for both developed and developing economies, there has been no research on potential benefits from the diffusion of medical technology. Our main hypothesis is that medical technologies resulting from R&D in advanced economies have beneficial effects on health status not only in countries originating these technologies but also other nations. The extent of these benefits is captured by direct imports of goods embodying these technologies and in terms of ideas flowing from the originators of R&D to the rest of the world. Moreover, these benefits depend on the

[32] Excluding the availability of physicians from Model 2b, the estimate for *MEDIM* becomes -0.0863 (p-value $=$ 0.043), for *RD* -4.07 (p-value $= 0.132$), and for *MEDS* -0.0624 (p-value $= 0.005$).

[33] Another study that considers the impact of the general level of trade openness on health is Owen and Wu (2004). They also find that greater overall openness reduces infant mortality. They do not consider male mortality and look at male and female life expectancy separately.

intensity of medical goods trade by each recipient nation, in the first instance, and, second, by the size of medical R&D expenditures in the medically advanced countries.

In this paper, we consider a framework in which spending on medical technology imports influences life expectancy. Moreover, informal network links resulting from the training of medical students in frontier economies may be important determinants of health status. We test this framework for a cross section of 63 economies that are not major producers of medical technology or goods, but instead rely heavily (if not exclusively) on imports of medical technology. In our regression specifications we introduce a number of additional health inputs to ascertain the importance of imports of medical goods and technology, independent of these inputs.

Our main finding is that imports of medical goods are positively correlated with the health status in non-R&D performing economies. We also find evidence favorable to the hypothesis that R&D diffuses from the originator nations to recipients in a disembodied form via the flow of ideas that enhances health status. The number of medical students from non-frontier countries studying in medically advanced countries also appears to be important in facilitating the diffusion of medical technology to other countries. An explanation for this is the potential creation of informal information networks that facilitate the transfer of frontier medical knowledge to countries removed from the frontier. Our results suggest that on average, an individual in a country at the top 75^{th} percentile in terms of all three measures of medical technology diffusion lives about seven to ten more years than one in a country at the bottom 25^{th} percentile in terms of these three factors (holding constant the impact of all other control variables). Moreover, imports of medical goods are consistently the more important factor (in terms of enhancing life expectancy), compared to the other two measures of the direct flow of technology (foreign R&D and medical students).

The importance of medical goods imports and the spread of knowledge is examined in a fascinating book by Rocco (2004) who traces the importance of medical discoveries and their diffusion across the globe in controlling the spread of malaria and, thus, facilitating major global economic events. Both trade in commodities and ideas played the decisive part in combating the devastating effects of this disease. Our paper provides evidence that suggests that these two channels have been important in improving the health level of a broad group of countries during the second part of the 20^{th} century. In doing so, we have provided empirical evidence for the relevance of the exogenous or non-income channel, emphasized in the work of Preston and, more recently, Soares and others, in driving advancements in health status.

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