# Migrants and the Transfer of Social Institutions

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**Abstract**

This paper considers the impact migrants have on the transfer of social institutions and explores the evidence of such impact in the literature. Using techniques employed in epidemiological study, the paper proposes models to describe the process by which migrants might influence the spread of social institutions in their home country.

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# 1 Introduction

The economic growth literature has evolved over the late 20th century. Beginning with the famous Solow growth equations, economic growth was considered to be the result of capital accumulation driven by the appropriate rate of savings. This later progressed to endogenous growth theories arguing that technological change was the primary driver of economic growth. Those, however, left open the question as to how technological progress was and could be promoted. More recently, the question of why some countries have been able to grow and consistently advance technologically has led to the rise of literature focusing on the so-called deep determinants of growth.[Acemoglu, Johnson, and Robinson, 2005] Institutions and geography have been two deep determinants of particular contestation. [Rodrik, Subramanian, and Trebbi, 2004]

At the same time, there has been much interest in the impact of migrants on developing countries. As Collier [2013] notes in his recent book *Exodus*, much of the research has focused on answering questions about the human and financial capital formation implications of migration: is there evidence of brain drain and what are the capital implications of monetary remittances? These questions are no doubt important aspects of economic growth but there has been less research into the impact migrants might have on the institutions in their home countries. This paper seeks to consider questions about how the transmission of ideas, and hence such social institutions, might be influenced by migrants and attempts to formalize a model of such transmission.

In the next chapter, this paper introduces a discussion on social institutions and how they might influence development. The discussion then expands to consider two important premises: first, how social institutions are transferred between communities and second, how migrants interact with their host and home countries. This context allows the paper to then explore the ways in which the existence of migrants can influence the transfer of social institutions and introduce some evidence in the literature of migrants impacting social institutions in their home countries.

To formalize this concept and the manner in which this process may occur, I borrow from the epidemiological literature. First, I explore the *Susceptible Infected Recovered* framework which is commonly used to model the spread of infectious diseases. By considering the differences between ideas and infectious diseases, I construct a model that better reflects the features of ideas. From there, I introduce additional features to take account of the role of migrants. Using these models, I simulated how various changes would interact with the presence of migrants and hence influence the spread of ideas.

Finally, as an exploratory excercise, I use data on the adoption of Facebook in its top thirty countries in order to explore the applicability of the models. The exercise shows that taking account of migrants is particularly important in explaining the initial spread of ideas but internal conditions remain the primary driver of an idea's subsequent adoption throughout a population.

# 2 Institutions and Development

## 2.1 What are social institutions?

The term "institutions" has become widely used across the social sciences. In many instances, the term is used generally without a clear definition and authors ignore that difficulty. Instead, many choose some practical example on which to focus empirical or theoretical research. In that light, I believe it necessary to better indicate what the paper means by "social institutions". The type of social institutions I want to consider are those that primarily influence the way individuals within a society interact with one another. In that sense, I borrow from Hodgson [2006] and believe that institutions can, without doing damage to the literature I explore here, be defined as normative structures and the "systems of established and prevalent social rules that structure social interactions."

In order to further clarify, it is important to identify what should be excluded from this concept of social institutions. First, conventions would be arbitrary implementations of an institution rather than an institution in of itself. For example, democratically electing a leader would be a social institution of a country but whether the president or the

prime minister is the title of the elected official would be an arbitrary convention. Second, not all social outcomes are social institutions. The fact that much of the Western world has a rising incidence of single-headed households is not in of itself a social institution although there may indeed be institutions that encouraged or generated this social outcome. This demographic outcome can influence social behaviour but in of itself should not be considered an institution. Third, a feature of social institutions is that they are socially transmitted. Institutions are not simply instinctive feelings of duty but rather normative injunctions on behaviour that are potentially passed among society's people and across generations.

Thus not only are laws, systems of governance and economic structures institutions, but so are the cultural norms of a society. This is similar to the approach taken by North [1990]. North hypothesized that even though there may be formal rules or institutions that could potentially be borrowed from other countries, there remained informal norms and customs that are not readily changed but can potentially have as important an impact. Such social institutions are distinct in that they are not formal institutions. They may, of course, lead to the construction of formal institutions. For example, a strong respect for women's rights within a culture may ultimately lead to the creation of a formal legal framework advocating gender equality. These formal institutions are distinct. This can be clearly seen if we consider a society in which the cultural norms place women in a subservient position in society and yet the legal framework of the country enshrines their equality. It is at this crux that I wish to highlight the limit of this paper's consideration of institutions to the informal social institutions and away from the formal legal, political and economic structures that may manifest, with or without, the underlying social norms, structures or customs (social insitutions) this paper discusses.

These "social institutions" matter in 2 ways. First, as North [1990] indicates, social institutions could render formal institutional reforms ineffective or greatly enhance their impact. Second, these social institutions can positively influence economic growth in of themselves [Barro and McCleary, 2003].

Why is this definition of social institutions important and why is it of particular interest that these social institutions impact development? It is important because this paper seeks to explore how these social institutions might be influenced by migrant networks. In order to achieve this, it will need to consider on a practical level how this type of social institution is transferred and how it flows along migrant networks: from formal engagement by diaspora and the return of migrants to their home countries; to the changing cultural perceptions, moral systems and ways of life that might be communicated by migrants back to acquaintances in their home countries.

## 2.2 Do social institutions affect growth and development?

I have argued that social institutions matter for the development of nations. There does exist a large amount of literature investigating the question. The approach typically taken stems from the work of Barro in trying to better explain cross-country disparities in growth [Barro and Sala-i Martin, 2003]. Many researchers have argued that explanations of economic growth disparities need to go beyond traditional economic variables and consider the impact of political, social and cultural forces. For example, it has often been argued that the ideological differences between Protestantism and Catholicism contributed to economic disparities before the 20th century either through work ethic or the fostering of literacy among protestant populace [Becker and Woessmann, 2009] . Religion is of course not the only instance of a social institution but it is the influence on norms and practices that social institutions, such as religion, have that arguably aid or hinder development. Indeed, Barro himself has investigated the connections between religions influence on norms and economic growth. Barro and McCleary [2003] argue that religious beliefs have an impact on economic growth. They find that strong personal beliefs in god (as instrumented by the belief in heaven or hell), rather than the attendance of religious ceremonies, are positively associated with growth. They argue the result is driven through the encouragement of personal traits and actions such as "honesty, thrift, willingness to work and trust between strangers." [Barro et al., 2003] In a similar vein, Tabellini [2005] investigates the role of social institutions in explaining the variation in economic development within regions in Europe. In order to overcome the endogeneity of economic development and social institutions, Tabellini [2005] finds that 18th Century literacy rates are strongly correlated to

responses in the World Value Surveys and measures of historical political institutions. As such, he is able to use the historical literacy rates and measures of historical institutions as instruments. The findings suggest that even in countries ruled by the same formal institutions, there are differences in income correlated with social institutions, or "regional culture". His argument is that the primacy of formal institutions over social institutions is not clear and there exists some persistent influence by social institutions on economic development.

What this literature suggests is that social institutions do affect economic development and given the differences in social institutions that are often apparent between migrants, their host countries and their home countries, it is an important consideration as to whether they have any influence on the social institutions of their home countries.

# 3 Institutions and Migrants

## 3.1 How are institutions transmitted?

Institutions, both formal and informal, matter. One question we might then ask is how these so-called deep determinants are transmitted or developed. The famous paper by Acemoglu, Johnson, and Robinson [2001] argue that, in certain instances, they travelled with colonial settlers. Acemoglu et al. [2001] argue that colonizers implemented extractive institutions in colonies not suited to permanent settlement and more development-minded institutions in those more suited to permanent settlement. They use settler mortality to instrument for the implementation of developmental institutions and find a strong relation to income per capita. The conclusion from Acemoglu et al. [2001] is that institutions, as instrumented by settler mortality, play a primary role in economic growth. The validity of the instrument, however, depends on the argument that these institutions were transferred with settlers. The idea that ideas can travel with migrating people is not novel but it does have important implications if the ideas that travel can be of such consequence to the economic, social and political well-being of a nation.

The research by the likes of Acemoglu has focused on the impact of migration on the

host country. As mentioned, the literature looking at the sending country has focused on the impact of remittances and the brain drain. Consider the paper by Schramm [2006] conducted for the World Bank that focused on migration in Egypt, Morocco and Tunisia. In this report, the consequences of migration for sending nations is limited to a chapter on remittances and education. Similarly, in a research report produced for the OECD, the impact of migration on development is argued to occur through only two transmission channels: changes in labour supply and financial remittances. [Katseli, Lucas, and Xenogiani, 2006] While the impact of financial and human capital flows is no doubt important, there has not been much focus on whether institutions flow along migrant networks. There are papers that have considered how technology or institutions might be brought back by returning migrants or through investment by the diaspora but with the continued shifts in international migration and changes in technology, there are bound to be changes in the way and degree to which institutional ideas are being transferred.

In order to answer the question of if institutions flow from migrant communities into their home countries and if those institutions affect change, one first needs to consider how migrants interact with their home countries.

### 3.2 How do migrants interact with their home communities

Diasporas have been influencing their home and host countries since the first migrants left their homes. Traditionally, the academic literature has focused on the historical treatment of diaspora communities in their host societies. In the last 30 years, there has been a move to study the impact of Diaspora on their home countries. This impact has become an increasingly complex area and a better understanding of the role of Diasporas in their home countries' development would allow for a greater effort in formulating policy. The scope and type of interactions Diasporas have are vast and impact across the social, economic and political landscape: outcomes for now. I will broadly categorize their interactions with their home countries in 3 categories: active, passive and circular. Active engagement by diaspora would be conscious actions taken by diaspora networks across the globe in trying to directly influence outcomes. Circular engagement I will consider to be the influence Diasporas have through the physical movement, permanent or temporary, of migrants

emigrating from their home country and then returning to their home country. Passive engagement would constitute the actions Diasporas have simply by interacting with their connections, family or otherwise, who remain in their home country without the express aim of influencing outcomes in their home country.

### 3.2.1 Active

One of the more traditional considerations of Diasporas impact is their role in the political landscape of their home countries. Perhaps this arises as a result of the endogeneous nature of the existence of diaspora communities. Countries with conflict often have segments of society who have emigrated as the result of persecution or, after losing power, emigrate in the aftermath. The political nature of the forces behind migration likely predispose the diaspora communities to remain involved, as best they can, in the political landscape of their home countries. Diaspora communities often provide financial support and contribute skills to movements in their home country or lobby their host governments and the international community for support. The impact of this engagement is mixed. In instances such as the Northern Irish, Filipino and South African resistance, it has been argued that the diaspora were prominent in supporting non-violent forms of resistance. In the case of the Bangladeshi War of Independence, the formation of East Pakistan House and action committees helped mobilize UK public and government sympathy for the Independence Movement. The role of Diasporas in conflict is by no means an exclusively positive one and perhaps is even the opposite.

Diasporas contribute to conflict around the world and prominently in the conflicts in Sri Lanka, Kosovo, Eritrea, Somalia, Turkey and Northern Island. Being sheltered from daily violence and sentiment shifts in their home country, diaspora groups often remain more uncompromising than their counterparts back home [Purdy, 2003] Irrespective of the justification of the conflict, it is undeniable that the estimated £27 million annually that the diaspora Tamil community provides in funding to the Liberation Tigers of Tamil Eelam (LTTE) has prolonged conflicted in Sri Lanka.

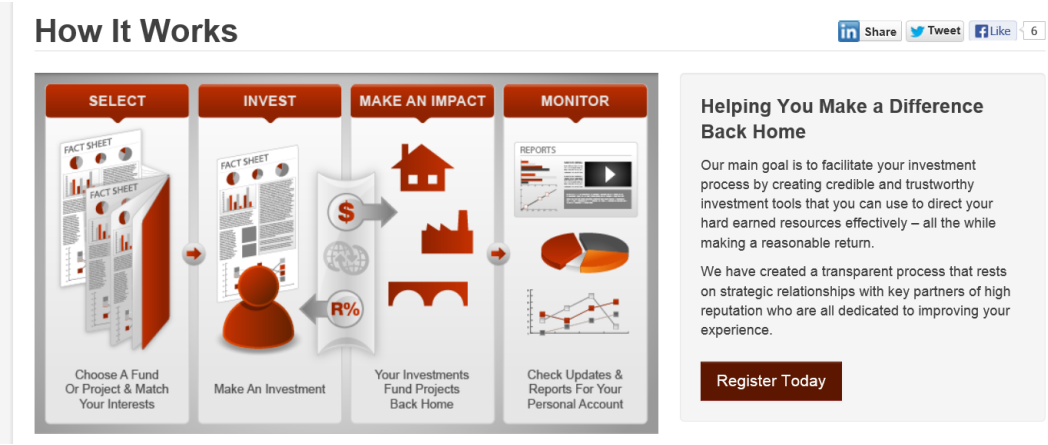
While Diasporas and conflict have important interactions, it is fortunate that economic engagement of Diasporas is a far more common and hopefully a more influential role Dias-

poras have in their home countries. Of course, one of the most common economic impact diaspora communities have is the remittances they send home. I will briefly acknowledge remittances under passive engagement as there is a separate and increasingly active role Diasporas are having on the economic development of their home countries.

There have long been diaspora networks providing business contacts and support. The most well-known of these are the Home Town Associations created by Mexican migrants. These associations look to pool resources and efforts to help build social and physical infrastructure in the local regions from where the group's members originate. In the same vein, Diasporas allow the formation of strong networks between their host and home countries which facilitates export/import business opportunities. One of the most cited examples of this is the Indian ICT sector. [Nanda and Khanna, 2010]. But there is a new movement in the Diaspora to engage in direct investment and that is having two effects. First, direct investment is potentially better able to pool resource for large capital projects. Second, it is extending the number of Diasporas involved in remittances. What do I mean by this? Typically first generation immigrants might send money home to their families as a means of direct support. As the direct personal connections to a need back home weakens, later generations might stop sending the same level of remittances back home. This, however, does not weaken the desire of some diaspora communities to be involved in the general development of their home countries and diasporas have been looking to other means of contributing to their home countries.

One recent example of a company seeking to address these two needs of the diaspora is Homestrings Ltd. Homestrings Ltd is a company that focuses on providing investment vehicles for diaspora to invest in their home countries. It was started by a 2nd generation Guinean who was looking to contribute to development in his home country. The company makes investment opportunities available to diaspora communities and carries the tag line "Make a difference back home"

Figure 1: Direct Collective Investment by Diaspora




### 3.2.2 Circular

One of the most oft discussed channels through which migration impacts development is the so-called "brain drain". Intuitively, the impact of short-term labour supply shocks as particular migrants (teachers, nurses or doctors) leave would be detrimental to development. That said, it is also argued that the incentives to up skill may increase human capital formation and hence productivity and growth. [Katseli, Lucas, and Xenogiani, 2006] . The debate is well documented and highly contested with some calling for developed nations to limit skilled immigrants from developing nations and others arguing the impact of brain drain is negligible if not positive. [Easterly and Nyarko, 2009]. While the discussions of brain drain are an important aspect of the general migration debate, a large portion of migration is not as permanent as many believe. Instead of rehashing the debate that is in the literature, I will consider the large circular flow of migration.

The circular flow of migrants is common and the to and fro movement creates the opportunity for the transfer of institutions, money and technology between countries. Similarly, it is often in this manner of movement that technological or cultural diffusion is thought to occur. One of the key instances of this is the large temporary migrant population that enters the USA from Mexico during the agricultural season. A particular example is that of the Jerez Valley in Mexico. Initially missionaries cultivated small quantities of peaches for personal consumption. Wide spread production did not take off because the overnight frost in early spring killed peach buds and, as a result, cultivation was difficult. In the

early 1960s, Jesus Valdez, a migrant labourer on the peach orchards of California, saw that the use of "Sumdge Pots" to heat the peach trees over cold nights avoided losing the crop to frost. Returning to Mexico, he utilized the idea and was able to produce a flourishing fruit crop in Jevez. So much so that other farmers followed suit and by the 1970s, Jevez was Mexico's largest peach producing region. [Nicols, 2004]. The increasing restrictions on permanent migration as well as the lower transport cost have helped facilitate a rapid increase in the number of temporary migrants. This circular flow is one avenue by which ideas, technologies, culture and social institutions diffuse across the world.

### 3.2.3 Passive

In addition to the previously mentioned impact of Diasporas, much of the research has focused on financial remittances. While such financial remittances are no doubt important and could arguably be the most influential, research has rarely looked beyond financial remittances to the potential impact of social remittances in shaping the future of their home countries. So here I acknowledge that one of the primary passive influences diaspora have is through their economic remittances but I hope to focus my discussions on the final way in which I view Diasporas interacting with their home countries. Namely, communications and interactions with family and friends that do not seek to actively influence outcomes in their home countries.

This idea that I want to focus on is often referred to as social remittances. This has largely been studied under the auspices of Diaspora driven cultural diffusion. But bringing together the concept that social institutions impact development and the more prominent and connected influence of Diasporas in their home countries, we could see the impact of this oft neglected element of Diaspora interaction playing a more important role going forward.

Previously, scholars of migration traditionally believed migrants cut off ties from their home countries. Work in the late nineteen eighties suggested that this was not the case and at the very least, some individuals maintain important connections with their home communities. This led to the concept of "transnational communities". These kinds of

relationships have existed long before they become an important part of mainstream academic thought. Prior research indicates that Irish and Italian Americans remained well-connected to their respective communities [Foner, 1997 and Wyman, 1993]. What is clear is that the impact of Diaspora communities are becoming more prominent in their home countries. This begs the question what has happened over the time that has made this possible. One approach to better understand these factors is to consider the micro-level diffusion of culture.

When I talk of micro-level cultural diffusion or social remittances, what is it that is exchanged? There are possibly a multitude of things that are exchanged, but as this paper is focusing on social institutions, there are two that I wish to explore: Normative structures and Systems of Practice. Normative structures can be defined as " ... ideas, values, and beliefs. They include the norms for interpersonal behaviour, notions of intra-family responsibility, ... and aspirations for social mobility " [Levitt, 1998]. Systems of Practice, on the other hand, are the actions shaped by normative structures. Examples of Systems of Practice might be household labour divisions, civil and political participation in the case of individuals and organizational structure for organizations. Returning to the definition of institutions used at the start of this paper, "systems of established and prevalent social rules that structure social interactions", normative structures and systems of practice align well with the definition of social institutions and so in this context, I will continue to refer to the former as social institutions.

When a migrant community exists, for social institutions to transfer from the host country to the home country, there needs to be two conditions:

(1) The migrant must develop an awareness and understanding of the host countries social institutions

(2) There must exist a mechanism of transmission between the migrant in the host country and individuals or organizations in the home country

Levitt [1998] investigates the relations spanning Miraflores, a semi urban village, and Jamaica Plain, a neighbourhood in Boston. Over 65 % of the households in Miraflores have

relatives in the greater Boston area. This situation provides a fertile ground to research how the micro-level diffusions of social institutions, if any, occur between the migrant Miraflorian community in Boston and their relatives and friends back home in the Dominican Republic.

In the first requirement, migrants need to become aware and develop an understanding of some of the local culture and institutions in their host countries. In this way, it is important to understand how migrants interact with their host communities. Migrants interact to varying degrees with their host societies. In one case, existing ideas and practices of migrants might go unchallenged. In another, new elements and adaptions might be merged with existing ones. In still others, new social and cultural structures and practices emerge as migrants adopt host country institutions using the interpretive frames they bring with them. [Foner, 1997]. The degree to which migrants choose to adopt host country institutions or gain indepth knowledge of them depends on the level of interactions they have once in their host countries. Levitt [1998] argues that Miraflorenos with enough money and education to either start their own businesses or enter professions have more contact with the broader community in their host country than those who, for example, clean offices at night and whose primary social engagement remains within migrant communities. Levitt [1998], while acknowledging it is more continuous than discrete, identifies 3 categories of interaction of migrants with their host communities. First, Miraflorenos who did not work outside of their homes or whose co-workers were other migrants. Such individuals tended to socialize with other Latinos and reported few interactions with Caucasians in Boston. Second, Miraflorenos who actively engaged in American life and adapted their cultural and social structures and practices in order to better get along in their host country. Finally, there were Miraflorenos who actively sought and absorbed new ideas and practices; forming a fusion of advantageous practices from their new host and old home cultures. Levitt argues that often these individuals who take on social institutions in their host country are keen to communicate the ideologies back to non-migrant friends and family. One interview Levitt conducts receives an answer:

" *When I go home, or speak to my family on the phone, I tell them everything about*

*my life in the United States. What the rules and law are like. What is prohibited here. I personally would like people in the Dominican Republic to behave the way people behave here. The first time I went back to the DR after nine years away, I arrived at the airport. I saw the floor was filthy and that smokers threw their cigarette butts everywhere. And I said wait a minute. I even said to the police who were there how can this be, the gateway to our country is the airport. It should be clean and neat and people should be polite... These things and many more, the good habits I've acquired here, I want to show people at home.*"

Turning to the second requirement, what is the mechanism for transfer of these social institutions once acquired by migrants? Traditionally, the answer has been via telephonic and written communication and the physical return, permanent or temporary, of migrants to their home communities. This can be seen in the answer given in the interview conducted by Levitt [1998] above. More generally, the information pertaining to a social institution must be communicated in some way. Once that communication has taken place, the information must be received, internalized and then accepted rather than rejected. This is important to understand so that we might consider what aids and what detracts from social institutions spreading along migrant networks.

New technology was typically considered to solely ease the cost of communication and travel. But technology is not just reducing the costs of traditional communication toward zero, but it is changing the very way in which distance interaction takes place. The new influence is taking shape in two ways. First, not only is the financial cost being reduced to almost zero but new technology is also reducing the opportunity cost and effort of communication. Consider the effort it would take to keep all one's friends up-to-date and involved in one's life over the telephone. The same is true for the effort required to keep up-to-date in the lives of others. Social media technologies, however, are providing ways for people to not only keep in constant contact with close friends, but also general acquaintances around the world. These technologies are fundamentally changing the costs associated with sharing a constant stream of information about one's life experiences with a wide network of people irrespective of geographic distance.

The second way that new technology is changing information sharing is that it now provides a far deeper immersion in the thoughts and lives of others, regardless of geographical proximity, and facilitates the passive transfer of ideas between sets of individuals. This is new. Consider in Levitt's [1998] work that she expressly says social remittances differ from general global diffusion because they are intentional transfers of information between a migrant and non-migrant. But in the world of Facebook, when a migrant posts an idea or shares aspects of their life with their wider social media network, is the adoption of such information by non-migrant acquaintances back home an intentional social remittance? Furthermore, the rich and constant stream of media - including videos, photos, the comments of second degree connections and other threads in the rich tapestry of information that services such as Twitter, YouTube and Facebook allow connections to share - immerse recipients in a far deeper experience. Consider the fact that Levitt [1998] found the Miraflorenos were able to describe life in Boston without having been there simple through telephone conversations, letters and descriptions from returning friends. Now consider that many of those remaining in home communities will now not only be able to describe but will also have seen a constant stream of images and other media from the lives of their migrant acquaintances. Furthermore, the non-migrants will be able to communicate directly with individual friends of their migrant connection, perhaps locals, through the comments, posts and other interactions they might have on the original connection's profile. In other words, individuals remaining in the home community are able to interact with second degree connections through their migrant friends and family.

All this suggests that the amount of contact between migrants and those in their home communities is growing and the depth and breadth of information being shared is expanding. The impact of this is not uni-directional. I have discussed how this dynamic has increased the information that those left behind in home communities receive but the same is true in the opposite direction. [Sultana, 2005]. Over time migrants lose local understanding of their home countries. This is important because institutions adapted for local settings are more powerful and in certain instances essential to the successful transfer of the institution or technology [Fu, 2008] The new features of social media outlined above have the effect of helping to negate these impacts by sharing more information and helping to maintain connections.

Clearly, technology affecting the rate and type of information flow is an important aspect of the transmission mechanism. The broadcast of information is not the only point at which the transfer of institutions is affected. Ultimately, the broadcast of the information needs to be heard and internalized by recipients in the home community. The political and social acceptance of migrants and the political and social environment into which the new ideas travel will also have an effect.

In certain communities, migrants are afforded a strongly positive social standing in their home communities. Levitt [1998] records instances of preferential access to health services the relatives of migrants received in their home communities as a result of the social prestige that having a family member working professionally in the U.S. bestows. More generally, if migrants are positively viewed in home communities, their influence in local affairs is more likely to be accepted. This extends to both informal societal views as well as official government policy. Kenya for example has actively engaged their diaspora in an official capacity. For example, they have issued Diaspora specific bonds to tap the capital Diaspora are willing to provide. The same is true in countries that may have active policies welcoming the physical return or contribution of migrants.

Government policy and societal views can of course run in the opposite direction. Migrants might be viewed as defectors or no longer in touch with society, rightly or wrongly, and attitudes to their ideas might be far more hostile. Of course, this can extend directly to foreign ideas themselves. Pakistan, for example, banned Facebook at one point. China regularly censors specific technologies, movies or ideologies. These examples are indicative of the hostility that certain societies display toward foreign ideas and this often extends to migrants as well. The transfer of ideas from migrants back into their home countries is likely to be retarded by such a hostile environment.

Finally, the likelihood of ideas being adapted and adopted into home communities will depend on the idea itself and its relative standing in comparison to local institutions and technology. Consider for example an environment in which two institutions or technologies are stark opposites. In many instances it would be costly to adopt or spread an idea when

the significant majority of individuals are sceptical and actively advocate opposing views. In instances of such extreme differences it may be difficult for foreign ideas to take an initial hold in home communities. This relationship, however, is likely to be quadratic. While it may be difficult to spread ideas in the instances of extreme hostility to the new idea, it is also likely that the spread of a new idea is unlikely to take place in the instance that the status quo is very similar. For example, if we look at the spread of twitter, it has moved rapidly through the world but remains unpopular in China. While state intervention is obviously important, the existence of the already popular service Weibo, which is for all intents and purposes the same as twitter, negates many of the advantages of adopting Twitter for the Chinese.

So in this discussion of the mechanisms of transfer, both the ability to broadcast information between host and home communities and also the reception the ideas might receive will influence the transfer of such ideas. This considered break down of influences is important because it helps us better understand how and when migrants might play a role in transmitting institutions back to their home country. Migrants need to be engaged in their host societies, involved and received to some degree in their home societies and they must have the ability, at an appropriate cost, to transmit the information.

# 4 Evidence of migrant influence on social institutions

## 4.1 Evidence in the Literature

I have hypothesized about the impact migrants could have on their home communities beyond economic remittances and potentially without ever returning. I have discussed the factors that might influence this impact. Of course the question that naturally arises is if there is any evidence currently that would suggest that this effect does in fact play an important role. The short answer is that there is and I would like to explore two papers in particular that highlight some tangible impact of migrants on the social institutions in their home countries.

Mexico has a large migrant population based in the United States of America and as such provides a fertile ground for research. The Encuesta Nacional de Dinamica Demografica (ENADID) (National Survey of Demographic Dynamics) from 1997, has presented the opportunity to measure the impact of migration on various social and economic outcomes at the household level. The questions in the survey ask if the household has relatives who are migrants in the US and at the same time asks a series of outcomes question. In particular, the survey asks detailed health questions including ones concerning the knowledge of contraceptive practices. Hildebrandt, McKenzie, Esquivel, and Schargrodsky [2005] construct a maternal health knowledge index based on such questions and show the index is associated with knowledge about the causes of diarrhoea. They hypothesize this indicator is likely to be reflective of greater knowledge about infant and child health and they show it is correlated with lower infant and child mortality and higher birth weights. Instrumentation is used to take account of the endogeneity of migration and the role remittances play. For example, households receiving remittances are 30 % more likely to have a doctor present at child birth which is likely a result of higher incomes associated with remittances.

The question they investigate is whether migration has any impact on the health knowledge of Mexican households. The results they find provide evidence for the role migrant networks play in the sharing information. Once instrumenting for migration, they find a strongly significant effect on health knowledge. When a household has a member with migration experience, the health knowledge index increases by 0.65 standard deviations. The hypothesis being that household members are likely to relay information about the best practices in child health that they have learnt back to their household. If this is the case, one would expect that if it was the mother herself that was a migrant and has now returned, then one would expect the effect to be stronger. And it is. The gain in the maternal health knowledge index is 3.8 times as great when a mother migrants and returns rather than the father migrating and returning. Furthermore, they present evidence to suggest this health knowledge slowly diffuses out from the migrant, to the migrant's household and into the migrant's home community. A one standard deviation increase in the proportion of households with migrant experience leads to a 0.11 standard deviation

increase in the health knowledge of non-migrant households. This evidence is indicative of the tangible impact migrant networks can have through the flow of ideas.

North Africa is one of the largest migrant sending regions. It also provides an interesting research opportunity because of the stark differences between the countries to which migrants go. For example, the majority of Morocco's migrants travel to Western Europe. On the other hand, most of Egypt's migrants travel to Libya or the oil-producing Gulf states, namely Saudi Arabia.[Fargues, 2008] There has arisen a so-called fertility puzzle in North Africa best encapsulated in the difference between Morocco and Egypt's declining fertility rates from the 1970s to the present. Both countries had an enormous rise in population during the 20th century. Egypt's population has risen from 10 million to its current 82.5 million and Morocco from 5 million to 32.5 million. Concern with rising populations began in Egypt in the 1930s when the country's leadership, with the backing from religious figures, attempted to address population growth. In contrast Morocco was viewed to be vastly underpopulated by its colonial powers, Spain and France, and they actively encouraged immigration to Morocco with half a million European migrants arriving. The policies of the two countries realigned again in the 1960s when both government adopted active measures to stem the rise of the population. Egypt introduced extensive family-planning programmes and Morocco, to a lesser extent, followed suit. By 1970, Egypt's programme had reduced fertility from 6.7 (which was at the time one of the lowest in the Arab world) to 5.95. Morocco, on the other hand, saw its fertility rate hardly change from 7.17 to 7.06. Over the next two decades, the fertility rate in Egypt slowly declined to around 3.35 in 2000 while Morocco's plummeted to 2.7. The puzzling question is why, when most standard predictors of fertility rates pointed to Egypt experiencing a more rapid decline, did Morocco's fertility fall so rapidly?

Courbage [1999] shows that martial fertility, breast-feeding, contraceptive availability and practices would suggest that Egypt should have experienced a more rapid decline or at the very least, the two countries should've experienced a similar rate of decline. For example, contraceptive availability and use in Morocco and Egypt is effectively equivalent with Morocco having a 35.9 % prevalence of birth control use by 1990 and Egypt 37.8 %. In a

similar article for the Middle East Report, Courbage [1994] considers many indirect factors commonly associated with fertility, namely infant mortality, standard of living, urbanization, literacy, education, participation of women in the labour force and the availability of child care. The evidence is once again puzzling. Since 1972, infant mortality declined much more rapidly in Egypt. Egypt remains considerably more urbanized than Morocco. One potential explanation is that Egyptians are able to commute daily into large cities from rural areas given the countries narrow inhabitable strip. This arguably would allow child bearing practices to remain the same in such households in Egypt while Moroccan families would have to entirely relocate to cities and eventually have fertility rates align with urban dwellers. This is not, however, born out in the evidence where the fertility differences between Morocco and Egypt extends to rural areas. In 1990, rural Egyptians still gave birth to 1 child more than rural Moroccans. Education and employment once again, fail to shed light on this puzzle. In 1960, 16 % of women in Egypt were literate while only 4 % in Morocco. By 1990, 45 % of Egyptian women were literate compared to 32 % in Morocco. Furthermore, of women educated, 7 out of 10 have attended secondary school in Egypt while only 5 out of 10 have done so in Morocco. And for children under 16, 89 % are in school in Egypt compared to just 50 % in Morocco. This is not reflected by stark differences in gender inequality. For every 100 boys in school there are 82 girls in school in Egypt while only 69 in Morocco. One of the primary drivers of fertility is the availability of childcare. But budget-time surveys in rural Morocco and Egypt suggest that there is no prominent difference in child care availability which would explain the large difference in fertility between Morocco and Egypt. With these sort of statistics, it is no surprise that demographers pre-1960 were predicting strong declines in Egyptian fertility in comparison to Morocco. Indeed, in 1970 the UN predicted that fertility in Morocco would be 5 while in Egypt 3.9.

So with the typical direct and indirect drivers of fertility failing to provide much insight, Courbage [1999] considers two potential drivers. First, he argues that a collapse in phosphate revenue in Morocco made the maintenance of large families economically unviable while oil revenues in Egypt allowed large family sizes to be maintained. This explanation potentially helps explain Morocco's decline in fertility during the late 1970s but fails to

account for the lack of a decline in Egypt when a similar reduction in oil revenues occurred. That said, economic growth was consistently higher in Egypt over the late 20th century resulting in 25% higher incomes in Egypt than in Morocco. This economic growth might have allowed Egyptians to maintain larger families but is unlikely to explain the full extent of the divergence in fertility between the two countries. The second driver presented is the migration patterns of Morocco and Egypt. Both countries have strong migrant communities living abroad. By 1990, 10 % of both Egypt and Morocco's population of a working age was abroad and sending home $ 3-4 billion and $ 2-2.5 billion every year respectively. But as previously argued, the exchanges between migrants and their home communities is not limited to financial remittances alone. And perhaps here, we might find a contributory factor to the differences between Egypt and Morocco's fertility rates.

95 % of Egypt's migrants went to either Libya or Saudi Arabia, while 87 % of Moroccan migrants went to Europe. This, however, has not always been the case. In 1960, the number of Moroccan migrants in other Arab states outnumbered those in Europe 2 to 1. That dramatically changed by 1970 when the stock of Moroccan migrants in other Arab states declined while those in Europe doubled. This continued right through until today with the stock of migrants in Europe outnumbering those in the Gulf by over 15 to 1. There are important implications to the geography of migration. The countries where Egyptian emigrants have gone are states in which governments explicitly viewed their population growth as too slow or satisfactory and the limitation of women's rights and roles in society were the norm. It is no surprise then that fertility rates in Western Europe were much lower than in the Gulf States. For example, France's fertility rate in 1970 was 2.55 while in Saudi Arabia and Libya it was 7.28 and 7.57 respectively. Courbage [1999] speculates that there appears to be adaptation to the norms and values of the host society. In 1960, Moroccan migrants continued to have large families (6.5 children) in line with families in Morocco but by 1990 the figure had dropped to 3.5 children. This change in the fertility of Moroccans abroad preceded the acceleration of the transition in Morocco. [Courbage, 1994]

The changing role of women in society and aspirations associated with migrants were

likely communicated back to home communities and in turn reduced the fertility rate among Moroccan households. Courbage [1999] notes a similar pattern in other countries whose migrants primarily go to the oil-rich gulf and Arab nations. Syria, for example, had its fertility rate plateau in the mid sevens from 1960 all the way to 1990. In contrast, Algeria and Tunisia whose migrants travel to Europe primarily, have undergone fertility reductions. Courbage [1994, 1999] considers the various element that might influence fertility and presents the argument that the differences in migration patterns present a probable contributor to the differences in the evolution of demographic patterns in North African countries.

Beine, Docquier, and Schiff [2013] attempt to formally test the hypothesis introduced by Courbage [1994, 1998] and Fargues [2008]. In their paper titled *International migration, transfer of norms and home country fertility*, they build a microeconometric model of fertility and education decisions by adults that takes into account income security, remittances and an altruistic feature in which adults derive utility from maximizing the future income of their children. An additional element is introduced to the model where adults derive (and internalize) utility from alining their fertility rate to the average fertility rate. In this way, a transfer of norms from migrants abroad back to their home country would lower the reference ferility in the home country and incentivize a reduction in fertility. The model theoretically predicts that home fertility should be increasing in average destination fertility; fertility should be ambiguously affected by remittances as the income effect positively contributes to fertility while the income security effect reduces fertility; fertility should be decreasing in the average emigration rate as the prospect for emigration encourages investment in education over additional children; and finally fertility should be decreasing in adult human capital formation as a higher opportunity cost in adult time lowers fertility. A number of common control variables such as GDP per capita, urbanization rates, regional and religious dummies are included in the regressions.

The results that Beine et al. [2013] produce provide empirical evidence of the transfer of norms along migrant channels. They run OLS, IV, Gravity and dynamic specifications

and, in each instance, they find robust evidence of the transfer of fertility norms from destination countries to home countries. They find that a one percent decrease in the average fertility in the destination country reduces the home country's fertility by 0.3 percent. This paper presents compelling evidence that the transfer of social institutions can occur through the migration channel and in particular from host to home country.

The literature considered above surveys the evidence that social institutions are transferred from host country back to the home country along migration channels. But the evidence presented above does not consider specifically how this diffusion process might occur. The paper by Beine et al. [2013] assumes the norms-diffusion process follows a linear process defined by a constant term and a second term linearly increasing with the probability of emigration. In the section below, we consider the diffusion process more specifically and how migrants might influence it.

## 4.2 Spread of Infectious Diseases and Ideas

An idea is similar to an infectious disease in many ways. An idea has a probability of being transferred when an individual comes into contact with it. And once an individual is "infected" by an idea, they too can spread that idea. As a result, epidemic models may present a way in which one might be able to formalize the study of how an idea spreads. [Bettencourt, Cintrón-Arias, Kaiser, and Castillo-Chavez, 2006] There are a number of different types of epidemic models that might prove suitable in their application to the spread of ideas. The classic epidemic model is the SIR model. SIR stands for Susceptible, Infected and Recovered. These three labels are used to categorize individuals who are susceptible to infection, those already infected and spreading the disease and those that are recovered from the disease and hence immune to reinfection. In this model, the spread of the disease is characterized by two parameters. The first is denoted by $\delta$. $\delta$ is the product of the per-capita contact rate and the probability of transmission. That is to say that there is a rate at which individuals come into contact with each other and in instances where that contact is between infected and susceptible individuals, there is a probability that the infection will be transferred. Thus $\delta$ describes the rate at which the disease spreads. The second parameter is $\gamma$. $\gamma$ is the rate at which those infected recover from

the disease and subsequently become immune to reinfection. So in this model, with each contact between a susceptible individual and an infected individual, there is a probability that the individual will become infected with the disease. Overtime, the infected recover at some rate and become immune to further infection. Such a model is characterised by the following set of differential equations:

$$\dot{S} = -\delta S \frac{I}{N} \tag{1}$$

$$\dot{I} = \delta S \frac{I}{N} - \gamma \tag{2}$$

$$\dot{R} = \gamma I \tag{3}$$

$$N = S + I + R \tag{4}$$

where $N$ is the total population.

Equation (1) describes the number of susceptibles that become infected each period. As can be seen by the equation, the number infected depends on the product of the contact rate per capita and the probability of transmission ($\delta$), the proportion of the population that is infected and the number of susceptible people. Intuitively, this says that the greater the interaction between people; the higher the "infectiousness" of the disease and the greater the number of infected, the more likely one is to become infected. Of course, the change in susceptibles also depends on the number of people that are susceptible to the disease at any particular time. As the number of susceptibles diminish, the infected are less likely to interact with susceptibles and the infection cannot spread as rapidly. Equation (2) describes the change in the number of infected each period. The change is simply the difference between the number of susceptibles that become infected and the number of infected that recover. We can now begin to see not only what causes diseases to spread or not but also what can lead them to die out. Infections can burn out once a significant proportion of the population has already been infected and the recovery rate exceeds the rate at which new susceptibles are infected. Finally, Equation (3) describes the change in the number of people that move from the infected population to the recov-

ered population each period. These people can no longer be infected or spread the disease.

What can be seen from these equations is that there exists 2 fixed points. First, the disease-free equilibrium of $S^* = N; I^* = R^* = 0$. Second, the immune equilibrium of $S^* = I^* = 0; R^* = N$. The question that is more interesting is under what circumstances does the disease spread. In other words, under what conditions does the number of infected increase from the initial conditions? To answer this we simply need to look at the right hand side of Equation (2), the change in infected, and work out when this is greater than zero. If we consider the initial condition to be such that the entire population is susceptible bar a single infected individual, then we can say that if $\frac{\gamma}{\delta} < \frac{S_0}{N}$ then the pandemic spreads. This is how immunization campaigns work: knowing the infection rate ($\delta$) and the recovery rate ($\gamma$), the number that $S_0$ needs to be reduced by through immunizing Susceptibles into Recovereds is known. This leads us unto the concept of the reproduction number in epidemic literature. The reproduction number defines the point at which the two equilibria exchange stability. For this reason, it is commonly thought of as the threshold conditions under which an infection will spread throughout a population or die out. The reproduction number can sometimes, depending on the mathematical complexity of the model, have an intuitive interpretation as the number of secondary infections generated by an infected individual between the time they are infected and the time they recover. While in this simple SIR model the reproduction number is obvious, it can become complex in more complete models. It is thus worth exploring a more formal definition of the reproduction number.

As previously mentioned, the reproduction number often has an intuitive description as the "expected number of secondary cases produced in a completely susceptible population by a typical infected individual" [Diekmann, Heesterbeek, and Metz, 1990]. More formally, the reproduction number, $R_0$, is defined as the expression under which $x_0$, a disease-free equilibrium, is locally asymptotically stable when $R_0 < 1$ and unstable when $R_0 > 1$. In order to determine such an expression for the reproduction number, we must consider the rate at which individuals enter an infected category and how long they remain in such a category. Van den Driessche and Watmough [2002] utilize this concept in their paper

outlining a proof for a general solution to the reproduction number for an epidemiological model and I follow their methodology in determining the reproduction number for the model I have proposed. Let $x_t = (x_1, ..., x_i, ..., x_n)_t$ be the number of individuals in each category $i$ at time $t$. Furthermore, let $\mathcal{F}_i(x)$ be the rate of appearances of new infections in category $i$ and let $\mathcal{V}_i(x)$ be the net rate at which individuals enter (or exit) category $i$. We can then describe the change in the number of individuals in category $i$ as $\dot{x_i} = f_i(x) = \mathcal{F}_i(x) - \mathcal{V}_i(x)$ for $i = 1, ..., n$. To determine the reproduction number we must first work out the average time spent in an infected category by an infected individual and at what rate the individual spreads the infection. In order to determine the fate of an individual in category $i$, we consider the dynamics of a lineralized system $\dot{x} = -D\mathcal{V}(x_0)(x - x_0)$ where $D$ is the derivative. I thus introduce

$$F = \left[\frac{\partial \mathcal{F}_i}{\partial x_j}(x_0)\right] \tag{5}$$

$$V = \left[\frac{\partial \mathcal{V}_i}{\partial x_j}(x_0)\right] \tag{6}$$

If we consider $\psi_i(0)$ to be the initial number of infected individuals in category $i$, then $\psi(t)$ is the number of infected individuals remaining in category $i$ after $t$ time units. We can then begin to approach the solution for the reproduction number. Integrating $F\psi(t)$ from zero to infinity gives the expected number of new infections produced by the initially infected individual over its infected lifetime . It can be shown [1] that $\int_0^\infty \psi(t) = V^{-1}\psi(0)$ and hence we can write the expected number of new infections to be generated by the initially infected as $FV^{-1}\psi(0)$. To interpret the entries of $FV^{-1}$ and help relate them to our intuitive understanding of the reproduction number, consider the lifetime of an infected individual introduced into category $k$ of a disease free population. The $(j, k)$ entry of $V^{-1}$ is the average amount of time the individual spends in category $j$ during its lifetime. The $(i, j)$ entry of $F$ is the rate at which the infected individual in category $j$ produces new infections in category $i$. Hence, the $(i, k)$ element of the matrix $FV^{-1}$ is the expected number of new infections in category $i$ produced by the infected individual. We can now present the formal mathematical definition of the reproduction number as

[1] see page 5 in [Van den Driessche and Watmough, 2002]

$$R_0 = \rho(FV^{-1}) \tag{7}$$

where $\rho(A)$ denotes the spectral radius, the maximum absolute eigenvalue, of matrix A.

This definition gives us a formula for the threshold conditions for when an infection is stable and when it will spread throughout the population. The similarity of infectious diseases to the spread of ideas is immediately intuitive. As individuals come into contact with proponents of new ideas, there is a probability that they too might adopt the idea. In turn, they may pass on the idea to others. On either side of some tipping point, an idea might spread or fade away. The concept and mathematical definition of the reproduction number will become helpful in understanding under what conditions an idea might spread throughout a population. Of course, while there are similarities, the simple SIR infectious disease model has some deficiencies that become apparent when considering its applicability to the spread of ideas. There remain some important differences that would make a modified model more compelling and I discuss them in *Table 1.*

Table 1: Ideas versus Diseases

(1) The first difference is that the spreading of an idea often involves an intentional act by both the transmitter and the adopter. An individual might actively seek to spread an idea and the potential adopter will likely influence her own openness to the idea. This difference highlights that individual behaviour has a strong impact on the probability of transmission. It is also clear that there involves more effort in the transmission of ideas compared to diseases.

(2) Second, the concept of recovery or becoming immune to an idea is not entirely analogous. Individuals generally absorb many ideas over their lifetime and in many instances, those ideas remain permanently. A similar notion might be that some individuals who hear an idea may choose to do nothing with it. There is in fact an extension of this idea. Unlike diseases, there may be individuals who reject the idea and actively try spread competing ideas. It is thus clear that the concept of recovery would need to be adjusted.

(3) Third, diseases are typically avoided. But in the instance of ideas, the incentive is not always clear. In some circumstances it may be advantageous to seek new ideas and in other instances it may be disadvantageous. In a similar way, the "infectiousness" of an idea may not be some exogenous factor, but in fact dependent on the extent of its adoption.

(4) Fourth, in the classic SIR model, there exists only a disease-free and a complete epidemic as possible points of stability. In the case of ideas, there may well be room for competing ideas to co-exist permanently.

(5) The fifth and arguably most important difference for this paper, is how diseases functionally spread. Typically, infectious diseases spread when susceptible and infected individuals come into physical contact. Ideas on the other hand, may not necessarily be spread within close geographically proximity or physical interaction. And in an evolving networked world, it is essential to understand the actual mechanism of transfer.

### 4.3 A Model for the Spread of Ideas

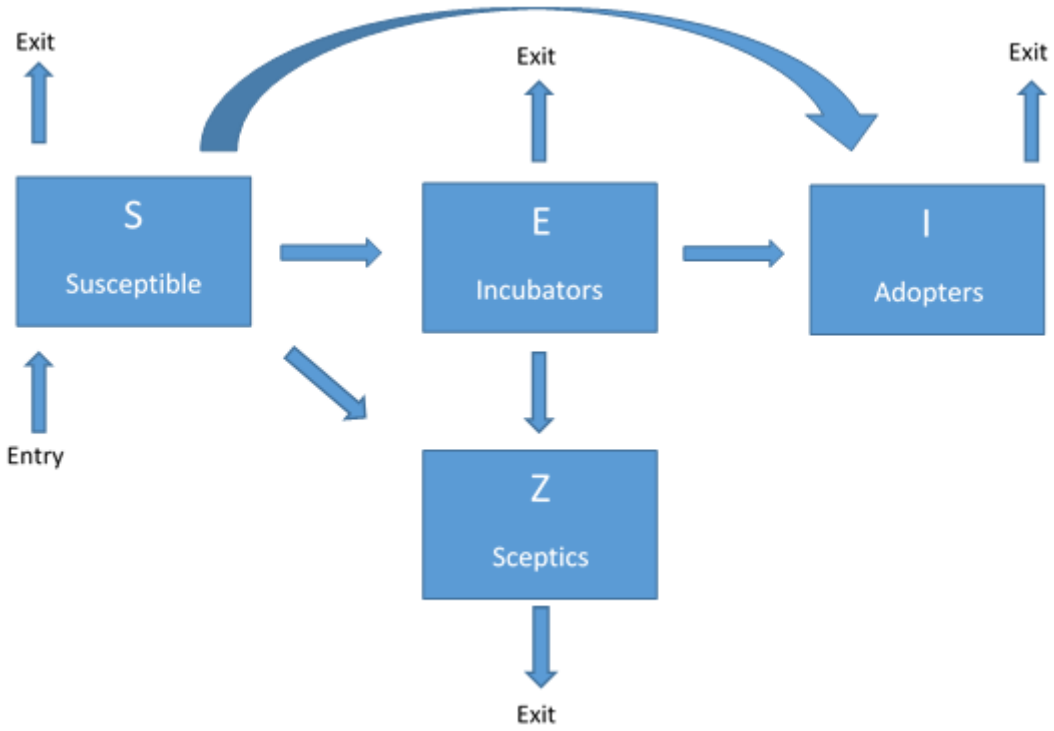
I will introduce a model based on the SEIR epidemic model and make some adjustments. The SEIR model introduces the concept of an incubator category (E). In epidemic models, this category is assigned to individuals who have been infected with the disease but have not become infectious themselves. This category will be useful because it allows us to create a category for individuals who have come into contact with an idea but have chosen neither to adopt nor reject it immediately. Furthermore, in order to adapt the model to better suit the differences highlighted in *Table 1*, I introduce the concept of Sceptics (Z) and drop that of Recovereds (R). Individuals that reject an idea and actively spread a competing idea are assigned to the Sceptics category. Such a model has four classifications for individuals: Susceptible (S), Incubators (E), Adopters (I) and Sceptics (Z). These four categories completely describe the population such that:

$$S + E + I + Z = N \tag{8}$$

where $N$ is the total population.

The dynamics of the model are governed by a number of flows outlined in *figure 2* below.

Figure 2: Group Dynamics



The basic construction above highlights the dynamics of the model. Susceptible individuals can transition either immediately to a Sceptic or an Adopter or alternatively find themselves as incubators of the idea for some time until they choose to adopt or reject the idea. At the same time, population dynamics are represented by a natural attrition of individuals in all categories while new entrants enter the susceptible pool only.

The primary area of interest in the model is the process under which these transitions between categories take place. Consider the population dynamics: here I assume that individual fatality is independent of category and individuals leave the system from all categories at rate $\mu$. For the moment, I consider a stable population and thus new individuals enter the Susceptible category at a rate $\mu$ of the total population, $N$.

Consider the process of how an idea might be transferred. An individual comes into contact with another individual who holds the idea. That idea is communicated and then, with a set of probability mappings, the original individual adopts, rejects or incubates it. Thus we might consider two groups of parameters that govern the dynamics of the spread of an idea. First, the per capita contact rate between different groups and second, the conditional probabilities that the individual transitions into a specific group. The final dynamic represented in *figure 2* is the transition from incubation to either adoption or rejection. Let us for a moment consider that individuals incubating the idea either remain incubators (in other words non-adopters) or transition to adopters only. In this case, we might consider two cases of incubators. First, incubators that simply take a certain time to digest the idea and then over time transition to the adopter class. Second, incubators that need further contact with other adopters before adopting the idea themselves. In this way, we would define a contact rate between adopters and incubators and a rate at which incubators transition to adopters over time. [Bettencourt, Cintrón-Arias, Kaiser, and Castillo-Chavez, 2006] I will now set out these parameters and their definitions below:

Table 2: Parameter Definitions

| Parameter | Definition |
|---|---|
| $\mu$ | Population birth and death rate |
| $\epsilon$ | Idea incubation rate |
| $\beta$ | Per-capita S-I contact rate |
| $b$ | Per-capita S-Z contact rate |
| $\rho$ | Per-capita E-I contact rate |
| $p$ | $Pr(S \to I \vert S - Icontact)$ |
| $1-p$ | $Pr(S \to E \vert S - Icontact)$ |
| $l$ | $Pr(S \to Z \vert S - Zcontact)$ |
| $1-l$ | $Pr(S \to E \vert S - Zcontact)$ |

Per-capita contact rates represent the rate at which contact between the two groups is made. Note, as was the case in the SIR model, this is not the same as the probability that two individuals from respective groups make contact with each other and, as such, is not the average interactions per time period. The average contacts would be dependent on the relative abundance of the respective groups in the population. From this we can express the differential equations governing the system:

$$\dot{S} = -\beta S\frac{I}{N} - bS\frac{Z}{N} - \mu S + \mu(S + E + I + Z) \tag{9}$$

$$\dot{E} = (1-p)\beta S\frac{I}{N} + (1-l)bS\frac{Z}{N} - \rho E\frac{I}{N} - \epsilon E - \mu E \tag{10}$$

$$\dot{I} = p\beta S\frac{I}{N} + \rho E\frac{I}{N} + \epsilon E - \mu I \tag{11}$$

$$\dot{Z} = lbS\frac{Z}{N} - \mu Z \tag{12}$$

There is an obvious stability point which is the idea-free state. Namely, $S^* = N; E^* = I^* = Z^* = 0$. In order to determine whether an idea will spread through the population, I turn to the definition of the reproduction number in Equation (7). In order to determine $R_0$ for the model, I must first generate $\mathcal{F}$ and $\mathcal{V}$. I will use the format where rows one to four correspond with category $S, E, I$ and $Z$ in that order. Thus we have

$$\mathcal{F} = \begin{pmatrix} 0 \\ (1-p)\beta S\dfrac{I}{N} + (1-l)bS\dfrac{Z}{N} \\ pBS\dfrac{I}{N} \\ 0 \end{pmatrix} \tag{13}$$

$$\mathcal{V} = \begin{pmatrix} \beta S\dfrac{I}{N} + bS\dfrac{Z}{N} - \mu(N-S) \\ \rho E\dfrac{I}{N} + (\epsilon+\mu)E \\ -\rho E\dfrac{I}{N} - \epsilon E + \mu I \\ -lbS\dfrac{Z}{N} + \mu Z \end{pmatrix} \tag{14}$$

The categories in this model which carry the idea are the Incubators (E) and Adopters (I). Analogously classifying these categories as the "infected" categories allows us to generate matrices $F$ and $V$ from Equations (4) and (6).

$$F = \begin{pmatrix} 0 & (1-p)\beta \\ 0 & p\beta \end{pmatrix} \tag{15}$$

$$V = \begin{pmatrix} \epsilon+\mu & 0 \\ -\epsilon & \mu \end{pmatrix} \tag{16}$$

Multiplying $F$ and the inverse of $V$ yields

$$FV^{-1} = \frac{1}{\mu(\epsilon+\mu)} \begin{pmatrix} (1-p)\beta\epsilon & (1-p)\beta(\epsilon+\mu) \\ p\beta\epsilon & p\beta(\epsilon+\mu) \end{pmatrix} \tag{17}$$

The eigenvalues of (17) are 0 and $\dfrac{\beta(\epsilon+p\mu)}{\mu(\epsilon+\mu)}$ and so it is clear that the spectral radius of $FV^{-1}$, the absolute maximum eigenvalue, is $\dfrac{\beta(\epsilon+p\mu)}{\mu(\epsilon+\mu)}$. We can repeat the process for the Sceptics category and then represent the reproduction number for both Adopters and

Sceptics. This is given by the vector:

$$R_0^{(I,Z)} = \left( \frac{\beta(\epsilon + p\mu)}{\mu(\epsilon + \mu)}; \frac{lb}{\mu} \right) \tag{18}$$

The number$R_0^I$ is of primary interest as it corresponds to the vector that includes a component of adopters. Note from the reproduction vector that it is possible for equilibrium to include both sceptics and adopters.

In order to visualize the dynamics of the system, it has been programmed into Matlab and simulated . The simulation is run for five different parameter sets. In each run $\beta$ (the contact rate between S-I) is increased by 0.025 and $l$ (the probability that someone transitions from S-Z given contact with Z) is increased by 0.1 each time. The system is run using 500 steps which is the point at which stability levels begin to become apparent for most of the runs. Note that the steps are the time units in which the parameters are defined. Changing this time unit would have only a scaling effect. 500 steps is chosen because it is the point at which the change in infected becomes approximately zero (stability is reached) for the third run. This allows us to see the impact of changing parameters on the dynamics and equilibrium levels and compare them to the impact they have on the Reproduction numbers, $R_0$ . In *figure 3 (a)* and *figure 4 (a)* we see the level of $R^I$ and $R^Z$ respectively. In *figure 3 (b)* and *figure 4 (b)* we can see that the corresponding dynamics of the Adopters and Sceptics population. The equilibrium populations reflect that values of $R_0$ above 1 correspond to a positive population of Adopters and Sceptics in equilibrium. The initial points and initial parameter values are given below.

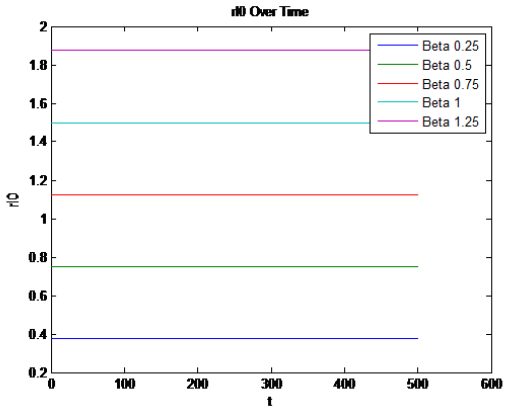
Table 3: Parameter Values

| Parameter | Value |
|---|---|
| $\mu$ | 0.05 |
| $\epsilon$ | 0.1 |
| $\beta$ | 0.025 |
| $b$ | 0.25 |
| $\rho$ | 0.5 |
| $p$ | 0.25 |
| $1 - l$ | 0.1 |

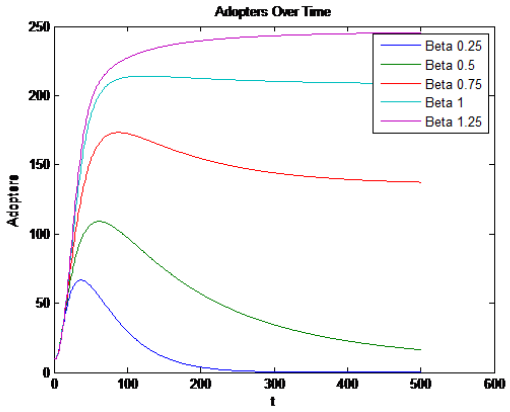
Table 4: Initial Values

| Parameter | Value |
|---|---|
| $S_0$ | 450 |
| $E_0$ | 0 |
| $I_0$ | 10 |
| $Z_0$ | 40 |
| $N_0$ | 500 |

Figure 3: Adopters

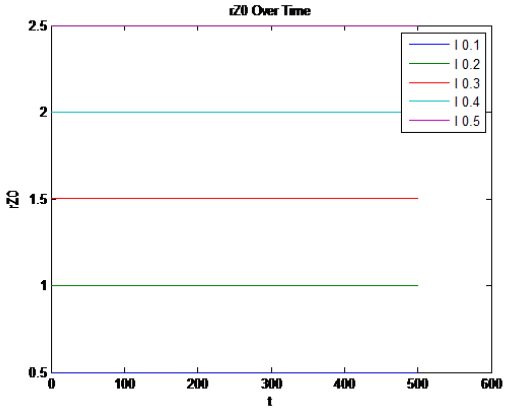



(a) Adopter Reproduction Number

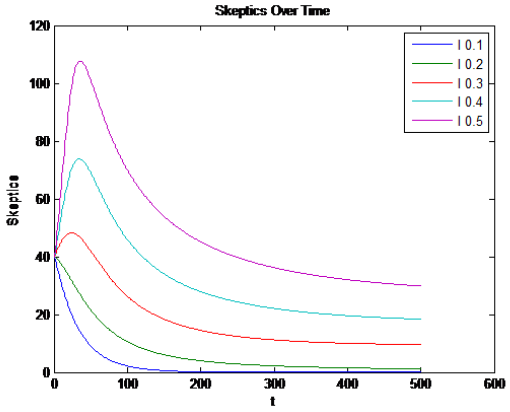



(b) Number of Adopters

Figure 4: Sceptics




(a) Sceptic Reproduction Number




(b) Number of Sceptics

## 4.4 A Model for the Influence of Migrant Networks on the Spread of Ideas

Let us now turn our attention to how this model might help address some of the particulars of the spread of ideas and how we might adapt this model to investigate the potential impact that migrants have on the spread of ideas in their home countries. This model helps us address some of the differences between how diseases and ideas spread. Consider the differences from *Table 1.* The first difference (1) raised was that unlike in the spreading of most diseases, there involves active effort in spreading institutional ideas. This effort can be represented by the per-capita contact rate between adopters and susceptible individuals. Furthermore, the ability to communicate with connections back home involves significant effort. Technology that reduces the cost of that communication should be considered as potentially having an impact on the contact rate between individuals. Thus we might understand the contact rate as a function of the of information and communication technology. This also addresses difference (5) in that it takes into considerations that ideas spread through physical as well as non-physical interaction.

The idea of individuals being immune to an idea is not clearly analogous as highlighted in (2). The model proposed introduces two additional classes, Incubators and Sceptics. The first addresses the concern that ideas may take time to germinate in individuals before they decide to accept or reject it. It also allows for individuals that may learn of the idea and choose to not act on it either way. The second allows for individuals to reject an idea and actively try spread competing ideas.

Institutions often impact the function of government or other power brokers in society. In many instances, these will be they people that are able to exert pressure on the spread of ideas. For example, through use of state entities such as security apparatus or a state broadcaster. Furthermore, in a society with extremely polarized views, the threat of ostracization or physical harm may dissuade people from adopting or spreading new ideas. Thus in the case of (3), it would be reasonable to assume that it may be costly to adopt or spread the idea in the instance when the significant majority of individuals are sceptical

and actively advocate opposite views. The current model currently has an effect of lower adoption rates since the fewer adopters in society, the less likely contact is and hence the idea is less likely to diffuse. The concern raised, however, goes one step further than the rate at which susceptible and adopters come into contact. Concern of adopting and spreading an idea would be best brought into the model by making the probability of conversion dependent on the extremity of differences in views between sceptics and adopters. In instances of extreme differences it may be difficult to adopt. This relationship, however, is likely to be quadratic. While it may be difficult to spread ideas in the instances of extreme hostility to the new idea, it is also likely that the spread of a new idea is unlikely to take hold in the instance the status quo is very similar. For example, if we look at the spread of twitter, it has moved rapidly through the world but remains unpopular in China. While state intervention is obviously important, the existence of the already popular service Weibo, which is for all intents and purposes the same as twitter, negates many of the advantages of Chinese people adopting Twitter. Furthermore, we might hypothesize that higher state interference reduces contact between Susceptible and Adopters. Difference (4) allows competing ideas, although the proposed model allows a simplification of only two ideas to co-exist. The model should also introduce avenues through which migrants may or may not have an influence on the spread of ideas. This will allow us to consider questions about the role of migrants: has the change in the type of migrant influence the flow of institutions. Does the evolution of technology increase or decreases any impact migrants might have on the transfer of institutions?

In order to do this, the SEIZ model is adapted in a number of ways. First, I introduce a new parameter, technology ($T$), which allows the contact rate and hence the effectiveness of idea transfer to be influenced. Second, I introduce a new category of individuals, migrant stock ($M$) as an exogenous source of adopters that are not influenced by the population decay and are unaffected by sceptics. It is important to consider how migrants influence the adoption of a new idea in their home country. Is it via the simple introduction of ideas, some of which take hold as a result of internal conditions, or is it the constant interaction of migrants with citizens in their home countries that facilitates the spread of the idea.

In the first instance, it may be best to consider the role of migrants as being depen-

dent on the total number of migrants outside the home country. In this way, the absolute number of migrants act as infected individuals who act to spread ideas . The relative intensity of migration in comparison to the number of infected individuals is also important. In this scenario, the relative intensity of migration is only important in so far as the more migrants there are, the more instances of contact between a migrant and susceptible individual there will be.

In the second instance, it might be that migrants are particularly influential in increasing contact with new ideas intially and that importance fades as the infection spreads. Furthermore, this influence might be driven by the relative intensity of migration. We might then consider a model in which the the intensity of migrant stock increases the contact rate between susceptible and infected classes with a diminishing marginal impact as the relative size of the infected population grows.

In the following section, I will propose a model for each of the above two instances.

### 4.4.1 Migration Model 1

$$\dot{S} = -\beta T S\frac{I+\alpha M}{N} - bS\frac{Z}{N} - \mu S + \mu(S+E+I+Z) \tag{19}$$

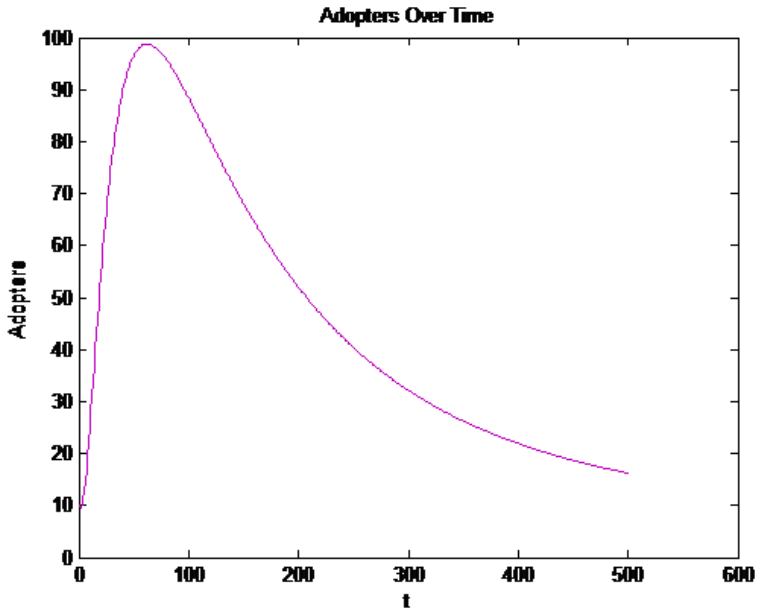
$$\dot{E} = (1-p)\beta T S\frac{I+\alpha M}{N} + (1-l)bS\frac{Z}{N} - \rho E\frac{I+\alpha M}{N} - \epsilon E - \mu E \tag{20}$$

$$\dot{I} = p\beta T S\frac{I+\alpha M}{N} + \rho E\frac{I+\alpha M}{N} + \epsilon E - \mu I \tag{21}$$

$$\dot{Z} = lbS\frac{Z}{N} - \mu Z \tag{22}$$

If we model this new system of equations into Matlab, we can see that we can achieve the same results if we create the appropriate initial conditions and parameter values. Let us consider the second case of the simulations run under the standard (unadapted) model. In this case, $\beta = 0.05$ and $l = 0.2$. If we set $M = 0; T = 1$ and $d = 0.5$ then we would expect to generate the exact same results as in the standard model. Running this simulation and plotting the adopter population for both models illustrates this mathematical fact in *figure 5*.

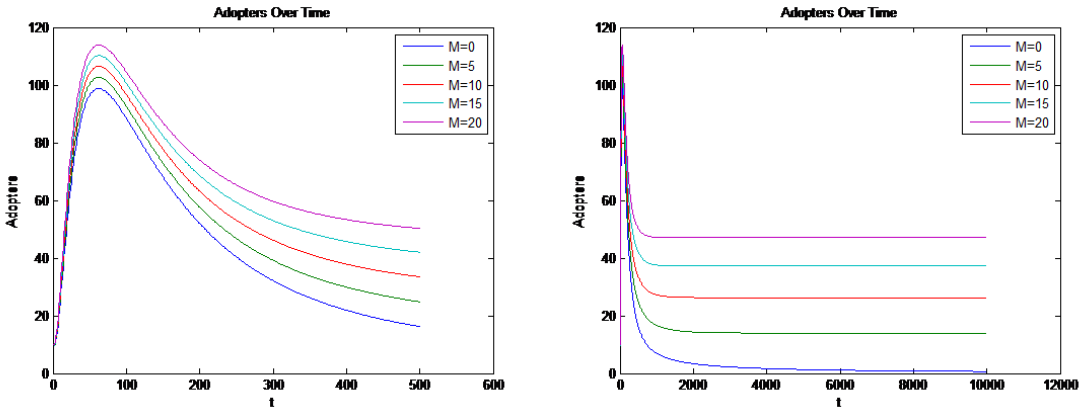
Figure 5: Adopters in Migration and SEIZ Model




Let us now consider the impact of a migrant stock and investigate by running the simulation with different levels of migrant stock ranging from 0 and increasing by 5 each run until we reach 20. I run the simulation over 500 steps for comparison to earlier simulations and given this adequately illustrates the short run dynamics, I also show the a simulation of 10 000 steps to clearly illustrate the equilibrium levels for each category. What we can see in *figure 6* is that while having a migrant stock sending ideas back to a country has a positive impact, it would seem to be rather negligible and only at the higher levels does it seem to make much difference on the number of adopters in equilibrium. Turning to technology, increasing the technology parameter from 1 by 0.15 (in other words, increasing effectiveness of idea transfer by 15% in the first instance) for each run results in a more varied impact on adopters. That said, the effect over a longer time horizon shows that the increase in technology has little influence on the existence of adopters in equilibrium as can be seen in *figure 7*. Only the top two, increases of 45% and 60% in the effectiveness of transfer, has much impact on the existence of adopters in equilibrium.

Now consider the combined effect of having a migrant stock constantly being a source of the new idea and more powerful technology facilitating idea transfer. From these simulations, we can see that the model combines the desired properties to form a system with

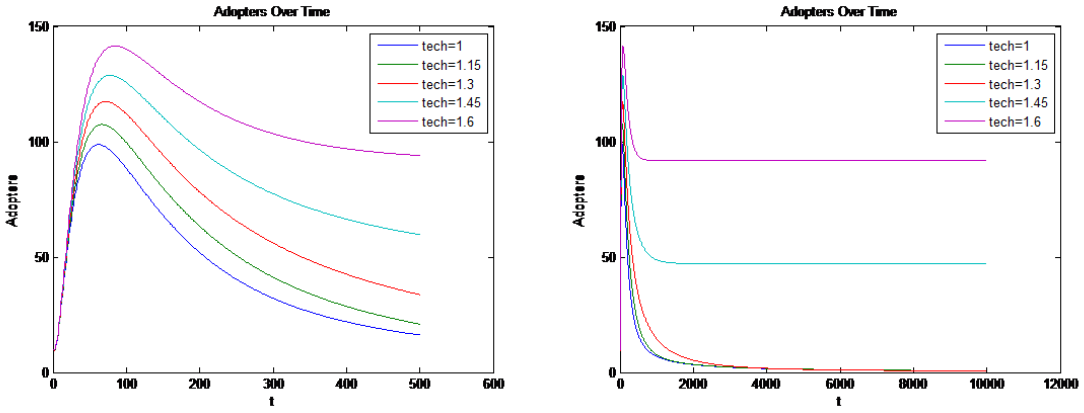
Figure 6: Adopters with Varying $M$




(a) 500 iterations

(b) 10 000 iterations

Figure 7: Adopters with Varying $T$

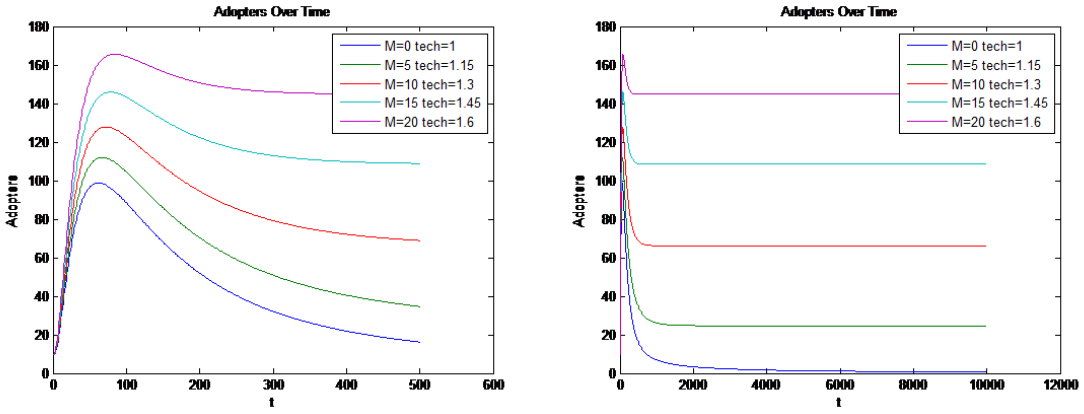



(a) 500 iterations

(b) 10 000 iterations

which we can fit to real world data and estimate the parameters.

Figure 8: Adopters with Varying $M$ and $T$




(a) 500 iterations

(b) 10 000 iterations

In the model above, the migrational intensity matters only in so far as the greater the relative size of the migrant stock, the greater the number of interactions between infected classes and susceptible classes. It might be the case, however, that the influence of migrants is primarily through the initial introduction and spread of an idea to their home society and this introduction depends more directly on migrational intensity. In such a case, the model previously introduced would not be best suited to describing the influence of migrants. I now consider an alternative and introduce a second model in which migrational intensity, $\frac{M}{N}$, increases the contact rate between infected and susceptible individuals with diminishing marginal impact with respect to the relative size of the infected population. That is to say, the marginal influence of migrational intensity is higher when the idea is in its early stages. Such a model would be described by the following system of differential equations:

### 4.4.2 Migration Model 2

Consider a new contact rate defined in the following way:

$$\hat{\beta} = \beta + \alpha \frac{M}{N} . \frac{N}{I} = \beta + \alpha \frac{M}{I}$$

In this way the contact rate increases in proportion to migrational intensity and its

influence is greatest when $I$ is small relative to $N$. We can then define a system of equations to describe such a model:

$$\dot{S} = -\frac{TS}{N}(\beta I + \alpha M) - bS\frac{Z}{N} - \mu S + \mu(S + E + I + Z) \tag{23}$$

$$\dot{E} = (1-p)\frac{TS}{N}(\beta I + \alpha M) + (1-l)bS\frac{Z}{N} - \rho E\frac{I}{N} - \epsilon E - \mu E \tag{24}$$

$$\dot{I} = p\frac{TS}{N}(\beta I + \alpha M) + \rho E\frac{I}{N} + \epsilon E - \mu I \tag{25}$$

$$\dot{Z} = lbS\frac{Z}{N} - \mu Z \tag{26}$$

## 4.5 Empirical Investigation of Migrant Stock Influence on the Spread of an Idea

The previous section has introduced a model which hypothesizes the process by which migrants might influence the spread of ideas. Such a model might be helpful in explaining the empirical data . Given the relatively long incubation and adoption of ideas, there is currently limited data that pinpoints both the location and time an individual adopts an idea. The specific nature of this data would typically require dedicated data collection as is the case with epidemics. That said, the growing world of "Big Data" collection has produced global services that are new, but data rich. In particular, the regular use of social media which is increasingly geo-located will produce a number of datasets which include both time and location entries. Furthermore, as some of these services grow, they capture and share more data. For example, while LinkedIn is unable to share data on the historical number of users in each country, they will publish this data each year going forward meaning the dataset will be available in a few years. Unfortunately, the availability of this kind of data is currently limited given its recent nature. That said, the type of data described is rapidly becoming available and the richness of such data has prompted a number of academic and research institutions to begin data collection projects and explore ways in which such data can be used in the social sciences [Oxford Internet Institute, 2013]. While it will take some years for much of this data to cover enough time,

the underlying registered users provide an opportunity to see how the models outlined in the previous section explain the spread of services such as Facebook.

Services such as Facebook or LinkedIn provide a dataset which pinpoints the time and place a user adopts the idea or new technology. That is to say, the moment that a user registers a new account. Furthermore, the websites have predefined locations from which individuals must choose their location. As a result, the time series tracking the number of registered users in each country provides an attractive dataset that tracks the spread of such services. Using this data, and combining it with control data on migrants and conditions in each country will allow the parameters of the model to be estimated by fitting the model to the data. This would hopefully reveal some insights into whether the spread of Facebook is in some way better explained by taking into account migrants. Since listing, Facebook has generated a time series of the number of daily active users since its inception. This datset however, is only broken into broad regions rather than individual countries. Fortunately, there is some data which has been extracted from Facebook's advertising services. Facebook previously made available the number of registered users in each country to advertisers. Facebook did this so advertisers could target specific countries and know how many users were registered in the country of interest. This data was captured semi-annually between July 2008 and December 2012 for the thirty countries with the most facebook users. Facebook no longer provides data on such a disaggregated level but the rapid nature of the spread of Facebook means this 4 year dataset provides a sufficient amount of data to fit the models and draw some conclusions on the relative applicability of the models in describing the spread of Facebook.

### 4.5.1 Data

Facebook user data is captured for the thirty countries with the most facebook users. The data initially came from Facebook's advertising platform in which it gave data on the total number of users in each country. Facebook stopped making this data available from 2013 when it moved to its quarterly release of monthly active users (MAU) and daily active users (DAU). This data is not released per country but by region and is not immediately comparable. There are some obvious pitfalls to user data taken from the advertising plat-

Table 5: Initial Populations

| Country | Initial Susceptible | Initial Infected | Migrant Stock |
|---|---|---|---|
| Australia | 6 760 482 | 4 330 040 | 296 336 |
| Canada | 7 813 803 | 10 862 040 | 1 065 761 |
| France | 25 389 490 | 6 587 240 | 995 246 |
| Germany | 42 748 963 | 1 255 480 | 2 384 054 |
| Italy | 15 094 024 | 5 585 700 | 2 836 314 |
| Netherlands | 9 633 066 | 351 280 | 722 501 |
| Spain | 17 865 629 | 2 596 080 | 1 060 235 |
| United Kingdom | 19 375 984 | 14 937 180 | 3 534 217 |

form. In the first instance, it represents the users signed up and registered in each country. This would include duplicate accounts or accounts in which users registered to the incorrect country. Facebook itself has estimated that the number of duplicate or misclassified accounts is between 4-8 %

I have used a number of different data sources to help estimate initial levels and parameters in order to sufficiently constrain the model. The initial susceptible population is estimated in the following way: I take the population data from the World Bank for 2008, multiply it by the 2008 proportion of the population with internet access (World Bank) and then multiply once again by the proportion of people between 15-65 (World Bank) before substracting the initial number of Facebook users. This may in some ways underestimate the susceptible population since the up take of Facebook among those younger than 15 and older than 65 has happened to some degree. That said, I think this is a reasonable estimate of each country's population which is susceptible to adopting Facebook. Given the lack of directly competing, mutually exclusive social networks, the skeptic data and dynamics are secondary in this simulation.

The exact measure to use for the migrant stock number is more difficult. Practically one would want to take the number of migrants in each country multiplied by the propensity of Facebook users among migrants in that country for each period. Given the lack of granularity in migrant data and accurate data about migrant take up of Facebook, we use total migrants that have emmigrated to one of the countries that have the thirty most Facebook users.

There are a number of additional difficulties in estimating the model. First, the roll out of additional internet access can create more dynamic changes to the susceptible population. Furthermore, while the time scale is short in absolute terms, countries with rapid population changes might also be difficult to estimate. Finally, with changes in methods in accessing Facebook (for example, the introduction of easy mobile access for Facebook), technology differences between countries might be particularly important. For this reason, I choose to limit the exploration to countries with relatively stable provision of internet and technological similarity. This limits the data exploration to eight countries which are primarily considered Western societies. In summary, the following countries are used with data for migrant stock, initial susceptible population and Initial Infected Populations given in *Table 5*.

### 4.5.2 Methodology

Three models are programmed into Matlab: the standard SEIZ model, Migrant Model 1 and Migrant Model 2. Using ode15s, Matlab's differetinal equation solver, and lsqcurvefit, the parameters are estimated by fitting the model to the data. I bound the data using the following limits:

Table 6: Parameter Bounds

| Parameter | Lower Bound | Upper Bound |
|---|---|---|
| $\alpha$ | 0 | 1000 |
| $\beta$ | 0 | 100 |
| $InitialExposed$ | 0 | Infected at $t = 2$ |
| $p$ | 0 | 1 |
| $\epsilon$ | 0.1 | 10 |

There exists the possibility of solutions being locally dependent on the initial conidtions. In order to minimize the possibility of this, the curve fitting is run from multiple different initial guesses for the parameters. The susceptible, exposed, infected and skeptic populations are plotted against the data. And the parameter estimates are recorded for each model.

### 4.5.3 Results

Using a traditional frequentist approach to assess the results of the curve fitting exercise would not be appropriate in this case. because there is little information regarding the nature of any measurement or statistical error, the sample size is small and the constrained optimization process results in an ill-defined jacobian restricting inferences around parameter values.

In order to then assess the applicability of the proposed models, we turn to methods from information theory. In this case, we will use Akaike Information Criterion adjusted for smaller sample sizes, (AICc), to determine whether each of the proposed models is more or less probable relative to a base model.

The AICc gives an estimate of the information lost when a model is used to explain a process that has generated data. In this sense, the AICc provides an estimate of the quality of a model but purely in a relative sense and does not give an indication of the absolute quality of the model. In this case, we use the SEIZ model as the base model and test whether the proposed models are more probable in their explanation of the spread of Facebook.

As mentioned we use the AICc is given by

$$AICc = 2k - 2\ln L + \frac{2k(k-1)}{n-k-1} \tag{27}$$

where $k$ is the number of parameters and $L$ is the maximized value of the likelihood function for the model. The absolute number of the AICc is not important but a relatively lower AICc indicates a greater explanatory power given the loss of information from additional parameters. The AICc for each model and country is given in the *Table 7* and the implied relative probabilities are given in *Table 8*.

Table 7: Model AICc Values

| Country | Model 1 | Model 2 | SEIZ Model |
|---|---|---|---|
| Australia | 246.3 | 248.5 | 245.3 |
| Canada | 271.5 | 271.5 | 271.4 |
| France | 266.9 | 268.3 | 266.2 |
| Germany | 271.9 | 281.9 | 272.0 |
| Italy | 262.3 | 264.1 | 261.9 |
| Netherlands | 240.5 | 241.7 | 243.7 |
| Spain | 259.8 | 259.6 | 261.9 |
| United Kingdom | 268.9 | 268.3 | 268.7 |

Table 8: Probability Model is Best Candidate

| Country | Model 1 | Model 2 | SEIZ Model |
|---|---|---|---|
| Australia | 0.34 | 0.11 | 0.55 |
| Canada | 0.32 | 0.33 | 0.35 |
| France | 0.33 | 0.27 | 0.50 |
| Germany | 0.51 | 0.00 | 0.49 |
| Italy | 0.39 | 0.14 | 0.47 |
| Netherlands | 0.56 | 0.32 | 0.12 |
| Spain | 0.40 | 0.46 | 0.14 |
| United Kingdom | 0.37 | 0.22 | 0.41 |

One of the interesting results from this parameter estimation is that for many countries, the introduction of additional parameters for migrants does not sufficiently reduce the errors associated with fitting the data to the proposed model. Consider the UK for example, where the best model to explain the data is the standard SEIZ model where the AICc criterion implies that there is a 0.41 probability that this SEIZ model is the best of the three models in explaining the underlying process generating the data. The same is true for a number of other countries. One notable observation is that the addition of migrants to the standard SEIZ model fails to better explain the spread of Facebook in countries in which Facebook spread first. The data from countries in which Facebook saturation is relatively lower and were later adopters of Facebook appear to be better explained by the models including migrants. One reason for this divergence might be that the importance of migrants is not constant across the life cycle of the spread of an idea between countries. That is to say, migrants might play a influential role in the introduction of ideas back into their home communities but it is primarily internal conditions that subsequently drive the propogation of ideas from that point onwards. Another reason would be that the data for migrants inputed into the model is constant and it does not capture the relative propensiting of adoption among migrants from the country. As a result, there is a difference in the relative accuracy of including such migrants for early and late adopting nations. This may explain why the model and its use of the data is considered more probable in its explanation of the process in nations adopting Facebook later. Further models that are able to use data that captures the more dynamic influence of migrants at earlier stages might better describe the role of migrants in the spread of Facebook more generally.

To illustrate this, the results of the parameter estimation are given for the Netherlands. Given the contrained optimization used to fit the data, the Jacobian is ill-defined at the point of solution and the lack of a model describing the errors theoretically mean that confidence interval estimates would be of little value. Beyond the primary assesment of the models in their entireity, the parameters have theoretical interpretations and the sensibility of these parameters is of interest. In the table below, the most evident result is the probability of transmission conditional on contact in the SEIZ model. At 0.998, the model effectively requires perfect transmission in order to fit the speed at which Facebook

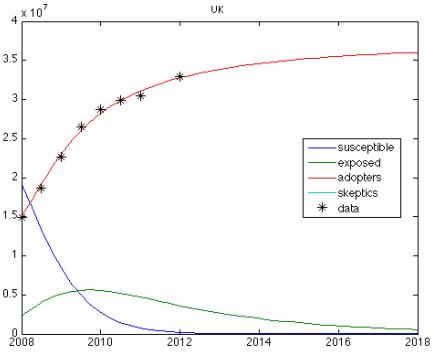
Table 9: Parameter Estimates for the Netherlands

| Parameter | SEIZ Model | Migrant Model 1 | Migrant Model 2 |
|---|---|---|---|
| $\alpha$ | - | 0.972 | 0.889 |
| $\beta$ | 0.802 | 0.776 | 0.778 |
| $e_0$ | 913 542 | 354 720 | 416 788 |
| $p$ | 0.998 | 0.627 | 0.681 |
| $\epsilon$ | 1.419 | 3.278 | 1.627 |

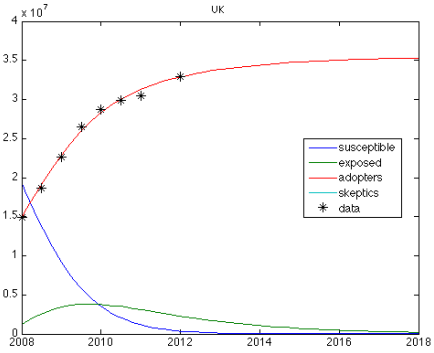
was initially adopted in the Netherlands. In a similar way, the initial exposed population estimated by the SEIZ model is high in order to accommodate the curvature at the start of the dataset. The migrant models, however, estimate what are arguably more reasonable estimates of the transmission probability. The existence of external sources of the idea allow for adoption to spread more quickly at the onset in countries that are late adopters than might otherwise be governed by internal conditions alone.

While not conclusive, Migrant Model 1 also appears to be better at explaining the spread of Facebook. This would suggest that perhaps the absolute number of migrants introducing ideas back into their home society, given the appropriate internal conditions, is more important than a higher migrational intensity. The different population dynamics estimated for Model 1 and Model 2 are plotted versus the actual data series in Figures 9 and 10. Each figure plots the two models for each country side by side. The y-axis gives the number of individuals in each respective category and the x-axis is measured in years.

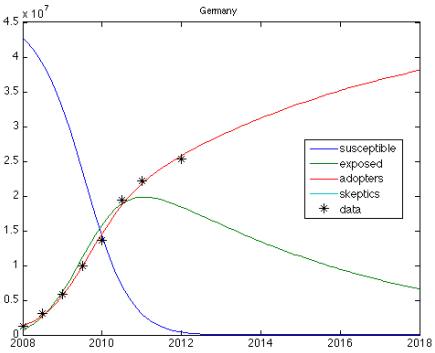
Figure 9: Model Comparison



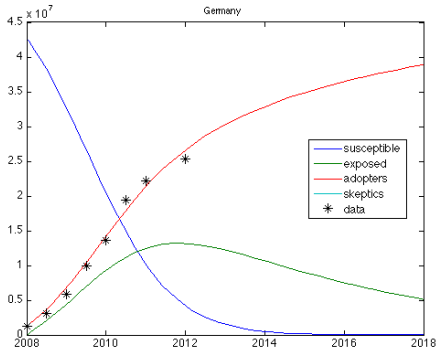

(a) UK Model 1



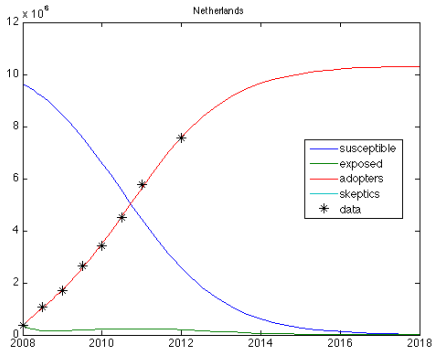

(b) UK Model 2



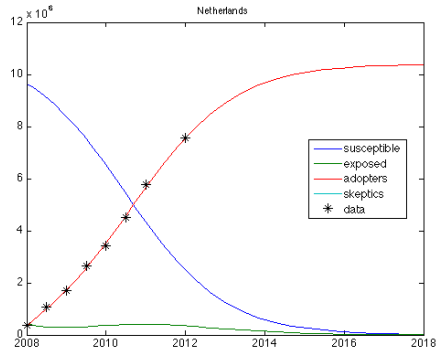

(c) Germany Model 1



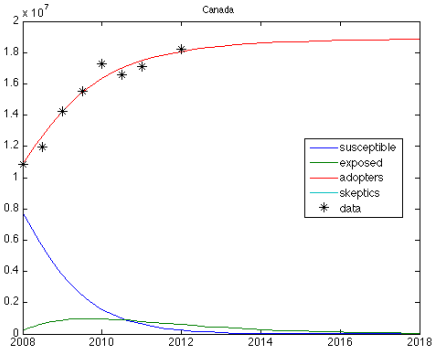

(d) Germany Model 2



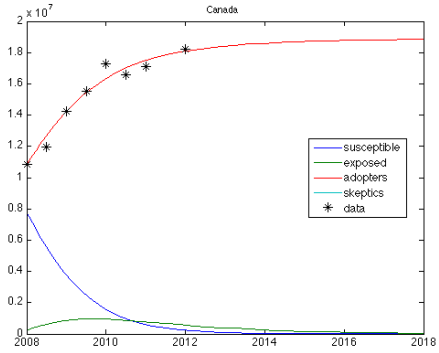

(e) Netherlands Model 1




(f) Netherlands Model 2

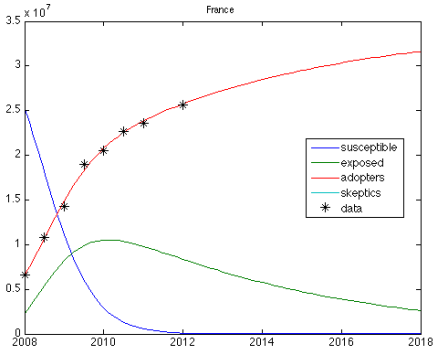



(g) Canada Model 1

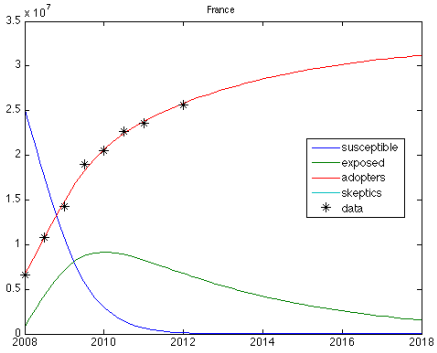



(h) Canada Model 2

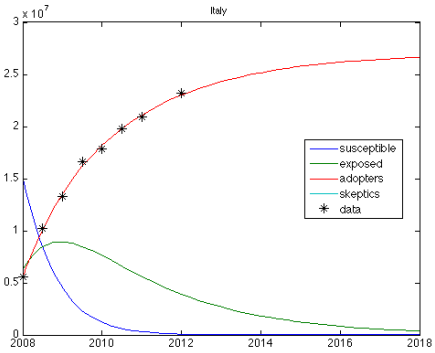
Figure 10: Model Comparison



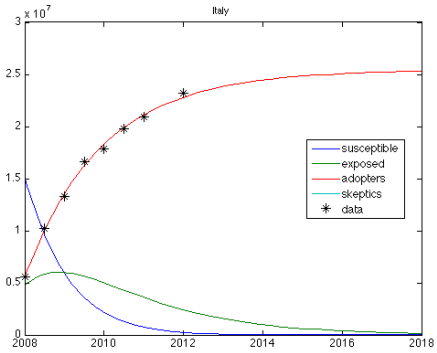

(a) France Model 1



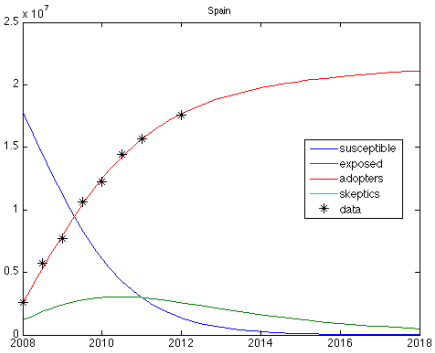

(b) France Model 2



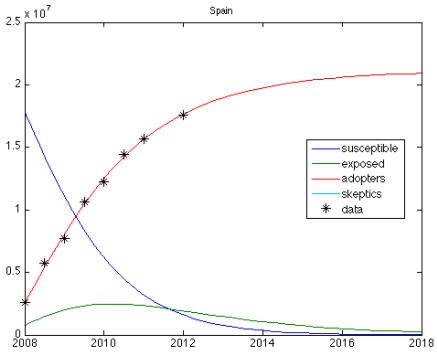

(c) Italy Model 1



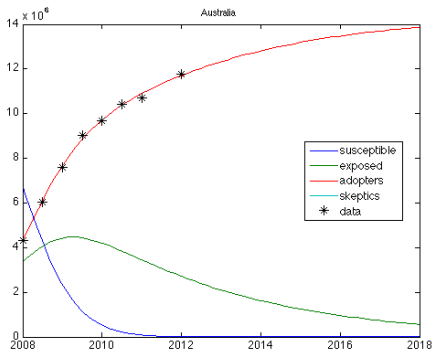

(d) Italy Model 2



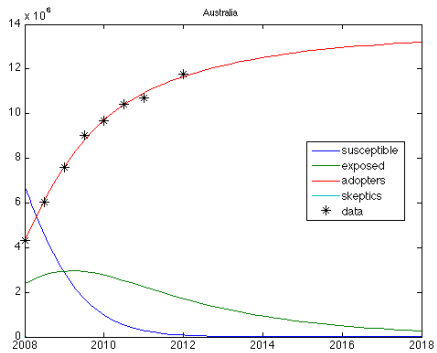

(e) Spain Model 1




(f) Spain Model 2




(g) Australia Model 1




(h) Australia Model 2

### 4.5.4 Conclusion

This paper has explored the role migrants play in the transfer of social institutions and has presented a review of the literature that gives evidence of the pivotal role migrants can play in the transfer of social institutions. I argue in the paper that the rise of new technologies, which lower the financial and opportunity costs as well as deepen the information shared across networks, is likely to increase this impact in the future.

Using techniques primarily employed in the field of epidemiological study, I have proposed two models to describe the process by which migrants can influence the spread of social institutions in their home country. As an exploratory exercise, I have investigated whether in the particular instance of Facebook, the proposed models might better describe the underlying process which drove the spread of Facebook. The evidence suggests that accounting for migrants can help to better explain the spread of ideas particularly so in the earlier stages of the propogation of an idea although internal dynamics unrelated to migrants are more important in the later stages of an ideas propogation With the growing recognition of the importance of social institutions and new data becoming available, this should be a fruitful ground for further research.

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# Appendices

## A Output

Table 10: Sum Squared Residuals

| Country | SEIZ Model | Migrant Model 1 | Migrant Model 2 |
|---|---|---|---|
| Australia | $6.56 \times 10^{10}$ | $7.43 \times 10^{10}$ | $9.77 \times 10^{10}$ |
| Canada | $1.71 \times 10^{12}$ | $1.74 \times 10^{12}$ | $1.74 \times 10^{12}$ |
| France | $8.88 \times 10^{11}$ | $9.82 \times 10^{11}$ | $1.16 \times 10^{12}$ |
| Germany | $1.84 \times 10^{12}$ | $1.83 \times 10^{12}$ | $6.42 \times 10^{12}$ |
| Italy | $5.20 \times 10^{11}$ | $5.47 \times 10^{11}$ | $6.87 \times 10^{11}$ |
| Netherlands | $5.33 \times 10^{10}$ | $3.6 \times 10^{10}$ | $4.15 \times 10^{10}$ |
| Spain | $5.22 \times 10^{11}$ | $4.03 \times 10^{11}$ | $3.90 \times 10^{11}$ |
| United Kingdom | $1.21 \times 10^{12}$ | $1.25 \times 10^{12}$ | $1.42 \times 10^{12}$ |

## B Matlab Code

Example 1

```
clear all
%define some initial variables
%This version uses the unclosed form differential equations and includes migrant
    influence

steps = 500;

AS = zeros(steps,5);
PS = zeros(steps,6);
initialSIR = zeros(1,5);
S0 = 90;
I0 = 10;
R0 = 0;
N = 100;
```

```
t0 = 0;

initialSIR(1,1) = t0;
initialSIR(1,2) = S0;
initialSIR(1,3) = I0;
initialSIR(1,4) = R0;
initialSIR(1,5) = N;

%How many different scenarios
for j=1:8
%Initial Parameters
output = [initialSIR; AS];
% parameters = [M, a, b, d, tech]
M = 0;
c = 2;
tech = 0;
d = 0.0005;
p = 0.01;
rr0 = c*p/d - I0*N*(N-1)/(2*S0*(I0+M));

initialp = [M c tech d p rr0];
param = [initialp; PS];

%Time step repetitions

for t = 1:steps

%Calculations
%This version uses my own formuli with migrant influence
%t%
output(t+1,1) = t;

%S%
output(t+1,2) = output(t,2) -
    param(t,2)*param(t,5)*2*output(t,2)/(output(t,5)*(output(t,5)-1))*(output(t,3)+param(t,1));
```

```
%I%
output(t+1,3) = output(t,3) +
    param(t,2)*param(t,5)*2*output(t,2)/(output(t,5)*(output(t,5)-1))*(output(t,3)+param(t,1))-par
%R%
output(t+1,4) = output(t,4) + param(t,4)*output(t,3);
%N%
output(t+1,5) =output(t,5);

%Parameters%

%M%
%Experiment bump
if t==1000
param(t+1,1) = param(t,1);
else
param(t+1,1) = param(t,1);
end
%c%
param(t+1,2)= param(t,2);
%tech%
param(t+1,3) = param(t,3);
%d%
param(t+1,4) = param(t,4);
%p%
if t==1000
param(t+1,5) = param(t,5)+0.005*j;
else
param(t+1,5) = param(t,5);
end
%rr0%
param(t+1,6) = param(t+1,2)*param(t+1,5)/param(t+1,4) -
    output(t+1,3)*output(t+1,5)*(output(t+1,5)-1)/(2*output(t+1,2)*(output(t+1,3)+
    param(t+1,1)));

end
```

```
if j == 1
% expIresults = [output(:,1)]
exp1Iresults = [output(:,3)];
exp1rr = [param(:,6)];
else
exp1Iresults = [exp1Iresults output(:,3)];
exp1rr = [exp1rr param(:,6)];
end
end

namegrp = 'C:\\test1';emph
grp = figure('visible','on');
plot(exp1Iresults);
xlabel('t');
ylabel('Infected');
title({'Infected Over Time'});
legend('Tech 0.1','Tech 0.2','Tech 0.3','Tech 0.4','Tech 0.5','Tech 0.6','Tech
    0.7','Tech 0.8','Tech 0.9','Tech 1')

namegrp = 'yyy';
grp = figure('visible','on');
plot(exp1rr);
xlabel('t');
ylabel('rr');
title({'rr Over Time'});
legend('Tech 0.1','Tech 0.2','Tech 0.3','Tech 0.4','Tech 0.5','Tech 0.6','Tech
    0.7','Tech 0.8','Tech 0.9','Tech 1')
```

Example 2

```
clear all
%define some initial variables
%This version uses the standard calculations without migrant influence

steps = 200;
```

```
AS = zeros(steps,5);
PS = zeros(steps,6);
initialSIR = zeros(1,5);
S0 = 90;
I0 = 10;
R0 = 0;
N = 100;
t0 = 0;

initialSIR(1,1) = t0;
initialSIR(1,2) = S0;
initialSIR(1,3) = I0;
initialSIR(1,4) = R0;
initialSIR(1,5) = N;

%How many different scenarios
for j=1:8
%Initial Parameters
output = [initialSIR; AS];
% parameters = [M, a, b, d, tech]
M = 25;
c = 2;
tech = 0;
d = 0.01;
p = j*0.0025;
rr0 = c*p/d;

initialp = [M c tech d p rr0];
param = [initialp; PS];

%Time step repetitions

for t = 1:steps
```

```
%Calculations
%This version uses the standard calculations without migrant influence
%t%
output(t+1,1) = t;

%S%
output(t+1,2) = output(t,2) -
    param(t,2)*param(t,5)*(output(t,3))*output(t,2)/output(t,5);
%I%
output(t+1,3) = output(t,3) +
    param(t,2)*param(t,5)*(output(t,3))*output(t,2)/output(t,5)-param(t,4)*output(t,3);
%R%
output(t+1,4) = output(t,4) + param(t,4)*output(t,3);
%N%
output(t+1,5) =output(t,5);
%Parameters%

%M%
param(t+1,1) = param(t,1);
%c%
param(t+1,2)= param(t,2);
%tech%
param(t+1,3) = param(t,3);
%d%
param(t+1,4) = param(t,4);
%p%
param(t+1,5) = param(t,5);
%rr0%
param(t+1,6) = param(t+1,2)*param(t+1,5)/param(t+1,4);

end
if j == 1
% exp1results = [output(:,1)]
exp1Iresults = [output(:,3)];
exp1rr = [param(:,6)];
```

```
else
exp1Iresults = [exp1Iresults output(:,3)];
exp1rr = [exp1rr param(:,6)];
end
end

namegrp = 'C:\\test1';
grp = figure('visible','on');
plot(exp1Iresults);
xlabel('t');
ylabel('Infected');
title({'Infected Over Time'});
legend('Tech 0.1','Tech 0.2','Tech 0.3','Tech 0.4','Tech 0.5','Tech 0.6','Tech
    0.7','Tech 0.8','Tech 0.9','Tech 1')

namegrp = 'yyy';
grp = figure('visible','on');
plot(exp1rr);
xlabel('t');
ylabel('rr');
title({'rr Over Time'});
legend('Tech 0.1','Tech 0.2','Tech 0.3','Tech 0.4','Tech 0.5','Tech 0.6','Tech
    0.7','Tech 0.8','Tech 0.9','Tech 1')
```

Example 3

```
% SEIZ model

function dx = seizs(t, x)
%SIR model with contigious recovery
%   t variable not used. x contains population vector
% output = first deriv of popn

global alpha ba beta epi la mu pro rho so eo M sg io eo nchange
```

```
%rho = 0.2;

%assuming mu is zero



dx = [0;0;0;0];
tempa= [1;1;1;1];


%S
dx(1) = -
    beta.*x(1).*x(3)./(x(1)+x(2)+x(3)+x(4))-ba.*x(1).*x(4)./(x(1)+x(2)+x(3)+x(4));
%E
dx(2) = (1-pro).*beta.*x(1).*(x(3))./(x(1)+x(2)+x(3)+x(4))
    +(1-la).*ba.*x(1).*x(4)./(x(1)+x(2)+x(3)+x(4))-rho.*x(2).*(x(3))/(x(1)+x(2)+x(3)+x(4))-epi.*x(
%I
dx(3) =
    pro.*beta.*x(1).*(x(3))/(x(1)+x(2)+x(3)+x(4))+rho.*x(2).*(x(3))/(x(1)+x(2)+x(3)+x(4))+epi.*x(2
%Z
dx(4) = la.*ba.*x(1).*x(4)/(x(1)+x(2)+x(3)+x(4));
%popn constaint

end
```

Example 4

```
function y = infectionseizm(a,x)

global alpha ba beta epi la pro rho so eo zo M io dayd sg



alpha = a(1);
```

```
beta = a(2);

eo = a(3);

pro = a(4);

epi = a(5);









[t, y] = ode15s('seizm', [0 x(end)], [so, eo, io, 0]);


y = interp1(t,y(:,3), x);

end
```

---