Volume 24 Fall 2012

MURJ

Massachusetts Institute of Technology
Undergraduate Research Journal

Cover Story: Inside the Bhatia Lab p. 18

UROP Summaries

Reports

Peter C. Dedon
Underwood Prescott Professor of Biological Engineering
Deputy Director of the MIT Center for Environmental Health Sciences
Principal Investigator in the Singapore-MIT Alliance for Research and Technology

Massachusetts Institute of Technology
77 Massachusetts Avenue, Building 56-787B
Cambridge, Massachusetts 02139–4307
pcdedon@mit.edu

December 2012

Dear MIT Community,

It is a great privilege to introduce this issue of the MIT Undergraduate Research Journal, just as it is a great privilege to work with undergraduates at MIT. Even after 20 years as a member of the faculty, I continue to be amazed at the intelligence, curiosity, creativity and innovative spirit of MIT students as they pursue the MIT mission of mens et manus - learning by doing. This translation of ideas into real applications, from mind to hands, continues to have a tangible impact on the world - from designing apps to mining the human genome, from launching satellites to curing diseases. One feature of the unique environment of MIT that fosters this practical thinking is the MIT Undergraduate Research Opportunities Program (UROP), which provides students with the intellectual tool kit needed to put ideas into motion - developing a research plan, writing a proposal, performing the research, analyzing the data and communicating the results. The peer-reviewed MURJ gives MIT students the opportunity to take the all-important final step of organizing their ideas and discoveries for presentation to the engineering and scientific communities – the fruit of their labors. This issue of the MURJ illustrates the power of the student research experience with topics ranging from basic discoveries in heat transfer and transistors to practical applications in windshield de-icing, biotechnology and international trade.

This issue of MURJ also highlights another concept that is both an important part of MIT's history and a critical feature of modern science and engineering – the idea of collaboration and team work. Consider the two people for whom my professorship is named – Samuel Prescott, a research assistant with MIT Prof. William Sedgwick, and William Lyman Underwood, grandson of the founder of the William Underwood Company. The two teamed up in the late 1800s to solve a major public health problem of the day: infectious poisoning caused by bacterial spores in canned food. This collaboration between academia and industry saved countless lives from bacterial infections and established food technology as both an industry and an academic discipline. Today, the complexity of modern, innovative science and engineering and the move to interdisciplinary approaches to solve problems demands collaboration among

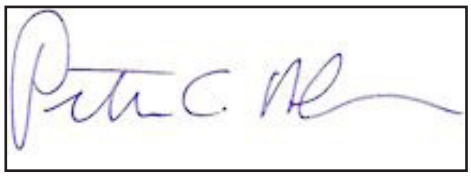
Linn Hobbs
MIT Professor
Departments of Material Science and Nuclear Engineering
President, MIT Chapter of Sigma Xi

Massachusetts Institute of Technology
77 Massachusetts Avenue, Building 13-4054
Cambridge, Massachusetts 02139–4307
hobbs@mit.edu

researchers in all areas. This issue of the MURJ illustrates the point well. One Feature article focuses on the Novartis-MIT Center for Continuous Manufacturing, an industry-academia collaboration to solve problems in drug manufacturing. Another Feature highlights the work of Professor Sangeeta Bhatia, whose collaboration with MIT Associate Professor Bevin Engelward led to the marketing of a new device to assay DNA damage caused by drugs and toxicants. Finally, the article on GaN power transistors describes work done as part of the MIT EECS Super UROP Program, which represents a collaboration between industry, UROP students and MIT faculty.

MIT students have an opportunity to work with their colleagues and with industrial scientists to put their minds and hands to work on solving the big problems facing the world. I welcome you to one of the best examples of this unique feature of MIT – the latest issue of the MURJ.

Sincerely,



Peter C. Dedon
Underwood Prescott Professor of Biological Engineering
Deputy Director of the MIT Center for Environmental Health Sciences
Principal Investigator in the Singapore-MIT Alliance for Research and Technology

Massachusetts Institute of Technology

UNDERGRADUATE RESEARCH JOURNAL
Volume 24, Fall 2012

May, 2012

Dear MIT community,

We are thrilled to present to you the 24th issue of the MIT Undergraduate Research Journal. It has been a pleasure to work alongside hard-working staff to be able to present this issue to you today. The outstanding work of the undergraduate researchers in this issue is evident in their numerous findings that will no doubt make a positive impact on the MIT community and the scientific community at large.

The feature articles in this issue include a look Inside the Bhatia lab, Manufacturing Medicine's Model T, and Markets of Life and Death: Health Care Economics at MIT all articles written by outstanding MURJ staff. Research articles in this issue range from a Convective Heat Transfer in Rotating, Circular Channels to a look at Solar Thermal Fuels for Rapid Windshield De-icing.

We would like to thank all of the student researchers, authors and editors for their tireless work on this issue, and we hope that you enjoy it!

Best,

Elizabeth Bearrick
(Co-Editor-in-Chief)

Sarine Shahmirian
(Co-Editor-in-Chief)

Science News In Review

MEDICINE

Fighting Cancer with Fruit Juice

Pomegranate juice is popularly thought to reduce cancer risks, have cardiovascular benefits, and reduce cholesterol levels. While this may suggest that consuming pomegranate juice should become a regular habit, it is important to weigh these potential benefits against its high caloric content.
Credit: http://upload.wikimedia.org/wikipedia/commons/thumb/2/29/Pomegranate03_edit.jpg/800px-Pomegranate03_edit.jpg

Pomegranate juice may have yet another health benefit to add to its already impressive list. A recently published study indicates that certain compounds in the drink can make cultured breast cancer cells less aggressive. Previously, pomegranate juice has been proved to inhibit the spread of prostate cancer, leading to questions about its effectiveness against other malignancies.

In this study led by scientists from UC Riverside, breast cancer cells were treated with pomegranate juice or a combination of chemicals found in the juice. Cancerous cells that were exposed to the juice were less likely to migrate or to detach from their surroundings. The treated cells therefore were less likely to spread throughout the body, reducing the chances of dangerous metastatic disease. The specific components of the juice responsible for this less-aggressive state were found to be the chemicals luteolin, ellagic acid, or punicic acid. No change was found in normal cells exposed to the juice or its components.

Future studies are aimed at studying the juice's effects on other types of cancer, and possibly developing the compounds important to the juice's effectiveness into cancer-fighting drugs.

—D. Van Egeren

Source: Wang, Penichet, and Martins-Green. Breast Cancer Res Treat (Dec 2012; 136(3))

Plasma: Not Just for Television Anymore

Cancer treatments of the future may not come as pills or liquids. Researchers at the Laser and Plasma Engineering Institute of Norfolk, Virginia are now using jets of plasma to kill cancer cells.

These streams of high-energy charged particles interact with oxygen-containing and nitrogen-containing compounds in the nearby air and water, generating reactive molecules including hydrogen peroxide (H_2O_2) and superoxide(O_2^-). These unstable compounds can damage DNA and other cellular components, killing the cell. This mechanism is similar to the way in which current radiation therapies treat tumors. In this study, scientists exposed samples of leukemic cells to plasma for varying lengths of time and determined how many cells from each sample survived the treatment. The results indicate that the treatment's efficacy depends strongly on the dose of plasma administered with longer exposure times leading to increased cell death. Ten minutes of plasma exposure killed 5% of the cancer cells immediately after treatment, while 60 hours of plasma exposure eliminated virtually all of the cells.

While these initial results appear promising, this experiment has not yet encompassed treatment of mixtures of cancerous and normal cells to determine if the plasma can kill the cancer selectively, without excessive damage to healthy tissue. Further studies also may include other types of cancer.

—D. Van Egeren

Source: http://ej.iop.org/images/0022-3727/45/42/422002/Full/jphysd439339f01_online.jpg

ENERGY

MIT Energy Night!

The MIT Energy Club recently held their annual Energy Night at the MIT Museum. The purpose of MIT's Energy Night is to showcase novel energy related research and products to the public.

The museum immediately reached maximum capacity with hundreds of students and faculty in attendance, while several hundred people waited outside (in the rain!) to have the opportunity to tour research posters and company exhibits, all of which advocated for energy exploration and development. Much interesting research was presented, including topics on biofuels, solar energy, nuclear energy, and wind energy – just to name a few. The evening's highlight was the Fisker Automotive's demo of a new energy-efficient

sport vehicle with a built-in solar panel roof.

Energy Night's Director Lea Poquerusse had this to say about the event's popularity: "After nearly four months of preparation, I am thrilled at how well the MIT Energy Night accomplished its missions this year! With 1,400 attendees, just under 100 presenters and 50 volunteers the event was a terrific success. It reunited people of a wide variety of backgrounds and sparked deep, passionate and interesting conversations! Exactly what I had hoped for."

Overall, the Energy Night was no doubt a success for the MIT Energy Club, as hundreds left the event more educated about green technology and inspired to pursue sustainability projects in the future.

—P. Finkelstein

The MIT Museum lit up for an enormously popular and engaging MIT Energy Night, organized by the Engergy Club.
Credit: http://web.mit.edu/newsoffice/images/campusnotes_images/20121017114630-large.jpeg

ASTRONOMY

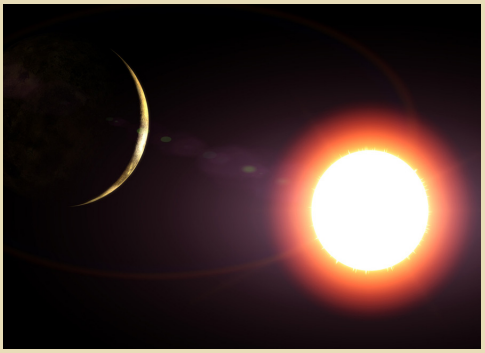
Earth-sized Planet Discovered in α-Centauri Star System

Astronomers have discovered an earth-sized planet orbiting α-Centauri B, a sun-like star, in the α-Centauri star system four light years away. Almost identical to Earth in mass, this exo-planet is the lowest-mass planet discovered yet. Unlike Earth though, it is scorched and barren.

To find exo-planets, scientists use a technique that monitors a star for 'wobble' in its motion that can be caused by the gravitational pull of an orbiting body. This technique, which measures a star's radial velocity, was used in the 1995 discovery of 51 Pegasi B, the first exo-planet ever detected that orbits a sun-like star.

This recent discovery in the α-Centauri star system was the major highlight of a campaign to monitor ten of the brightest, nearest stars visible from the southern hemisphere. Performed using the High Accuracy Radial Velocity Planet Searcher (HARPS) spectrograph on the European Southern Observatory's telescope in La Silla, Chile, planets orbiting three other stars were also discovered.

Finding an "Earth-twin", i.e. an exo-planet circling a sun-like star at an orbital radius similar to Earth's around the Sun, requires heightened sensitivity to the motions of a star. Most astronomers believe a planet-finder rival to HARPS, the NASA spacecraft Kepler, has a higher chance of identifying Earth-like planets. Data from Kepler in its first two years of operation revealed approximately 3,000 potential exo-planets. However, Kepler's mission may end before any additional discoveries can be made, as one of the spacecraft's four reaction wheels, which keep the probe aimed towards its target, has already failed. If another wheel malfunctions, Kepler may not be able to fulfill its potential.



α-Centauri comprises of two stars that, when merged into one by the human eye, form the third brightest star, following Sirius (also a binary star system) and Canopus.
Credit: http://www.bisbos.com/images_exoplanets/alphacenb/alpha-cent-b-b-1024.jpg

From a theoretical standpoint, the presence of an Earth-twin in the α-Centauri system can be supported by the orbital interactions of two of the suns in the system. Given this most recent exo-planet discovery, some astronomers argue that attention should be directed towards plans for a space-based telescope that could image other planets near α-Centauri B.

—L. Jiang

Sources: Nature News (Oct. 16, 2012)

HEALTH

Study Suggests that Diet and Weight Loss Do Not Reduce Cardiovascular Disease in Diabetics

Diabetes mellitus is a very common metabolic disease affecting the pancreas and blood sugar levels. Type I diabetes occurs when a person's body is incapable of producing insulin, while Type II occurs when a person's body cannot use insulin, leading to insulin resistance.
Credit: http://www.totaldiabetessupply.com/blog/wp-content/uploads/2012/07/diet-with-exercise-300x225.jpg

Diabetes is an increasingly growing public health burden. Over 25 million Americans have Type 2 diabetes, and many of these patients are overweight or obese. According to researchers at the Joslin Diabetes Center in Boston, diabetes increases the risk of heart disease by 2-2.5 times.

Many prominent researchers, including Brown Alpert Medical school professor Dr. Rena Wing, believed that diet and weight loss would lower blood sugar, blood pressure, and cholesterol levels, and thus help people with heart disease. To study this, a large federal study randomly assigned over 5,000 overweight or obese people with Type 2 diabetes to two separate groups: some were assigned to an intensive diet and exercise program, and the others were assigned to sessions with general health information. After 11 years of research and monitoring, researchers found that the people in the two groups had nearly identical rates of heart attacks, strokes, and cardiovascular deaths.

Although the study's results did not match expectations, researchers were able to show that participants assigned to the exercise and diet program lost about 5% of their weight, and were able to reduce cardiovascular risk factors. Furthermore, although these dieters ended up with the same levels of cholesterol, blood pressure, and blood sugar as those in the control group, they used fewer medications.

According Dr. David Nathan, a principal investigator at Massachusetts General Hospital, this result may highlight a choice for overweight and obese people with Type 2 diabetes: take "expensive medications" or change your lifestyle.

—C. Huang

Source: NYTimes (Oct. 2012); Obesity (2012)

New Male Birth Control

Nowadays, women often take responsibility for birth control. However, although there are countless pills targeting female hormones to prevent conception, there are very few male contraceptives. Part of the reason behind this large disparity is the high standard needed for male contraceptives. These drugs must have the ability to alter sperm without creating any side effects. Furthermore, since already available female drugs work fairly well, pushing a male contraceptive onto the market is much less urgent. However, according Lawrence Finer, director of domestic research at the Guttmacher Institute, the large frequency of unplanned pregnancies calls for more contraceptives.

Researchers have approached male contraception with countless strategies: plugs, hormones, underwear, gene therapy, etc. The ultimate goal of these strategies is to reversibly slow down sperm proliferation and reduce sperm counts. Recently, scientists have shifted away from disrupting male hormones, such as testosterone, and have begun moving towards studying testes-specific molecules.

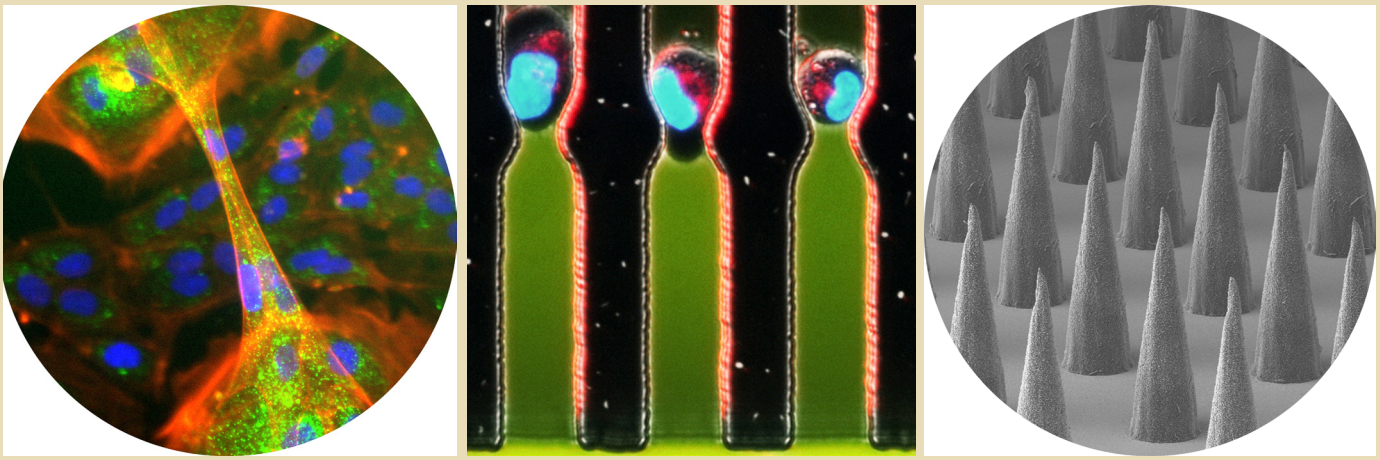
In the late 1950s, scientists began clinical trials on male prisoners. The drug that they were testing, WIN 18,446, was successful in reversibly stopping sperm production, but it also disrupted the breakdown of alcohols, sickening males who drank alcohol.

Although the original researchers stopped testing WIN 18,446, other researchers have been targeting retinoic acid, a molecule involved in the same testes-specific pathway. Other drugs of interest include JQ1, an anti-cancer drug that interferes with testes-specific bromodomain proteins, thus halting sperm maturation, and H2-gamendazole, also disrupting sperm maturation.

While female birth control ranges from the popular option of pills to more lasting options such as IUDs, very few male birth control options exist, apart from the disposable condom.
Credit: http://feministsforchoice.com/wp-content/uploads/2010/12/contraception_591.jpg

DESIGN

Art Selection at the Koch Institute



These are images of the photographs currently on display at the Koch Institute.

Credit: http://ki-galleries.mit.edu/

The urban design objectives for the City of Cambridge call for ground floors to consist of spaces that are actively inhabited by people and compatible with the principal use for which the building is designed. In response to this objective, MIT opted to create the Koch Institute Public Galleries, designed to showcase the research that is taking place within the building and in the larger realm of cancer research.

The galleries, located on the first floor of building 76, are open not only for MIT students, but also for the general public. Multiple events are held in the galleries throughout the year, including school tours and outreach programs, scientific product shows, and research poster exhibits.

A unique aspect of the large, iconic photos currently on display is that they are actual scientific images that were taken and submitted by MIT labs and affiliates to an annual competition. Every year, a special committee initiates an arduous selection process in November, which ultimately culminates with the unveiling of the new exhibition in March.

A view of the Koch Institute Public Galleries at dusk.

Credit: David H. Koch Institute for Integrative Cancer Research at MIT

An inside look of the Koch Institute Public Galleries from the lobby.

Credit: David H. Koch Institute for Integrative Cancer Research at MIT

The first year the galleries opened, less than 100 entries were submitted. The competition is now in its third year and this year over 170 images were submitted. The winners of the competition are selected based on the aesthetic criteria of the images, as well as the scientific explanations behind them. If you haven't been to the Koch Institute Public Galleries before, you should check out last year's winning photos before they are replaced with new winners!

—P. Finkelstein

(Edited with assistance from Alexander Fiorentino, Public Outreach Coordinator of the Koch Institute for Integrative Cancer Research at MIT)

Sources: http://web.mit.edu/newsoffice/2012/alzheimers-hdac2-inhibitors-0301.html

While early testing of both drugs have been promising, lack of sufficient funding is proving to be an issue, as clinical trials are significantly more costly. Despite these funding obstacles, Dana-Farber Cancer Institute biologist James Bradner remains optimistic, believing that male oral contraception may become one of the most important medicines worldwide.

—C. Huang

Sources: Science (Vol. 338, 2012)

Does chocolate make you smarter?

Scientists have long known that regular consumption of dietary flavonoids, compounds commonly found in plant-based foods, can enhance cognitive function. The health benefits of consuming flavonoids include reduced risk of dementia and improved performance on certain cognitive tests. Flavanols, a subclass of flavonoids, are found in cocoa, red wine, green tea, and some fruits. Dietary flavanols have been shown to slow down or even reverse degeneration in cognitive function due to aging, along with other health benefits such as lower blood pressure and improved endothelial function.

Based on this information, Dr. Franz Messerli of St. Luke's-Roosevelt Hospital and Columbia University in New York, used the total number of Nobel laureates per capita to test whether the amount of chocolate a country consumes is related to its population's cognitive abilities. A list of countries ranked by Nobel laureates per capita was obtained from Wikipedia, and data on yearly chocolate consumption in 22 countries was obtained from Chocosuisse, Theobroma-cacao, and Caobisco.

Messerli found a significant linear correlation between chocolate consumption per capita and the number of Nobel laureates per 10 million people in a given country. Switzerland was the top performer in terms of both the number of Nobel laureates and chocolate consumption. According to Messerli's calculations, to increase the number of Nobel laureates in a given country by 1, an additional 0.4 kg of chocolate per capita would need to be consumed.

Of course, correlation does not imply causation. Chocolate consumption and the number of Nobel laureates in a given country can be influenced by a common factor. These findings will need to be tested in a randomized trial to form an appropriate conclusion.

—L. Jiang

Sources: New England Journal of Medicine (2012: Vol. 367)

MURJ Features

Manufacturing Medicine's Model T

Researchers at the Novartis-MIT Center for Continuous Manufacturing seek to transform drug production into a continuous process that is faster and cheaper. Such a sea change could help prevent future cases of drug shortages and contamination, which are currently harming care in the U.S.

BY EBAA AL-OBEIDI

"Any customer can have any car painted any color he wants, so long as it is black." [1] Those were the words of Henry Ford in October 1908 when he introduced the Model T to the American market. It was hailed as the "car that put the world on wheels," because it was durable, easy to repair, and, most of all, cheap – $825, half the price of any other car at the time [2]. Yet the real legacy of the Model T was its innovative manufacturing process. Ford is considered the father of the assembly line because he was the first to make the leap toward continuous mass production rather than individual hand crafting [3]. He streamlined and standardized the process of manufacturing, and in so doing, launched the American automobile industry.

"...the Novartis-MIT Center for Continuous Manufacturing aims to bring about its own manufacturing renaissance: to the pharmaceutical industry."

In much the same vein, the Novartis-MIT Center for Continuous Manufacturing aims to bring about its own manufacturing renaissance: to the pharmaceutical industry. Currently, pharmaceutical companies rely mostly on batch-based manufacturing to produce drugs, and this method is both costly and inefficient [4]. Generally, drug production begins with the synthesis of active ingredients in a chemical manufacturing plant, followed by large-batch processing where the ingredients are formulated into pills, creams, or liquids [5]. This process suffers from frequent interruptions and serious time delays, as each step occurs in a separate facility and the intermediates must be transported between the various plants. In addition, this arrangement makes scale-up for new drugs exceedingly difficult and expensive, leading to a manufacturing process which is inefficient and financially unsustainable.

Figure 1. A system of six connected units which make up a drug-manufacturing prototype built in a MIT chemical engineering lab. *Photo: Dominick Reuter [7]*

In light of these shortcomings, the collaboration between MIT and Novartis is aimed at developing a continuous manufacturing process that can be done at one site, cutting down on time and money, and improving supply flexibility [4]. Additionally, this streamlined production could allow for continuous monitoring of drug quality rather than the current method, which is to perform post-production batch-based testing [7].

Recent reports of drug shortages and contamination accent the importance and the necessity of these improvements. For example, the current national meningitis outbreak – which has been traced back to the New England Compounding Center here in Massachusetts – is an example of drug production gone awry due to poor process reliability and inability to respond to market needs [8]. Moreover, recent nationwide drug shortages have persisted, harming care and proving difficult to fix [6]. Blame has fallen largely on "an array of manufacturing problems," including delays at plants because of serious quality issues [6]. As a result, ambulances and hospitals alike are struggling to keep critical medicines in stock, turning to extreme lengths such as rationing, less potent alternative medicines, and expired drugs [6]. The problem peaked in 2011, when 251 drugs were declared in short supply; since then, the numbers have continued to rise, and patients continue to suffer [6]. The goals of the Center for Continuous Manufacturing address many of these issues, and thus may prevent future crises. Executive Director of the center, Stephen Sofen, confirmed in an email that "because successful operation of a continuous operation requires online process and product quality monitoring, and because of shorter manufacturing cycle times, implementation of continuous manufacturing of pharmaceuticals should help reduce contamination and drug shortages."

"To go truly continuous is going to involve a massive effort employing new technology."

The Novartis-MIT collaboration began in 2007 and is intended to continue for 10 years [4]. Back in 2007, Thomas Van Laar, the head of global technology operations for Novartis, said that, "To go truly continuous is going to involve a massive effort employing new technology." [5] He added that the decade-long project was designed to develop technologies that would be implemented over a larger period of time, on the order of 20 years [5]. Now in its fifth year, the partnership includes about a dozen MIT faculty members who are working on various aspects of the drug manufacturing process [5]. That includes "reactions between drug precursors, purification, crystallization, tablet formation and monitoring of the overall process" [7]. The researchers have succeeded in building a prototype which produces tablets of a drug manufactured by Novartis via a continuous process (Figure 1). It relies on a system of six connected units, and when run continuously, they can transform raw starting materials into finished tablets, such as those in Figure 2 [7].

In 2010, during a panel discussion about the future of manufacturing, Bernhardt Trout, MIT chemical engineering professor and director of the Center for Continuous Manufacturing, stated that basic pharmaceutical manufacturing technologies have not changed for decades. Thus, the hope is that the collaboration between MIT and Novartis will ultimately drive the industry forward by reinvigorating its focus on goods-production and process development [5]. Indeed, if the collaboration yields a success, it will revolutionize not only pharmaceutical manufacturing, but

Figure 2. Drug tablets made from drug-manufacturing prototype built as part of the Novartis-MIT Center for Continuous Manufacturing collaboration. *Photo: Dominick Reuter [7]*

can be applied across chemical and food industries as well.

In light of recent drug contamination outbreaks and drug shortages, the goals of the Novartis-MIT Center for Continuous Drug Manufacturing take on an even greater importance, as the future of healthcare in America hangs in the balance. Just as with Ford's Tin Lizzie, manufacturing takes center stage as the Institute works to apply its expertise in innovation to enhancing the drug production process and revitalizing the American economy.

Acknowledgements:

I would like to thank Stephen Sofen, Executive Director of the Novartis-MIT Center for Continuous Manufacturing, and Professor Timothy Jamison for their advice and feedback on this article. ■

References

1. Hamilton, M. (2012, January 30). The Ford legacy. Retrieved from http://fordnhd.weebly.com/the-model-t.html

2. Brooke, L. (2008). Ford Model T: The car that put the world on wheels. (1st ed., pp. 5-15). Minneapolis, MN: Motorbooks.

3. Hounshell, D. (1984). From the American system to mass production, 1800-1932. (1st ed., pp. 7-9). Baltimore, MD: The Johns Hopkins University Press.

4. Novartis-MIT center for continuous manufacturing. (n.d.). Retrieved from http://engineering.mit.edu/research/labs_centers_programs/novartis.php

5. Mullin, R. (2007). Novartis and MIT study drug production. Chemical & Engineering News, 85(41), 10.

6. Thomas, K. (2012, November 16). Drug shortages persist in U.S., harming care. The New York Times. Retrieved from http://www.nytimes.com/2012/11/17/business/drug-shortages-are-becoming-persistent-in-us.html?hpw&_r=0

7. Trafton, A. (2012, March 12). Continuous drug manufacturing offers speed, lower costs. MIT News Office, Retrieved from http://web.mit.edu/newsoffice/2012/manufacturing-pharmaceuticals-0312.html

8. Pollack, A. & Tavernise, S. (2012, November 21). Oversight failures documented in meningitis outbreak. The New York Times, A27, Retrieved from http://www.nytimes.com/2012/11/22/health/documents-show-fdas-failures-in-meningitis-outbreak.html?ref=health

Markets of Life and Death: Health Care Economics at MIT

MIT's economics department produces lot of great, policy-relevant research. Professors Finkelstein and Gruber exemplify this with their research on health care economics.

BY MAX TIMMONS

Professor Amy Finkelstein
Credit: http://economics.mit.edu/timages/5

Professor Jonathan Gruber
Credit: http://economics.mit.edu/timages/3

Although MIT is primarily known for science and engineering, its economics department is one of the best in the world [1]. The department is notable for its focus on real-world issues and public policy [2]. MIT's Amy Finkelstein (PhD '01) exemplifies these traits in her work on health-care economics, which have studied the effects of information asymmetries and market failures in insurance markets and the effects of expanding Medicaid. Professor Finkelstein won this year's John Bates Clark medal, the second most prestigious award in economics after the Nobel Prize. The previous eight John Bates Clark medalists before Finkelstein all either got their PhDs from MIT or were faculty members at MIT as well [3]. Paul Krugman, the New York Times columnist and Nobel laureate is another MIT alum (PhD '77) and a former faculty member. MIT is also notable for the high representation of its alum in central banks around the world. Notable MIT alum heading central banks include Ben Bernanke (PhD '79), Chairman of the Federal Reserve, Mario Draghi (PhD '76), President of the European Central Bank, and Stanley Fischer (PhD '69), Governor of the Bank of Israel [2]. Another prominent MIT health care economist is Professor Jonathan Gruber (BS '87) aka 'Mr. Mandate'.

Some of Professor Finkelstein's most notable work deals with the Oregon's Medicaid experiment. In 2008, Oregon decided to expand Medicaid coverage for low-income adults but due to limited funding was only able to give coverage to a fraction of those eligible. Hence, Oregon conducted a lottery to determine which eligible adults would get coverage. This gave researchers like Professor Finkelstein a rare opportunity to observe the effects of expanding health care on a randomized sample that could be rigorously compared to a control group (those who entered the lottery but did not get coverage). Although, the study is still ongoing the preliminary data suggest that increasing coverage both increases health outcomes and health care costs [4]. Those results and others that may come from

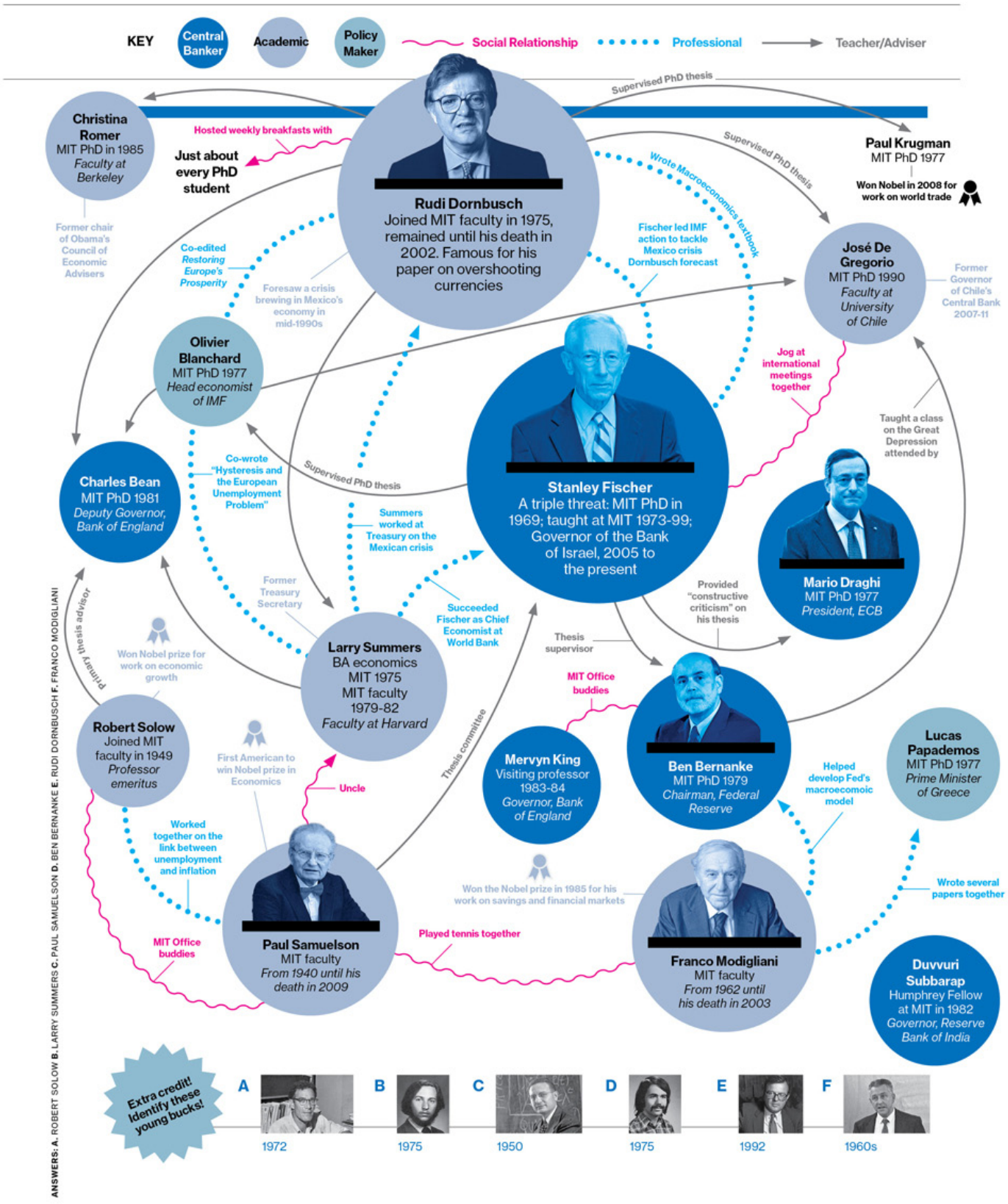


Figure 1. The MIT Family Tree of Economics. *Photo: Bloomberg Businessweek (http://www.businessweek.com/magazine/the-mit-family-tree-01192012-gfx.html)*

the study are likely to influence future health care policy decisions regarding possible expansions of Medicaid or other government insurance programs.

Another important strand of Professor Finkelstein's work deals with information asymmetries in insurance markets. Her 2006 paper "Multiple Dimensions of Private Information: Evidence from the Long-Term Care Insurance Market," coauthored with Kathleen McGarry showed the existence of multiple degrees of information asymmetries in long-term care insurance markets. While previous research was divided on the existence of information asymmetries, where the sides to a business deal have different levels of information in such markets, the paper found evidence that the divergence of previous results stemmed from correlation of information asymmetries. The paper found that buying such insurance was correlated with being a worse risk and being more risk-averse when controlling the health conditions of such individuals [5]. The existence of such a market failure is likely to have important policy implications as well. If only worse risks buy insurance it is likely that without a mandate there will be no market for health insurance for people with preexisting conditions.

Another prominent MIT health care economist is Professor Jonathan Gruber (BS '87) aka 'Mr. Mandate'. Professor Gruber helped design both Governor Romney design Romneycare and President Obama develop Obamacare. Professor Gruber's work focuses on modeling health care systems and his work has found that an individual mandate is essential for preventing free-loader and adverse selection problems. The free rider problem occurs when the uninsured receive emergency health care which they are unable to pay for. The adverse selection problem occurs when only the sick sign up for health insurance driving up insurance premiums. The adverse selection problem can also lead to cost increase spirals where for any given cost of coverage only those sick enough to get more benefits than the cost sign up leading to further cost increases and more people going without insurance and so on. His Gruber microselection model for predicting the effects of changes in health care policy is widely considered the best in the field because of its immense amount of detail. Professor Gruber has also written numerous articles in support of the Affordable Care Act outlining why his research suggests it will be beneficial and why the mandate is essential to law. Last year, Professor Gruber wrote a comic book outlining the benefits of the Affordable Care Act, Health Care Reform: What it is, Why it's Necessary, How it Works [6].

"The work of Professors Finkelstein and Gruber is just the latest in a long tradition of MIT economics scholarship using relatively simple models to explain important real-world phenomena."

The work of Professors Finkelstein and Gruber is just the latest in a long tradition of MIT economics scholarship using relatively simple models to explain important real-world phenomena. Professor Emeritus Robert Solow and Nobel Laureate developed a model for explaining long-run economic growth in terms of various types of capital. Krugman won his Nobel for developing New Economic Geography, which analyzed how agglomeration and economies of scale led to concentrations of industry in particular locations, an observation that previously dominant theories of trade that focused solely on comparative advantage were unable to explain. Krugman also produced a body of work on liquidity traps in the aftermath of Japan's stagnation during the 1990s that proved very relevant during the recent global financial crisis. Another Nobel MIT Laureate, the late Institute Professor Paul Samuelson, developed many tools of modern analytical economics during his career at MIT. The common thread in all these professors is their commitment to theoretically important, empirically robust, and policy relevant research. ■

References

[1] National Research Council Doctoral Rankings. (2010, September 30). Retrieved from http://chronicle.com/article/NRC-Rankings-Overview-/124724/.

[2] Rich, M., Ryan, J. (2012, January 12). Europe Crisis Rescue Begins With MIT Men as a Matter of Trust. Bloomberg. Retrieved from http://www.bloomberg.com/news/2012-01-12/rescuing-europe-from-debt-crisis-begins-with-men-of-mit-as-matter-of-trust.html.

[3] Dizikes, P. (2012, April 27). Amy Finkelstein wins John Bates Clark Medal. MIT News. Retrieved from http://web.mit.edu/newsoffice/2012/amy-finkelstein-wins-clark-medal-0427.html.

[4] The Oregon Health Insurance Experiment. (n.d.) Retrieved from http://www.nber.org/oregon/study_information.html.

[5] Report on Amy Finkelstein. (n.d.). AEA Honors and Awards Committee. Retrieved from http://www.aeaweb.org/aea/AmyFinkelstein.pdf.

[6] Rampell, (2012, March 28). C. Academic Built Case for Mandate in Health Care Law. New York Times. Retrieved from http://www.nytimes.com/2012/03/29/business/jonathan-gruber-health-cares-mr-mandate.html?pagewanted=all.

Inside the Bhatia Lab

Dr. Sangeeta Bhatia, a leader in the field of tissue engineering and nanotechnology, sheds light on her path to becoming who she is today. "Inside the Bhatia Lab" gives us a glimpse of the cutting edge research and work that Dr. Bhatia and the rest of her lab are working on to push the limits of discovery in the biomedical field.

BY FELICIA HSU

Meet Dr. Sangeeta Bhatia

Dr. Sangeeta Bhatia, the John J. and Dorothy Wilson Professor of Health Sciences and Technology (HST), Electrical Engineering and Computer Science (EECS) and Institute for Medical Engineering and Science (IMES) at the Massachusetts Institute of Technology, is a leading researcher in the field of nanotechnology and tissue engineering. As the Director and Principal Investigator of the Laboratory of Multiscale Regenerative Technologies (LMRT) at the Koch Institute for Integrative Cancer Research, Bhatia focuses on the application of nanotechnology in tissue repair and regeneration. In particular, her lab's long term goals are to improve therapies for liver disease, develop models and tools to more accurately study living cells and organs, and utilize nanotechnology for cancer therapies.

However, contrary to what many people might think, her journey in finding her dream job as a professor and researcher working to integrate nanotechnology with the medical field was not always clear cut. Throughout high school, Bhatia's father encouraged her to consider a career in engineering because she displayed a passion and inclination for math and science. When she matriculated to Brown University, she ultimately intended to work in industry. She quickly realized over her time at Brown that in order to rise to the top of research based companies, she needed a PhD. After graduating from Brown University with a Bachelor's Degree in Biomedical Engineering, she decided to take a gap year to work at a pharmaceutical company before beginning a PhD at MIT and MD at Harvard, with her mind set on returning to the pharmaceutical world after her graduate studies. Her path seemed set. It was not until her years as a graduate student that her career path took a wide and unexpected turn.

Dr. Sangeeta Bhatia, Director and Principal Investigator of the Laboratory of Multiscale Regenerative Technologies (LMRT) at the Koch Institute for Integrative Cancer Research. Photo: Sangeeta Bhatia

Over the course of her MD-PhD at the Harvard MIT Division of Health Sciences and Technology, her advisor, Mehmet Toner, was impressed by her abilities and encouraged her to apply for faculty positions. Taking a bold and unpredictable step, Bhatia veered from her original plan to try a

"...being a professor required so much creativity that she saw it as a 'merger of art and science'. The innovative, engineering mindset she possessed finally found its niche."

hand at the teaching profession. Bhatia had always thought that being a professor entailed sitting behind a desk in an office grading papers and writing lesson plans. However, as she acclimatized to the world of academia, she realized this could not be further from the truth; being a professor required so much creativity that she saw it as a "merger of art and science". The innovative, engineering mindset that she possessed finally found its niche. She received her tenure at UCSD and after moving to MIT in 2005, she was promoted to full professor with an endowed chair and received her Howard Hughes Medical Institute (HHMI) investigator title.

Lab Dynamics

One of the distinctive aspects of the Bhatia lab is the supportive lab environment that Bhatia cultivates, which reflects her deep commitment to training graduate students and undergraduate researchers (UROPs). UROPs are heavily involved in all aspects of the lab's work, from experimental design to data analysis, and have the opportunity to contribute to cutting edge research. For instance, Cheri Li, a graduate student, and her UROPs particularly involved in the tissue engineering and liver focus of the lab. The goal of Li's project is to model integrated human physiology in vitro by linking together microfluidic modules that represent different organs of the body. She is working to scale the 3D engineered liver tissues previously developed in the lab into 100-250 μm "microtisssues" that can then be seeded into an endothelial cell-lined "liver module". In order to achieve this, she has made a microfluidic emulsion chip where cells are encapsulated in droplets of photopolymerizable prepolymer.

As part of the lab subgroup that focuses on cancer, Tal Danino, along with his UROP, works to engineer bacteria for cancer drug delivery and diagnostic devices. Because bacteria are known to localize to tumors and have the ability to shelter from the immune system by growing inside the tumor's nutrient-rich environment, Tal and his UROP aim to engineer probiotic bacteria that will produce therapeutics once inside the tumor. This would give greater control over the precision of drug delivery to such tumors. Furthermore, they hope to use bacteria as diagnostic devices to locate the tumors.

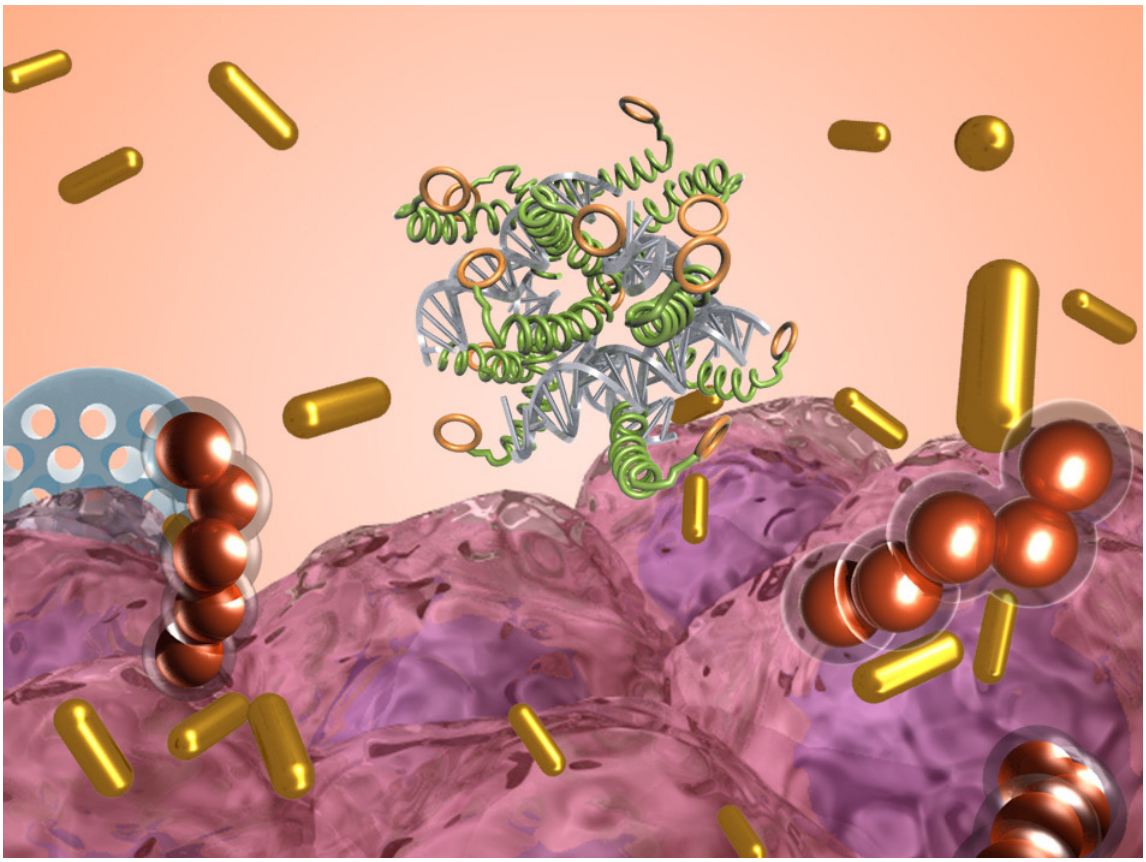
Similarly, Justin Lo, also a graduate student, and his UROP are developing a short interfering RNA (siRNA) delivery vehicle for pancreatic cancer, which is notoriously difficult to treat with traditional chemotherapy. By designing multifunctional tumor-targeting and tumor-penetrating peptides and formulating them to assemble into nanoparticles with siRNA, they hope to target and destroy realistic models of pancreatic cancer. The ultimate goal is to use this delivery system as a platform for both screening new genetic targets in animal models and as potential therapy for pancreatic cancer.

Looking Forward

With the world of biomedical engineering having evolved exponentially over the last few decades, new technologies have now made the unimaginable possible. Dr. Bhatia foresees the development of tools and technology

Seeded hepatocytes (red) using a collagen patterning technique into the MIT crest. Photo: Cheri Li

that address the "holy grail" of cancer research: successful cancer prevention, earlier detection and better treatments. With increasing knowledge of the cancer genome, the introduction of nanotechnology could not have come at a better time. One of the greatest challenges that she feels is important to address is how to bridge the gap between in vitro experiments and clinical trials. While there are several projects focusing on how to target and effectively destroy certain cancers, the next crucial step is to be able to predict how effectively these drugs and methods would perform in an actual human. "There needs to be an improvement in the screening process, as so many drugs that make it to clinical trials have a low success rate when applied into actual human models." she says. Hepregen, a company Dr. Bhatia co-founded, is currently addressing this concern and has already obtained promising data showing that they were able to better predict a human response to specific drugs than the current models. Of course, one of the major obstacles Dr. Bhatia has faced is that of the long-term nature of academic and clinical research. Fourteen years have elapsed since the time she first conceived the idea of developing an accurate human model of the liver and the day this model became clinically available on a global scale. However, having experienced this process once, she hopes to learn from it and make future projects more efficient.



3D rendering of various nanoparticles used in the Bhatia Lab. Photo: Justin Lo

"With the world of biomedical engineering having evolved exponentially over the last few decades, new technologies have now made the unimaginable possible."

The field of nanotechnology and tissue engineering is riddled with barriers that make advancement in the field difficult. But with Dr. Bhatia's leadership and utmost dedication to her work, the Laboratory for Multiscale Regenerative Technologies is tackling and overcoming each of these obstacles in order to push the limits of discovery in the biomedical field with significant promises for advancing medical treatment for the future.

Acknowledgements:

I would like to thank Dr. Sangeeta Bhatia, Cheri Li, Justin Lo, UROPs in the Bhatia lab, and all other members and staff of the Bhatia lab for their help and support with this article. ■

MURJ UROP Summaries

Solar Thermal Fuels for Rapid Windshield De-icing

Sam W. Shames[1] and Jeffrey C. Grossman[2]

[1]Student Contributor, Class of 2014, Department of Materials Science and EngineeringMIT

[2]Grossman Group, Department of Materials Science and Engineering, MIT

Solar Thermal Fuels are a class of materials that store solar energy in the form of chemical bonds and can later release that stored energy as heat. The Grossman group has been working on developing novel solar thermal fuels made from the templating of photoswitchable light absorbing molecules to carbon nanotubes and other nanostructures. My research has been focused on characterizing the de-icing application for this fuel.

A solar thermal fuel could be made into a transparent thin film that would harvest and store solar energy and use that energy to de-ice a windshield. This is a promising application because current de-icing methods are both time consuming and energy inefficient. The solar fuel addresses both these issues. De-icing a windshield today means warming up a car for 20-30 minutes, burning gas to heat the engine, to heat the air, to heat the windshield and eventually the ice. In addition to these problems, another limitation of this process is that it relies on the waste heat generated by the engine, a feature absent in electric and other high efficiency vehicles. Because it addresses the most important de-icing issues, it is of great interest to characterize the potential of solar thermal fuel thin films for such applications.

Using Stefan theory to model heat transfer in the de-icing system, I developed an interactive model that predicts how long a solar thermal fuel thin film would take to de-ice a windshield as a function of thin film thickness, glass thickness, the temperature at which the heat is released, and ice thickness. I published this model online through the Wolfram Demonstrations Project.

Another part of my research involves experimentally measuring the energy required to de-ice a windshield for the purpose of determining if the required film thickness needed to melt the ice is thin enough that the film remains transparent.

My experimental approach involves recording the temperature of a sheet of glass as it heats up, both with and without a block of ice frozen to the surface. When the ice is on the surface, it absorbs energy from the glass, lowering the temperature of the glass. By measuring the difference between the glass temperature with and without ice, I am able to calculate how much energy the ice absorbs as it melts. Currently, I am continuing to run these experiments in order to get reproducible, statistically meaningful data.

The overall aim of my research is to characterize the de-icing application of a transparent thin film made from the Grossman group's novel solar thermal fuels. I hope to determine the minimum necessary thickness for the thin film as well as provide quantitative analysis on the performance of this de-icing process compared to conventional methods. Early results indicate that the solar fuel could de-ice a windshield to safe driving conditions in less than 10 seconds, a 100 fold improvement over traditional methods.

References

1. Kolpak, Alexie, and Jeffrey Grossman. " Azobenzene-Functionalized Carbon Nanotubes As High-Energy Density Solar Thermal Fuels." Nano Letters 11.8 (2011): 3156-3162. Print.
2. Park, W.G, M.S. Park, Y.R. Jung, and K.L. Jang. "NUMERICAL STUDY OF DEFROSTING PHENOMENA OF AUTOMOTIVE WINDSHIELD GLASS." Numerical Heat Transfer, Part A 47 (2005): 725-739. Print
3. "First-Order Solution to Glass-Ice Stefan Problem". http://demonstrations.wolfram.com/FirstOrderSolutionToGlassIceStefanProblem Wolfram Demonstrations Project. Published: May 21, 2012

Thermal and Electrical Optimization of GaN Power Transistors

William A. Gaviria[1], Tomas Palacios[2], David Perreault[3]

[1]Student Contributor, Class of 2013, Department of Electrical Engineering and Computer Science, MIT

[2] Perreault Group, Department of Electrical Engineering and Computer Science, MIT

An estimated 5% to 10% of the world's power is lost as heat in the necessary power electronics circuits needed for everyday use. Fortunately, the unique properties of GaN transistors have the potential to reduce the cost, volume and losses of power in electronic circuits by at least an order of magnitude [Bin Lu, 2010]. GaN high electron-mobility transistors (HEMTs) have reported power gain cutoff frequencies and breakdown voltages as high as 300GHz [Dong Seup Lee, 2011] and 1400V [U.K Mishra, 2010], which are more than an order of magnitude higher than those of Si MOSFETs used today. Recent developments in the processing of GaN devices on Si (100) [Hyung-Seok Lee, 2012] drastically reduce the fabrication costs of GaN devices, allowing them to compete with current Si CMOS technology. These properties make GaN devices an ideal candidate for the next generation high-power, high-frequency applications in power electronics circuits.

This project is concerned with the effect of large voltage and current densities - as seen in high-power electronics - on the thermal dissipation and total electrical resistance of GaN multi-finger HFETs devices. We aim to optimize the device topology of our GaN devices in order to reduce on-resistance and power losses caused by parasitics.

The first step for optimization will be to develop a model for power dissipation for our GaN HFETs and how power dissipation scales with geometrical parameters (Gate width, length, etc) and input waveforms (operating voltage, switching frequency, etc) for our parasitic components. The second part of our optimization will be to develop a basic building block from which we may construct our multi-finger devices. This is done so that our optimization algorithm will deliver a geometry that is feasible for fabrication, and to place boundaries on our optimization. In addition, we will specify a fabrication process that can be easily reproduced in industry.

The optimized device layouts will then be fabricated in the Microsystems Technology Laboratory (MTL). First, we will characterize the fabricated devices to confirm their topology and check for any processing errors. Then, in order to test the validity of our model and optimizing algorithm, we will compare the measured values with those predicted from our model. If time allows, we will implement different geometries such as the waffle and bent gate configurations, and also improve the computation time and functionality of our algorithm as needed. These new geometries will also be fabricated and characterized.

References

1. Bin Lu; Piedra, D.; Palacios, T.; "GaN power electronics," Advanced Semiconductor Devices & Microsystems (ASDAM), 2010 8th International Conference, 105-110, 25-27 Oct. 2010
2. Dong Seup Lee; Xiang Gao; Shiping Guo; Kopp, D.; Fay, P.; Palacios, T.; , "300-GHz InAlN/GaN HEMTs With InGaN Back Barrier," Electron Device Letters, IEEE , vol.32, no.11, pp.1525-1527, Nov. 2011
3. Mishra, U.K.; , "AlGaN/GaN transistors for power electronics," Electron Devices Meeting (IEDM), 2010 IEEE International , vol., no., pp.13.2.1-13.2.4, 6-8 Dec. 2010
4. Hyung-Seok Lee; Ryu, K.; Min Sun; Palacios, T., "Wafer-Level Heterogeneous Integration of GaN HEMTs and Si (100) MOSFETs," Electron Device Letters, IEEE , vol.33, no.2,pp.200-202, Feb. 2012

Do Dendritic Spines Shrink Differently During Synaptic Plasticity in the Autistic Brain?

Sofia Essayan-Perez[1], Miquel Bosch[2], Mark F. Bear[3]

[1]Student Contributor, Class of 2015, Department of Brain and Cognitive Sciences, MIT

[2] The Picower Institute for Learning and Memory, Department of Brain and Cognitive Sciences, MIT

[3]Howard Hughes Medical Institute, The Picower Institute for Learning and Memory, Department of Brain and Cognitive Sciences, MIT

An important challenge in Neuroscience is understanding developmental disorders that impact social interaction and communication capabilities of children. Fragile X Syndrome (FXS) is the leading cause of genetically-based mental retardation. Patients with FXS express behaviors such as mental retardation and obsessive-compulsive disorder. FXS is characterized by the mutation of X-linked Fmr1 gene, causing a loss of FMRP protein (Bear, Connors, Paradiso, 2006). Also, it is the most frequently inherited form of autism (Pfeiffer, Huber, 2009). While the chances of developing autism are 1 in 500 for general population, individuals with FXS have a 1 in 5 chance (Bear, Connors, Paradiso, 2006). This project is part of a larger research effort under the direction of Professor Mark Bear and Dr. Miquel Bosch, conducted at the MIT Picower Institute for Learning and Memory. This project, while directly linked to FXS, will offer important parallels for understanding neurobiology underlying autism spectrum disorders (ASD).

The Bear Lab is using principles of synaptic plasticity to study FXS. Plasticity is a process by which our brain changes its neural connections and cellular structure (Bear 2003). Plasticity allows selected neuronal circuits to have more effective synaptic transmission, while causing less utilized networks to have less efficient communication. These changes in the brain occur through the mechanisms of Long Term Potentiation (LTP) and Long Term Depression (LTD). LTP is related to strengthening electrical transmission and to the growth of dendritic spines, microscopic protrusions along the dendrite where synapses are located (Bear, 2004; Bosch, Hayashi, 2011). In LTD, certain connections are trimmed, synapses are weakened and dendritic spines shrink (Bosch, Hayashi, 2011). In both LTP and LTD, there are two resulting types of changes in the brain: functional and structural. In functional plasticity, neurons change their electrical properties to adjust synaptic strength. Simultaneously, structural changes alter the morphology or shape of the cell, notably at dendritic spines. This dynamic and constantly evolving process relies on experiential input. It has been observed that patients with FXS have too many and too elongated dendritic spines (Bear, 2004). The same phenotype has been detected in other forms of autism.

This project aims at observing structural evolution of dendritic spines as they undergo plasticity, particularly LTD. Experimentally, LTD can be induced by activating NMDA receptors (NMDAR) or metabotropic glutamate receptors (mGluR). Interestingly, mGluR-LTD has been found to be exaggerated in mouse models of FXS. Using 2-photon microscopy, this will give us more insight into what is occurring over time in FXS and Autistic brains. Currently, the functional plasticity has been well studied in FXS compared to the structural plasticity, but the latter is essential to advance our knowledge beyond the static spine morphology. Thus, this project is aimed at providing more information on the correlation between structural and functional plasticity.

I am analyzing changes in dendritic spine length, volume, and density in FXS knock-out and wild type mouse models using 2-photon microscopy images. To analyze the morphology data from these images, I have learned Fiji software. Further, I am integrating data of each experimental recording in a comparative manner for knock-out and wild type mice. Through this research, I have learned laboratory techniques like baselines and

drug applications to induce LTD in neurons. This UROP is enabling me to apply what I am learning in my Brain and Cognitive Sciences classes, particularly regarding cellular neurobiology. This project is developing my practical skills that are important to complement the theoretical knowledge I gain in the classroom. Moreover, gaining understanding of plasticity in FXS and Autism provides an evolving picture of the molecular mechanisms of learning, memory, and development. This research is providing more information regarding plasticity in the context of developmental disorders, and contributes to the search for potential treatment targets.

References

1. Bear, M. F. (2003). Bidirectional synaptic plasticity: from theory to reality. Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences (London) (358), 649-655.
2. Bear, M. F., Connors, B. W., & Paradiso, M. A. (2006). Neuroscience: Exploring the brain. (3rd ed., p. 706). Baltimore: Lippincott Williams & Wilkins.
3. Bear, M. F., Huber, K. M., & Warren, S. T. (2004). The mGluR theory of Fragile X mental retardation. Trends in Neuroscience, 27(7), 370-377.
4. Bosch, M., & Hayashi, Y. (2011). Structural plasticity of dendritic spines. Current Opinion in Neurobiology, (22), 1-6.
5. Pfeiffer, B., & Huber, K. M. (2009). The state of synapses in Fragile X Syndrome. Neuroscientist, (15), 549-568.

MURJ Reports

Convective Heat Transfer in Rotating, Circular Channels

Brenna Hogan[1]

[1]Student Contributor, Department of Mathematics, MIT

The study of flow and heat transfer in the rotating reference frame has important implications for real world applications. Rotation gives rise to secondary flows, perpendicular to the primary radial flow. These secondary flows are produced by Coriolis forces in the rotating reference frame. The case of a straight circular cross-section channel rotating around a perpendicular axis is examined in this work. Rotation is relevant in the study of cooling passages because rotation influences cooling performance via secondary flows generated by Coriolis forces and centripetal buoyancy. Rotation improves heat transfer from the stationary case by increasing heat transfer on the trailing edge of the channel compared to the leading edge, resulting in an overall increase in the convective heat transfer coefficient. However, an increase in the flow resistance from the stationary case is also seen with rotation. Nusselt number values for flow in a rotating reference frame are obtained through computational fluid dynamic (CFD) analysis for Rossby numbers, Ro ~1-4, and Reynolds numbers, Re ~1,000-2,000. In this abbreviated version of the work, the model validation is omitted; however, the heat-transfer model was first validated according to known Nusselt number correlations for laminar, developing flow in circular tubes and by friction factor correlations for fully developed flow in circular cross-section pipes rotating at constant angular velocity about an orthogonal axis. The results from an analysis of a rotating channel show heat transfer enhancement for increasing rotational speeds, as predicted through secondary flows caused by Coriolis forces. Moreover, the heat-transfer enhancement is found to be greater than the resulting increase in friction losses due to secondary flows.

Introduction

The case of a straight circular cross-section channel rotating around a perpendicular axis, as shown in Figure 1, is examined in this work.

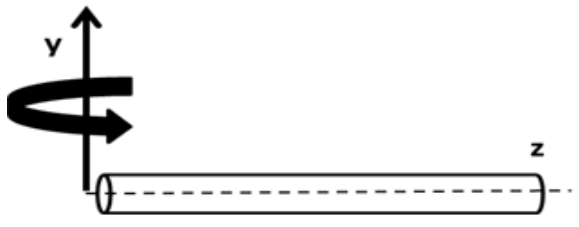


Figure 1. Circular cross-section tube rotating about perpendicular axis

The objective is to study heat transfer in rotating tubes of circular cross-section and to obtain Nusselt number and friction factor correlations for various flow conditions. In this work, we consider developing laminar flow at constant wall temperature subject to perpendicular rotation, where the flow direction is perpendicular to the axis of rotation. In particular, the focus is on the limiting case where the flow is purely radial, as depicted in Figure 1.

Formulation of the Problem

We consider the motion of a fluid in a channel rotating with a constant angular velocity. The Navier Stokes equation for a Newtonian viscous fluid when the flow is incompressible in the inertial reference frame is given by:

$$\rho\left(\frac{D\vec{V}}{Dt}\right) = \nabla P + \mu\nabla^2\vec{V} + \vec{F} \quad (1)$$

where the left hand side describes acceleration of the fluid particle and the right hand side is a summation of body forces and divergence of stress including pressure and shear stress. In the rotating frame of reference, the total derivative term of the left-hand side becomes

$$\frac{D\vec{V}}{Dt} = \frac{\partial\overline{V^*}}{\partial t} + \overline{V^*}\cdot\nabla\overline{V^*} + \bar{\Omega}\times(\bar{\Omega}\times\bar{r}) + 2\bar{\Omega}\times\overline{V^*} \quad (2)$$

where $\bar{\Omega}\times(\bar{\Omega}\times\bar{r})$ is the centrifugal force and $2\bar{\Omega}\times\overline{V^*}$ is the Coriolis force. Substituting the rotational terms to the Navier-Stokes gives

$$\frac{\partial\overline{V^*}}{\partial t} + \overline{V^*}\cdot\nabla\overline{V^*} = \frac{-\nabla P}{\rho} - \bar{\Omega}\times(\bar{\Omega}\times\bar{r}) + \vartheta\nabla^2\overline{V^*} - 2[\bar{\Omega}\times\overline{V^*}] + \bar{F} \quad (3)$$

By vector identity, the centrifugal acceleration term can be expressed as

$$-\bar{\Omega}\times(\bar{\Omega}\times\bar{r}) = \frac{1}{2}\nabla(|\bar{\Omega}\times\bar{r}^2|) \quad (4)$$

A new pressure-like variable P^* can be defined as

$$P^* = P - \frac{1}{2}|\bar{\Omega}\times\bar{r}|^2 \quad (5)$$

which represents the pressure modified by the centrifugal force [1]. This substitution is commonly made in the rotating reference frame to separate dynamic from hydrostatic pressure. Since the flow is steady with respect to the rotating coordinate system and gravitational forces are assumed to be negligible, the time derivative term on the left hand side of Equation (3) disappears and the vector of body forces in the stationary reference frame, $\bar{F}$, on the right hand side disappears as well. Equation (3) thus becomes

$$\overline{V^*}\cdot\nabla\overline{V^*} = \frac{-\nabla P^*}{\rho} + \vartheta\nabla^2\overline{V^*} - 2[\bar{\Omega}\times\overline{V^*}] \quad (6)$$

Equation (6) can be non-dimensionalized by introducing the dimensionless variables

$$\overline{V^*}' = \frac{\overline{V^*}}{v}, \quad \left(\frac{P^*}{\rho}\right)' = \left(\frac{P^*}{\rho}\right)\frac{1}{v^2}, \quad \bar{\Omega}' = \frac{\bar{\Omega}}{\Omega_o}, \quad \nabla' = D\nabla$$

which gives

$$\overline{V^*}'\cdot\nabla'\overline{V^*}' = \frac{-\nabla' P^{*'}}{\rho} + \frac{\vartheta}{Dv}\nabla'^2\overline{V^*}' - \frac{2D\Omega_0}{v}[\bar{\Omega}'\times\overline{V^*}'] \quad (7)$$

The inverse Reynold and Rossby numbers appear from the dimensionless momentum equation. Substituting the known dimensionless parameters, we obtain

$$\overline{V^*}'\cdot\nabla'\overline{V^*}' = \frac{-\nabla' P^{*'}}{\rho} + \frac{1}{Re}\nabla'^2\overline{V^*}' - \frac{1}{\mathrm{Ro}}[\bar{\Omega}'\times\overline{V^*}'] \quad (8)$$

The non-dimensional Reynolds and Rossby numbers are explicitly given as

$$Re = \frac{Dv}{\vartheta} \quad (9)$$

$$\mathrm{Ro} = \frac{v}{2D\Omega_0} \quad (10)$$

The Reynolds number is a dimensionless number that is the ratio of inertial to viscous forces. Laminar flow occurs at low Reynold's numbers where viscous forces dominate the flow and the flow is characteristically smooth. At high Reynold's numbers, the flow is dominated by inertial forces which tend to produce eddies, vortices, and other flow instabilities, and the flow is said to be turbulent. The Rossby number is the ratio of inertial to Coriolis forces. A small Rossby number signifies flow strongly affected by Coriolis forces, and a large Rossby number indicates flow in which inertial and centrifugal forces dominate.

In addition to the momentum equation, given are the continuity equation for incompressible flow,

$$\nabla\cdot\overline{V^*} = 0 \quad (11)$$

and the energy equation,

$$\rho c_p\left(\frac{\partial T}{\partial t} + \overline{V^*}\cdot\nabla T\right) = \nabla\cdot(k\nabla T) + \rho(\varepsilon + q) \quad (12)$$

where ε represents viscous dissipation in the fluid and q represents heat generation in the fluid (i.e. from a chemical reaction), and k is the thermal conductivity of the fluid. Our flow is steady, includes no viscous dissipation or chemical reactions, and we assume constant properties. For our flow, the energy equation then becomes

$$\overline{V^*}\cdot\nabla T = \alpha\nabla^2 T \quad (13)$$

Where $\alpha = \frac{k}{\rho c_p}$ is the thermal diffusivity of the fluid. The choice of non-dimensionalizing parameters in this case will be D, α, and v.

$$\frac{Dv}{\alpha}\overline{V^*}\cdot\nabla T = \alpha\nabla^2 T \quad (14)$$

The dimensionless group on the left-hand side is defined as the Peclet number,

$$Pe = \frac{Dv}{\alpha} = RePr \quad (15)$$

where

$$Pr = \frac{\vartheta}{\alpha} \quad (16)$$

The Prantl number is a dimensionless number which is the ratio of momentum diffusivity to thermal diffusivity. Our experiments involve air, which has a Prandtl number of 0.7. With a Prandtl number ~ 1, the momentum and thermal boundary layers will develop at the approximately the same rate, so the hydrodynamic and thermal entrance lengths are approximately equal.

Based on the dimensionless analysis just performed, we expect the heat-transfer coefficient in a fully developed rotating system to be a function of the three dimensionless parameters: *Re, Ro, Pr*. In the case

of developing flow, we therefore expect the Nusselt number Nu to be governed by the relationship

$$Nu = f\left(Re, Ro, Pr, \frac{L}{D}\right) \quad (17)$$

Nusselt Number-Rotating Reference Frame

The axial and circumferential distribution of mean temperature is found for the constant surface temperature condition by the equation,

$$\frac{d(T_s - T_m)}{dzd\theta} = \frac{\pi Dh}{\dot{m}c_p}(T_s - T_m) \quad (18)$$

In the rotating case, the heat transfer coefficient will now be axially and circumferentially dependent. Integrating Equation (18), we obtain

$$\ln\left(\frac{\Delta T_o}{\Delta T_i}\right) = \frac{\pi DL}{2\dot{m}c_p}\int_0^L\int_0^{2\pi} h dz d\theta \quad (19)$$

The average heat transfer coefficient is thus

$$\bar{h} = \int_0^L\int_0^{2\pi}\frac{h}{2\pi L}dxd\theta \quad (20)$$

CFD simulations were run and corresponding Nusselt numbers for Re~1,200 and Re~2,000 as well as Rossby numbers, Ro~ 4.1, 2.2, 1.5, 1.7 were obtained. Plots of velocity profiles at the outlet for no rotation, slow rotation, and fast rotation for the case Re~1,200 as well as contours of velocity for these cases are shown in the Results section.

Results

In the stationary, fully developed laminar case, we observe the expected parabolic velocity profile. In the contour plot in Figure 2b, the core velocity at the center of the circular tube is highest and the flow is slowed down near the walls and zero at the walls by the no-slip condition.

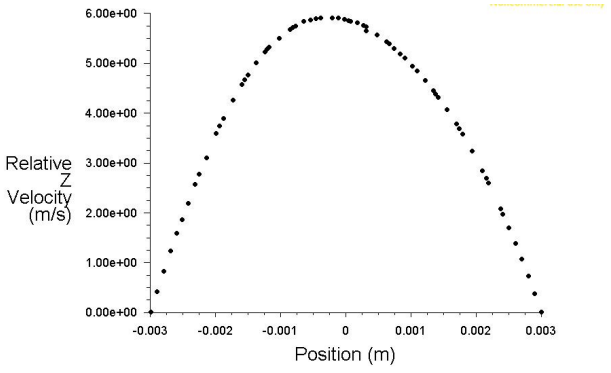


Figure 2a. Cross-section at outlet of circular tube showing parabolic velocity profile in stationary (i.e. no rotation) case

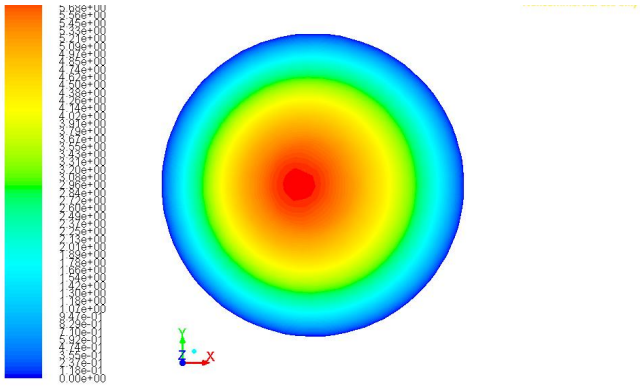


Figure 2b. Contours of z-velocity showing velocity distribution inside circular tube in non-rotating case

In Figure 3a with low rotation, instead of displaying the parabolic profile we expect in the stationary laminar case, the flow profile is shifted towards the trailing edge of the tube, away from the leading edge, resulting in an asymmetrical parabolic profile. In this case, we do not attain the maximum velocity obtained in the stationary, laminar case, but a lower velocity. The flow on the leading edge is now characterized by slower speeds than the stationary, laminar case as well as in the center of the channel. However, the flow further to the side of the trailing edge has increased speed, reaching a maximum at about 250 cm.

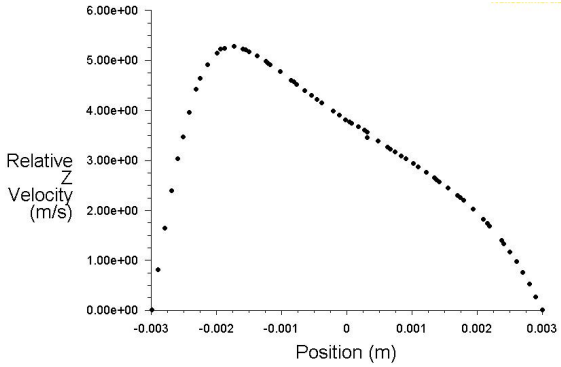


Figure 3a. Cross-section at outlet of circular tube showing parabolic velocity profile shift for low rotational speed, Ω_o= 60 rpm, for channel rotating counter-clockwise about the y-axis

At higher rotational speeds, in this case, 300rpm, the asymmetric parabolic curve is seen again. Again, the maximum velocity attained in the stationary case is not attained, even at the peak, which shifts from the center of the channel further to the trailing edge, and rests at around 200cm. Towards the leading edge, the flow is slowed more from the stationary case and from the low rotation case. Flow has been shifted closer to the trailing

edge and the velocity of this flow near the trailing edge has increased from the low rotation case seen previously.

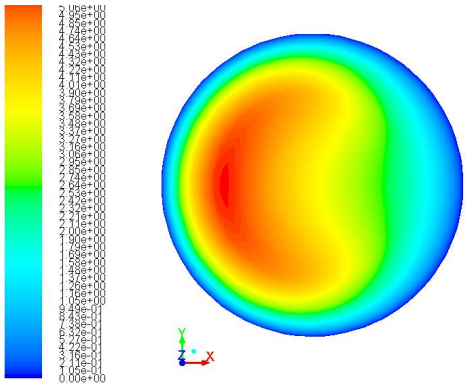


Figure 3b. Contours of z-velocity showing velocity distribution inside circular tube in low-rotation case for channel rotating counter-clockwise about the y-axis.

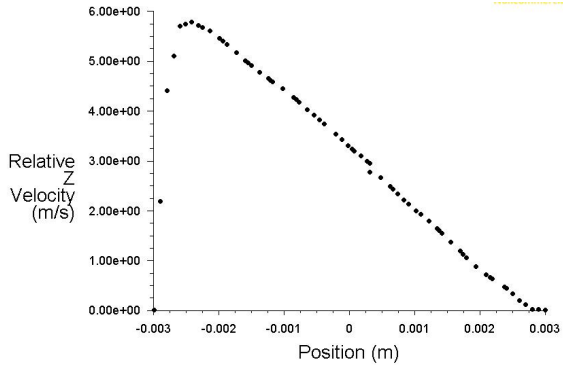


Figure 4a. Cross-section at outlet of circular tube showing parabolic velocity profile shift for high rotational speed, Ω_o= 2000 rpm, for channel rotating counter-clockwise about the y-axis

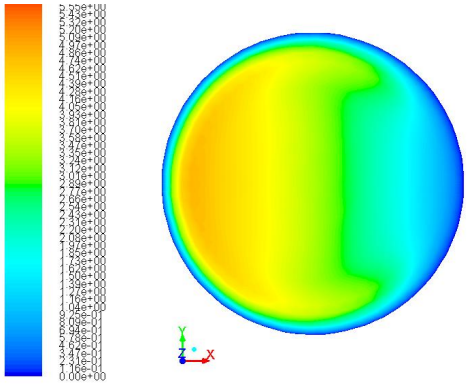


Figure 4b. Contours of z-velocity showing velocity distribution inside circular tube in rotation case Ω_o= 2000 rpm for channel rotating counter-clockwise about the y-axis.

At the high rotation rate of 2000rpm, we see the most shift toward the trailing edge of the channel, with the maximum of the velocity profile the furthest shift to the left of all the cases, resting at around 175cm. The value of the radial velocity is also the highest of the cases involving rotation, with the peak velocity reaching around 5.75 m/s. This case shows significant decrease in radial flow velocity near the leading edge and significant increase in flow velocity near the trailing edge.

In the high rotation case, the secondary flow caused by the Coriolis forces arising in the rotating reference frame is the greatest of the three cases. Secondary flows caused by Coriolis forces are said to increase heat-transfer effects. The following analysis presents and discusses data simulated for Re~1,200 and 2,000 and Ro~4.1, 2.2, 1.5, 1.7.

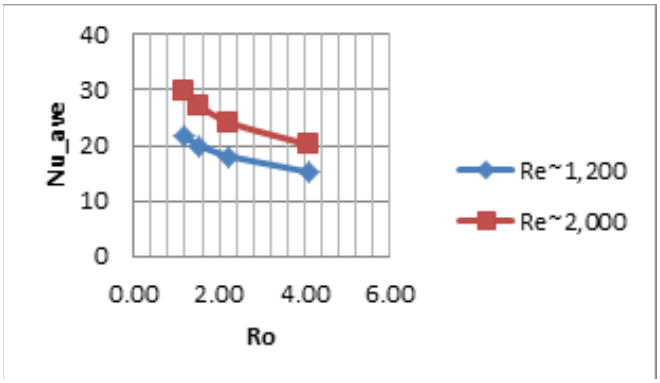


Figure 5. Average Nusselt number results obtained over length of tube for Ro~ 4.1, 2.2, 1.5, 1.7 and Re~1,200, 2,000. Increased heat transfer effect with increased rotation can be seen.

The average Nusselt number is higher at a given Rossby number for higher Reynolds number. Increasing rotational speed (decreasing Rossby number) for a given Reynolds number leads to enhanced heat transfer effects. In the range of 1.2<Ro<4.1 for both Re~1,000, 2,000, the average Nusselt number increases about 50%.

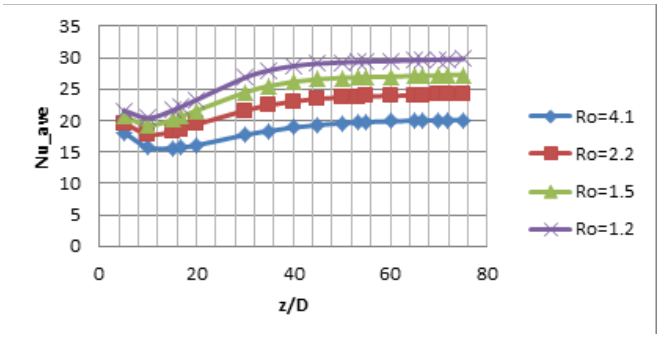


Figure 6. Average Nusselt number obtained for axial positions for Re~2,000 and Ro~4.1, 2.2, 1.5, 1.7. Increased heat transfer with increased rotation speeds can be seen.

In Figure 6, the average Nusselt number obtained for axial locations throughout the tube for a given Reynold's number and Rossby number are reported. Increased rotational speeds (decreased Rossby number) lead to increased heat transfer effect.

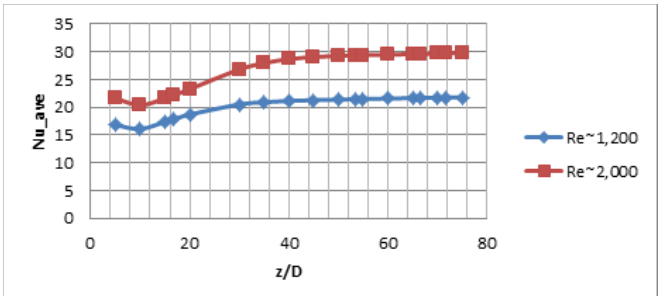


Figure 7. Average Nusselt number obtained for Ro~1.2 for Re~1,200 and Re~2,000. Enhanced heat transfer at given Rossby number for a larger Reynolds number.

Figure 7 shows the average Nusselt number obtained for Ro~1.2 and Re~1,200, 2,000. Enhanced heat transfer over the length of the tube is seen for a larger Reynolds number. Interestingly, the curves show a dip followed by an increase and plateau to a value at infinity. As seen in the stationary, constant wall temperature case, the coefficient of convective heat transfer is large in the entrance region and then decreases to a constant value in the fully developed region. As is seen in the stationary case, the Nusselt number first decreases in the rotating case; however, it then increases, and finally plateaus to a higher value at infinity. The Coriolis forces due to rotation are interfering with the boundary layer development downstream so that increased heat transfer effects are seen downstream so that the average Nusselt number plateaus to a higher value.

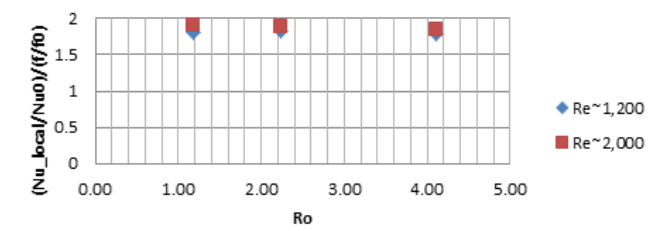


Figure 8. Ratio of heat transfer enhancement to friction losses

Figure 8 shows the ratio of heat transfer enhancement to friction losses as a function of the Rossby number which is of particular importance in cooling applications because it quantifies the price which must be paid for heat transfer enhancement (that is, increased friction losses) with increased rotation. The data shows the ratio of heat transfer enhancement to friction factor penalty is always greater than one for every rotational speed, meaning that at any rotational speed, the heat transfer enhancement wins out over increased pressure drop. The ratio appears to remain fairly constant over the span of rotational numbers.

Conclusion

Increasing rotation speed leads to increased heat transfer effects due to secondary flow caused by Coriolis forces. Rotation improves heat transfer from the stationary case by increasing heat transfer on the trailing edge of the channel compared to the leading edge, resulting in an overall increase in the convective heat transfer coefficient as well as an increase in the flow resistance from the stationary case. However, the data shows the ratio of heat transfer enhancement to friction factor penalty is always greater than one for every rotational speed, meaning that at any rotational speed, the heat transfer enhancement outweighs the increased pressure drop.

List of Variables

For a full list of variables, please see the supplementary data that can be obtained from the author.

References

1. B. M. Boubnov and G. S. Golitsyn (1995). Convection in Rotating Fluids. Springer, pp 5-10. ISBN 0-7923-3371-3.
2. E. N. Sieder and G. E. Tate. Ind. Eng. Chem., 28, 1429, 1936.
3. H. Hausen. Z. VDI Beih. Verfahrenstech., 4, 91, 1943.
4. H. Ito and K. Nanbu (1970). "Flow in Rotating Straight Pipes of Circular Cross Section," ASME paper No. 70-WA/FE-13.
5. Incropera et al (2002). Fundamentals of Heat and Mass Transfer. pp 465-490. ISBN 0-471-38650-2.
6. W. D. Morris. "Rotating Facility to Study Heat Transfer in Cooling Passages of Turbine Rotor Blades," Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 1996. online version: http://pia.sagepub.com/content/210/1/55.
7. Whitaker, S., AIChE J., 18, 361, 1972.
8. Y. Mori and T. Fukada. "Convective Heat Transfer in Rotating Radial Circular Pipe (2nd report)." Int. J. Heat Mass Transfer, 14, pp 1807-1824, 1971.

The Impact of the Internet on International Trade

Katelyn Gao[1]

[1]Department of Statistics, Stanford University, Stanford, CA 94305

Over the last twenty years, the Internet has transformed our world. In this paper, we investigate the impact of increased Internet use on bilateral trade, and examine differences in these impacts for developing versus developed countries. The analysis surprisingly suggests that increased Internet use in the importing country leads to a decrease in exports, yet increased Internet use in the exporting country has no effect. If the exporting country is developing, there is greater growth in exports due to increased Internet use in that country than if it were developed. However, the same is not always true for the importing country. These conclusions can be useful for government policy makers seeking to expand trade internationally.

1 Introduction

Since the early 1990's, the Internet has had a profound impact on the everyday lives of people around the globe. It has made communication and information discovery nearly instantaneous across large distances. Now, companies from the United States and China are easily able to conduct business virtually face-to-face. In 2007, it was estimated that over 97% of all communication took place over the Internet. (Hilbert, Lopez, 2011)

There has been much anecdotal evidence that the spread of the Internet has increased international trade. For example, Guyanese women from a remote part of the country use the Internet to sell their handmade crafts to the rest of the world. (Romero, 2000) The Internet has also enabled the formation of global markets in a variety of industries, including automobiles, metals, and agriculture. (Freund, Weinhold, 2004)

Indeed, we would expect that the Internet would have a beneficial effect on trade between countries. The Internet, by expediting communications, has opened international markets and lowered business startup costs. A company that was previously limited to domestic markets by the high costs of market research and establishing connections in other countries would now be able to accomplish these tasks online and enter foreign markets. Furthermore, someone who does not have the startup capital necessary in their home country would now be able to conduct business with people around the globe by paying the relatively inexpensive cost of a domain name. But, it is important to note that for this effect to be possible, both partner countries need to have access to Internet.

However, there may also be an opposite effect. By opening up markets, the Internet has also increased competition; this may in turn decrease bilateral trade between certain countries. For example, country M, that used to import its supply of good X from country A, through the Internet may now import from any of countries A, B, and C. Unless country A remains the cheapest option available, the volume of trade in X between M and A would decrease. Whether this negative effect is enough to balance out the positive effect discussed in the previous paragraph is unclear and remains to be seen from our analysis.

According to the World Bank's Doing Business Project (World Bank, 2011a), it is harder to do business in developing countries. Thus, the Internet, which increases the ease of doing business, is expected to have a larger impact on foreign trade for developing countries. Moreover, developing countries have fewer established trade ties. Therefore, the increased ease of market

research and networking due to the Internet would be of greater assistance in increasing foreign trade.

In this paper, we quantify the changes in bilateral export volumes due to increased Internet use in the importing country and due to increased Internet use in the exporting country. We also investigate the differences in these changes for developing versus developed countries. We hypothesize that the effect of increased Internet use is greater in developing countries.

The rest of the paper is organized as follows. In Section 2, we review previous literature on the effect of the Internet on international trade and provide a brief description of the models used in our analysis. In Section 3, we describe our data. In Section 4, we present our methods. Section 5 shows and analyzes our results, and lastly, Section 6 concludes.

2 Background

There are a number of theoretical and empirical studies of the effect of the Internet, or e-Commerce in general, on international trade and economic growth. He, Li, Wu, and Jiang (2011) build a theoretical model of the impact of e-Commerce on international trade and conclude that it does in fact increase exports and in some cases total international trade. Many empirical studies, including Meijers (2010), Freund and Weinhold (2004), and Vemuri and Siddiqi (2009), have confirmed that conclusion.

Much of the past research was focused on developed nations, in particular Europe and the United States, or on the global average effect of the Internet on trade. Clarke and Wallsten (2004) take it one step further by dividing a subset of countries into two groups, high-income and low-income and comparing the magnitudes of that effect for the two groups. They conclude that the Internet's stimulatory effect on trade is greater in low-income countries. We extend these previous analyses to investigate differences between developed and developing countries worldwide.

The gravity model, shown below, is an econometric model of bilateral trade between countries first proposed by Tinbergen (1962). It is analogous to that of Newton's Law of Universal Gravitation,

$$T_{ij} \propto \frac{M_i^a M_j^b}{D_{ij}^c}$$

where T_{ij} is the volume of exports from country i to country j; Mi is the "mass" of country i, measured by variables such as Gross National Product (GDP) and population; M^j is defined similarly; D^{ij} is the "distance" between the two countries, measured by geographic distance, language differences, etc., and a, b, and c are constants. (Gravity Models, 2008)

This model has been used widely in empirical studies, such as Freund and Weinhold (2004), Wheatley and Roe (2005), and Bojnec and Ferto (2010), and has been shown to have theoretical basis. In this paper, Mi and Mj are extended to include the percent of the population that uses Internet as well as GDP and population. We use the gravity model in our analysis.

3 Description of Data

To distinguish between developing and developed countries, we use the International Monetary Fund's (IMF) World Economic Outlook Report's 2011 categorization. (International Monetary Fund, 2011a) The IMF classifies countries as developed versus developing based on three main criteria: per capita income over a number of years, export diversification, and degree of integration into the global financial system. (International Monetary Fund, 2011b)

Our data on bilateral export volumes between countries comes from the Correlates of War Project Trade Data Set. (Barbieri, Keshk, Pollins, 2009; Barbieri, Keshk, Pollins, 2010) We also use data on population, GDP, and the percentage of population that has access to Internet in each country from the World Bank World Development Indicators. (World Bank, 2011b) Since we are particularly interested in the difference in the effect of increased Internet use on bilateral export volumes for developing countries and it was only in the 1990's that the Internet spread to countries other than the advanced economies

Table 1: Original Variables

Variable	Variable Description
Trade	Volume of exports from country *i* to country *j* in year *t* in millions of 2008 US dollars
GDP1	Gross Domestic Product of country *i* in year *t* in millions of 2000 US dollars
GDP2	Gross Domestic Product of country *j* in year *t* in millions of 2000 US dollars
Pop1	Population of country *i* in year *t* in millions
Pop2	Population of country *j* in year *t* in millions
Internet1	Percent of the population of country *i* in year *t* that uses Internet
Internet2	Percent of the population of country *j* in year *t* that uses Internet
Developing1	Indicator variable for country *i* being a developing country
Developing2	Indicator variable for country *j* being a developing country

Table 2: Summary Statistics of Original Variables

Variable	Mean	Standard Deviation	Minimum	Maximum
Trade	457.622	4078.17	3.40×10^{-13}	315362
GDP1	312767	1130630	17.8233	1.14×10^{7}
GDP2	322238	1135150	17.8233	1.14×10^{7}
Pop1	50.2260	161.384	0.009419	1311
Pop2	52.8559	165.811	0.009419	1311
Internet1	12.9330	19.3262	0.000018	88.8055
Internet2	13.6249	19.7387	0.00018	88.8055
Developing1	0.703705	0.456624	0	1
Developing2	0.685478	0.464326	0	1

of North America, Western Europe, and Asia, we restrict our data to the years 1990 to 2006. (Computer History Museum, 2006) The data set is a panel, where the panel variables are year and pairs of countries. The countries in each pair come from a set of approximately 180 countries that includes both developed and developing countries. Table 1 describes the original variables of the data set and Table 2 contains their summary statistics.

We see that the beginning stages of Internet penetration are present in the data, since the minimum is nearly zero. It is also interesting to note that as of 2006, no country in the world has yet reached 100% Internet use among its citizens. Around 30% of the countries in our data set are developing. This shows that our data set is suitable for determining the differences in the effects of increased Internet use on bilateral export volumes for developing and developed countries.

4 Regression Models

4.1 Model Variables

Table 3 describes the variables used in our analysis.

Table 3: Model Variables

Variable Name	Variable Description
lnTrade	Natural logarithm of *Trade*
lnGDP1	Natural logarithm of *GDP1*
lnGDP2	Natural logarithm of *GDP2*
lnPop1	Natural logarithm of *Pop1*
lnPop2	Natural logarithm of *Pop2*
lnInt1	Natural logarithm of *Internet1*
lnInt2	Natural logarithm of *Internet2*
lnInt1lnInt2	Interaction variable of *lnInt1* and *lnInt2*
DevlnInt1	Interaction variable of *Developing1* and *lnInt1*
DevlnInt2	Interaction variable of *Developing1* and *lnInt1*
DevlnInt1DevlnInt2	Interaction variable of *DevlnInt1* and *DevlnInt2*

4.2 Model Specification

We use a panel regression framework, with pairs of countries as the panel variable and year as the time variable. Our model assumes fixed effects, with country pair clustered standard errors. Therefore, we do not need to take into account the "distance" between two countries, which generally only changes over long periods of time, in our specifications.

Our base specification is derived from taking the natural logarithm of the gravity model discussed in Section 2[3].

$$(1)\ \ln Trade_{iit} = \beta_0 + \beta_1 \ln GDP1_{ijt} + \beta_2 \ln GDP2_{ijt} + \beta_3 \ln Pop1_{ijt} + \beta_4 \ln Pop2_{ijt} + \beta_5 \ln Int1_{ijt} + \beta_6 \ln Int2_{ijt} + \alpha_{ii} + \delta_t + \varepsilon_{iit}$$

The more people who use Internet in the importing country, the more easily suppliers in the exporting country would be able to contact buyers in the importing country, and vice versa. Therefore, the impact of increased Internet use in the exporting country on bilateral export volumes may also be dependent on the level of Internet use in the importing country.

Hence, we add the interaction term *lnIntlnInt2* to (1) to obtain our second specification.

To determine if there is a difference in the effect

$$(2)\ \ln Trade_{iit} = \beta_0 + \beta_1 \ln GDP1_{ijt} + \beta_2 \ln GDP2_{ijt} + \beta_3 \ln Pop1_{ijt} + \beta_4 \ln Pop2_{ijt} + \beta_5 \ln Int1_{ijt} + \beta_6 \ln Int2_{ijt} + \beta_7 \ln Int1 \ln Int2_{ijt} + \alpha_{ii} + \delta_t + \varepsilon_{iit}$$

of increased Internet use in the exporting country on trade volumes when it is developing compared to when it is developed, and to do the same for the importing country, we add the interaction variables *DevlnInt1* and *DevlnInt2* to (1) to obtain the third specification.

With the same reasoning as for (2), we add the

$$(3)\ \ln Trade_{iit} = \beta_0 + \beta_1 \ln GDP1_{ijt} + \beta_2 \ln GDP2_{ijt} + \beta_3 \ln Pop1_{ijt} + \beta_4 \ln Pop2_{ijt} + \beta_5 \ln Int1_{ijt} + \beta_6 \ln Int2_{ijt} + \beta_7 Devln Int1_{ijt} + \beta_8 Devln Int2_{ijt} + \alpha_{ii} + \delta_t + \varepsilon_{iit}$$

interaction variables *lnInt1lnInt2* and *DevlnInt1DevlnInt2* to obtain our final specification.

For the sake of rigor, it may be interesting to do

$$(4)\ \ln Trade_{iit} = \beta_0 + \beta_1 \ln GDP1_{ijt} + \beta_2 \ln GDP2_{ijt} + \beta_3 \ln Pop1_{ijt} + \beta_4 \ln Pop2_{ijt} + \beta_5 \ln Int1_{ijt} + \beta_6 \ln Int2_{ijt} + \beta_7 \ln Int1 \ln Int2_{ijt} + \beta_8 Devln Int1_{ijt} + \beta_9 Devln Int2_{ijt} + \beta_{10} Devln Int1 Devln Int2_{ijt} + \alpha_{ii} + \delta_t + \varepsilon_{iit}$$

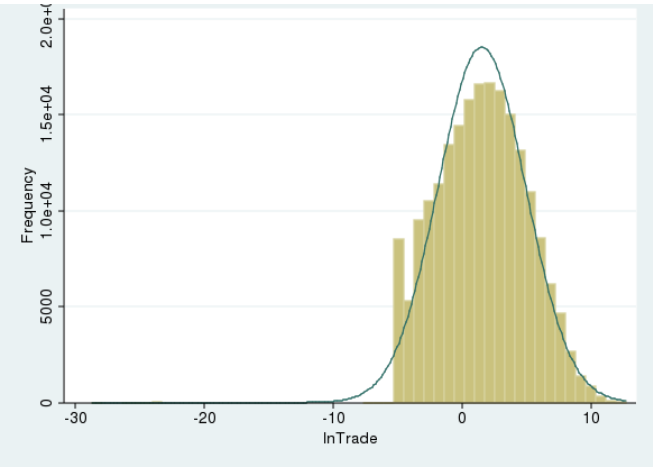
the same regressions under a random effects model, and carry out a Hausman test to see which model is appropriate. However, given the distinct differences between pairs of countries and changes in the world economy from year to year, we believe that a fixed effects model is correct.

4.3 Model Validation

We use clustered standard errors to account for heteroskedasticity arising from country-pair clustering in the data. To check that there are no outliers to bias our estimates, we plot our dependent variable *lnTrade*, given as Figure 1. It appears to follow a normal distribution and have no outliers.

In our specifications, we assume that the regressors are orthogonal. One was to test this is to calculate the mean variance inflation factor (VIF) foe each specification. (UCLA, 2011) Doing so for each specification, we see that none of the mean VIFs are large; indeed, the largest is 6.03. Therefore, our assumption appears to be valid.

Figure 1: InTrade



Endogeneity problems arise with some regressors. For instance, for the variables *lnInt1* and *lnInt2,* there is omitted variable bias and possibly reverse causality. The type of government is correlated with both Internet use in a country and the volume of its exports to other countries. For example, the presence of a dictatorship in a country would adversely affect both the availability of Internet there and the extent to which it trades with other countries. It is also plausible that increased exports leads to increased Internet use, as the additional funds may be spent on building telecommunications infrastructure, including establishing Internet connections.

To address the endogeneity problem, we substituted two-year lagged values of the Internet use variables for the contemporaneous variables in our regressions. The coefficients that were statistically significant remained significant, indicating that our model and conclusions are valid.

5 Results of Analysis

Table 4 contains the results from our four regressions. All regressions are fixed effects panel regressions, with clustered standard errors. From (1), we can conclude that there is no significant effect on the volume of exports from one country to another associated with increased Internet use in the exporting country. However, the percent increase in the volume of exports associated with a 1% increase in the amount of Internet use in the importing country is -2.82% and significant at the 1% level.

From (2), we cannot say that the effect of an increase in Internet use in the exporting country on export volumes between countries is dependent on the level of Internet use in the importing country and that the effect of an increase in Internet use in the importing country on export volumes between countries is dependent on the level of Internet use in the exporting country.

From (3), for a developed country, the percent increase in its exports to another country associated with a 1% increase in the amount of Internet use is -3.54% and significant at the 1% level. However, for a developing country, the increase is 0.56% and significant at the 1% level. On the other hand, for a developed country, the percent increase in its imports from another country associated with a 1% increase in the amount of Internet use is -2.75% and significant at the 1% level. This percent increase is not significantly different if the country is developing.

From (4), we can conclude that when the importing country is developing, the percent increase in bilateral trade associated with increased Internet use in the exporting country is higher if the exporting country is developing than if it is developed. This is also true if the importing country is developed; these results are consistent with those from specification (3). We can also infer that when the exporting country is developing and has greater than 1% Internet use, the percent increase in bilateral trade associated with increased Internet use in the importing country is higher if the importing country is developing than if it is developed. Otherwise, there is no significant difference.

6 Conclusion

Table 4: Panel Estimates of the Effect of Internet on Trade

	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)
lnGDP1	1.3549 (0.0451)	1.3711 (0.0464)	1.3824 (0.0451)	1.3716 (0.0462)
lnGDP2	1.2523 (0.0494)	1.2700 (0.0509)	1.2802 (0.0495)	1.2689 (0.0509)
lnPop1	0.2541 (0.1026)	0.2454 (0.1028)	0.0932 (0.1057)	0.1055 (0.1056)
lnPop2	-0.4541 (0.1163)	-0.4609 (0.1164)	-0.4943 (0.1194)	-0.4853 (0.1195)
lnInt1	0.0039 (0.0041)	0.0032 (0.0041)	-0.0354 (0.0079)	-0.0317 (0.0080)
lnInt2	-0.0282 (0.0042)	-0.0290 (0.0043)	-0.0275 (0.0075)	-0.0234 (0.0075)
lnInt1lnInt2	N/A	-0.0011 (0.0007)	N/A	-0.0030 (0.0011)
DevlnInt1	N/A	N/A	0.0410 (0.0061)	0.0404 (0.0062)
DevlnInt2	N/A	N/A	0.0103 (0.0055)	0.0095 (0.0057)
DevlnInt1DevlnInt2	N/A	N/A	N/A	0.0068 (0.0015)
Constant	-25.066 (0.521)	-25.379 (0.565)	-25.149 (0.5208)	-24.978 (0.5707)
R^2	0.4801	0.4815	0.4939	0.4929
# of obs.	202447	202447	202447	202447

We conclude that increased Internet use in the exporting country is not associated with any change in export volumes. But, increased Internet use in the importing country is associated with a decrease in export volumes. Therefore, it appears that the effect of increased competition outweighs the effect of greater ease of communication. This result seems to be contrary to those of the literature discussed in Section 2.

Upon closer examination, we concluded that increased Internet use in the exporting country is associated with an increase in export volumes only if the exporting country is developing. This result is consistent with that of Clarke and Wallsten (2004). However, when the importing country is developing versus when it is developed, there is a greater increase in export volumes due to increased Internet use there only in certain situations.

This research can be of policy interest to governments, especially those of developing countries. Given these results, they may be able to increase exports by increasing Internet availability in their countries. A direction for future research would be to investigate the impact of geographic distance on the effect of the Internet on trade. Logically, the Internet would be more effective for countries further apart. Another direction would be to do country-by-country case analysis. For example, many countries in Africa differ from the rest of the world in that they have received subsidies to build telecommunications infrastructure.

Acknowledgements

This paper originated in the course Research and Communication in Economics at MIT in the fall of 2011. I would like to thank Professor Heidi Williams and Bruno Ferman and Mikka Rokkanen, the graduate Teaching Assistants, for their insight and many helpful suggestions.

References

1. Barbieri, K., Keshk, O. M. G., & Pollins, B. (2009) Trading data: Evaluating our assumptions and coding rules. Conflict Management and Peace Science, 26(5), 471-491.
2. Barbieri, K., Keshk, O., & Pollins, B. (2010). Correlates of war project trade data set codebook, version 2.01. Available from http://correlatesofwar.org
3. Bojnec, S. & Ferto, I. (2010). Market-creating effect of the Internet on food trade. 84th Annual Conference of Agricultural Economics Society. Edinburgh, Scotland.
4. Clarke, G. R. G, & Wallsten, S. J. (2004). Has the Internet increased trade? Evidence from industrial and developing countries. (World Bank Policy Research Working Paper 3215). Available from http://econ.worldbank.org
5. Computer History Museum. (2006). Internet History Timeline. Retrieved from http://www.computerhistory.org/internet_history/
6. Freund, C. & Weinhold, D. (2004). The effect of the Internet on international trade. Journal of International Economics, 62, 171-189.
7. Gravity models: Theoretical foundations and related estimation issues. [PDF Document] ARTnet Capacity Building Workshop for Trade Research, Phnom Penh, Cambodia, 2008. Retrieved from http://www.unescap.org/tid/artnet/mtg/cbcam_d2s3.pdf
8. He, Y., Li, J., Wu, X., & Jiang, J. (2011). Impact of e-Commerce on international trade – Based on a iceberg cost model. International Journal of Trade, Economics, and Finance, 2(3), 175-178.
9. Hilbert, M. & Lopez, P. (2011). The world's technological capacity to store, communicate, and compute information. Science, 332(6025), 60-65.
10. International Monetary Fund. (2011). Advanced economies list, World Economic Outlook, 173.
11. International Monetary Fund. (2011). Frequently asked questions, World Economic Outlook. Retrieved from http://www.imf.org/external/pubs/ft/weo/faq.htm
12. Meijers, H. (2010). Trade, Internet and economic growth: A cross country panel analysis. 1st ICTNET Workshop, Parma, Italy. Available from http://community.oecd.org
13. Romero, S. (2000, March 28). Lethem journal; Weavers go dot-com, and elders move in. The New York Times. Available from http://www.nytimes.com
14. Tinbergen, J. (1962). Shaping the World Economy: Suggestions for an International Economic Policy. New York: the Twentieth Century Fund.
15. UCLA: Academic Technology Services, Statistical Consulting Group. (2011). Regression with STATA. Retrieved from http://www.ats.ucla.edu/stat/stata/webbooks/reg/chapter2/statareg2.htm
16. Vemuri, V. K., & Siddiqi, S. (2009) Impact of commercialization of the Internet on international trade: A panel study using the extended gravity model. The International Trade Journal, 23(4), 458-484.
17. Wheatley, W. P., & Roe, T. L. (2005) The effects of the Internet on U.S. bilateral agriculture and horticultural commodities. American Agricultural Economics Association Annual Meeting, Providence, RI.

18. World Bank. (2011). Economy Rankings, Doing Business in 2011. Retrieved from http://www.doingbusiness.org/rankings
19. World Bank. (2011). World Development Indicators. Available from http://data.worldbank.org/indicator
20. To see, where the Hecke algebra arises naturally, we will look at the general linear group over the finite field , at the flag variety , where is the Borel subgroup of upper triangular matrices, at Bruhat decomposition of into double cosets, and finally at functions on double cosets. We will see that the functions on double cosets have the same generators and relations as the Hecke algebra.

We live in a time when you can go as far as your ideas can take you—and nowhere is this more true than at Akamai. We're at the heart of the Internet, helping the most innovative companies like Facebook, Apple and Salesforce remove the complexities of delivering any experience, to any device, anywhere.

Founded in the halls of MIT and headquartered in Cambridge, MA, Akamai remains dedicated to a youthful optimism of problem solving through intellectual curiosity, collaboration and commitment. And we're growing quickly! If you'd like to work in a culture where hard work and innovative ideas are consistently rewarded, join us and help shape the future of the hyperconnected world.

Learn more at: **jobs.akamai.com**

Akamai
FASTER FORWARD

NASDAQ-100

The Boston Globe
TOP PLACES TO WORK 2012

STANDARD
&POOR'S 500