Subscript-Based Geospatial Migration Dynamics

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Subscript-Based Geospatial Migration Dynamics

Abstract

Between 2013 and 2015, over one million migrants entered Europe. Many European countries were unprepared for and overwhelmed by the rapidly unfolding, chaotic situation. To better handle future migration waves, and allow quicker exploration of government policy effects and interactions, a geospatial-based system dynamics model of migration flows across Europe was developed together with the national police of a major EU country. The model, built around subscripted data and vector operations, distributes migration inflows across the continent based on dynamic mechanisms such as societal stress, social group pull and country attractiveness. It is lightweight yet versatile, and is useful for exploratory, early-stage policy modelling, especially when investigating the system-wide effects and interactions of national migration policies.

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Introduction

When over a million migrants entered Europe between 2013 and 2015, this caused significant tension within the European Union. As countries disagreed on how to deal with this massive influx, there was no widely supported unified approach. Instead, most national governments chose to adopt self-serving policies, such as closing their borders to prevent migrants from entering, or employing busses to make sure the migrants left again as quickly as possible. These policies further aggravated the situation, and demonstrate that Europe was completely unprepared for the migration wave that it was facing. This not only caused confusion and suffering for the migrants, but also led to unnecessary societal tensions and public backlash across the continent due to the perceived failure of (supra-)national authorities to deal with the crisis.

Over the course of 2016 and 2017, migration has fallen to its pre-crisis numbers, and Europe has had time to recover. However, the migration problem is far from over. Recent studies argue that climate change might be a major contributor towards population displacement in the future (e.g. Reuveny, 2007). In addition, the expected explosive population growth in Africa might lead to population pressure, food scarcity and even conflict (Zinkina and Korotayev, 2014). It is therefore likely that future migration waves from Africa and Asia to Europe will occur.

To be better prepared for these situations, insight into the flows of migrants across Europe may be useful. To address this challenge, an exploratory model that shows the effects and interactions of (supra-)national migration and asylum policies, both temporally and geospatially, may be helpful.

Driven by an urgent request from the national police force of a major European Union country, a suitable model was developed, based on literature review and expert consultation. Starting from a highly aggregated mental model of the nonlinear and time-dependent migration flows across Europe, the underlying mechanisms driving transit routes and final destinations were modelled, with special focus on the geospatial relations between European countries. The resulting model can be used to explore the effects and interactions of country-level migration policies on a European level.

In the following, the model and its underlying data, assumptions and mechanisms are presented. Exemplary policies are implemented and reviewed for behavior to illustrate the versatility and potential applications. Lastly, recommendations for future expansion are provided.

Method

Concept

The model is aimed at analyzing intra-European refugee flows. Since most undocumented migrants enter Europe through Greece, Italy, and Spain, the model boundary is set at the inflow from outside of Europe into these countries. Migrants that have entered one of these countries will then have two options: stay, or leave to another country. This decision is based on the attractiveness of the country and its neighbors. If they decide to stay, their journey ends there – the model scope precludes a return to the country of origin, or a later rejoining of the intra-European flow. If they decide not to stay, they can depart to any of the neighboring countries. In the next country, they then have the same options again. This decision-making concept stands somewhat in contrast to the belief that many migrants enter Europe with a fixed destination in mind. However, we believe our approach more accurately reflects reality – many migrants end up in countries not classically considered attractive (UNHCR, 2017), which we believe is due to this decision-making.

A problem of international migration would generally lend itself to be modeled more usefully using Agent-Based Modeling techniques, where heterogenous populations with distinct interests and decision-making preferences can more easily be introduced (Kniveton et al., 2011). However, we felt that an ABM might not capture the dynamic feedback effects of temporally changing national policies as well as an SD model.

A schematic overview of the inflow of migrants into Europe, and the possible border crossings in each country is shown in Figure 1. This represents the European-level interaction of the countries in the model. In the next section, several variables will be introduced that affect the distribution of migrants for each country: *attractiveness of a country*, *societal stress*, and *migrant settling rate*.

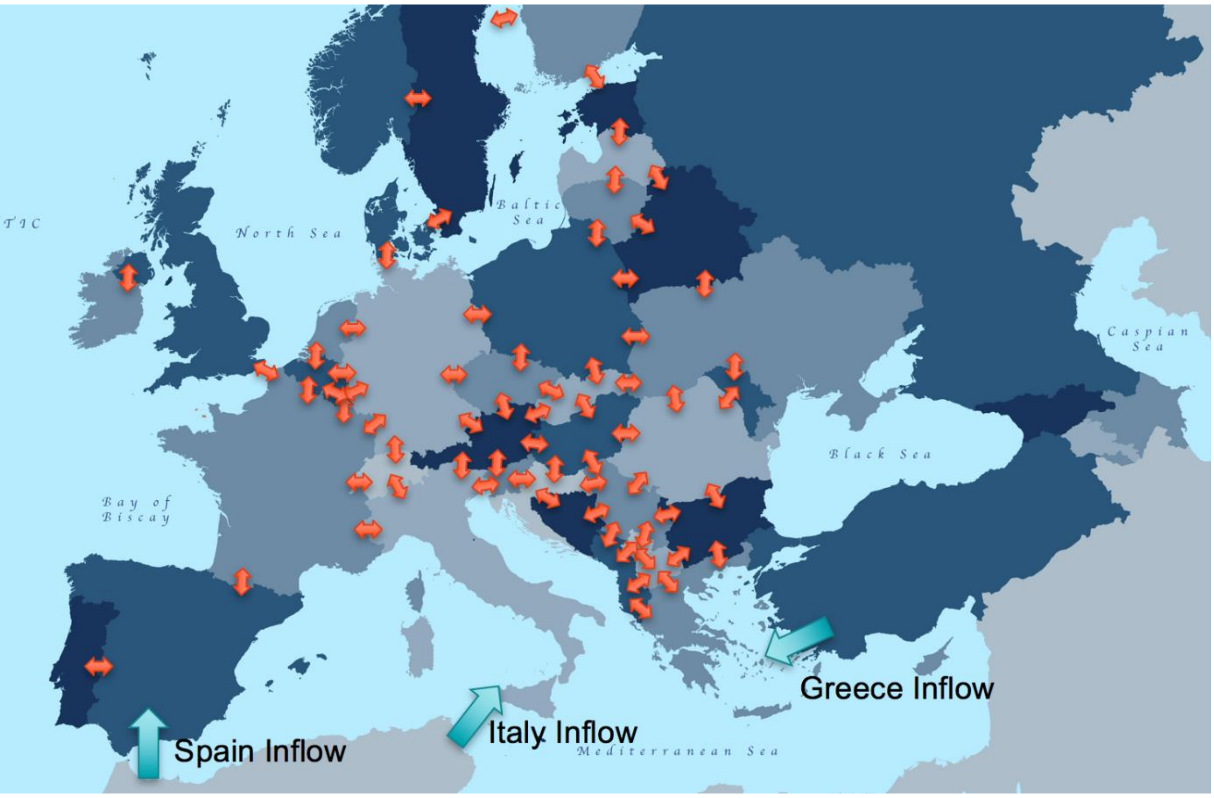

Figure 1 European Inflows and Border Crossings

Country Model

The attractiveness of a country is divided into two separate concepts: residence attractiveness and transit attractiveness. This division was made because migrants may have different incentives to travel to a certain country. Some countries are attractive because they offer a high standard of living (high residence attractiveness) (Jong, 1981), while some countries are attractive because they offer the easiest travel route towards these countries with high residence attractiveness (transit attractiveness).

The residence attractiveness of a country is based on the following factors: gross domestic product, democracy index, population, and number of migrants already in a country. The first two factors are a measure of the welfare of a country, which is an important element in the decision process of migrants (IAB-BAMF-SOEP Refugee Survey, 2016). Population is included because we believe that larger countries tend to attract more refugees. Expert feedback indicates there is also a 'birds of a feather' effect caused by social networks in destination countries making those places more attractive to following countrymen and -women (also in Haug, 2008). Hence, a country will get a higher residence attractiveness as more migrants arrive in that country.

Transit attractiveness of a country is represented through two factors: *transitability*, and quality of the ground transportation network. The transitability of a country is an estimated score of the difficulties encountered when passing a country, and the value of passing through a country based on the number of neighbors that country has. In combination with the quality of the ground transportation network, this shows to what extent a country is valuable to pass through.

Societal stress is defined as the ratio between the number of migrants in a country, and that country's migrant capacity. As more migrants enter a country, societal stress builds, which then reduces both residence- and transit attractiveness.

The migrant settling rate is made dependent on the relative residence attractiveness of a country. A higher residence attractiveness leads to more migrants staying. As more migrants stay in a country, societal stress will build, which in turn leads to lower residence attractiveness and a lower migrant settling rate for that country. Figure 2 shows a strongly aggregated causal loop diagram (CLD) of the system in each country.

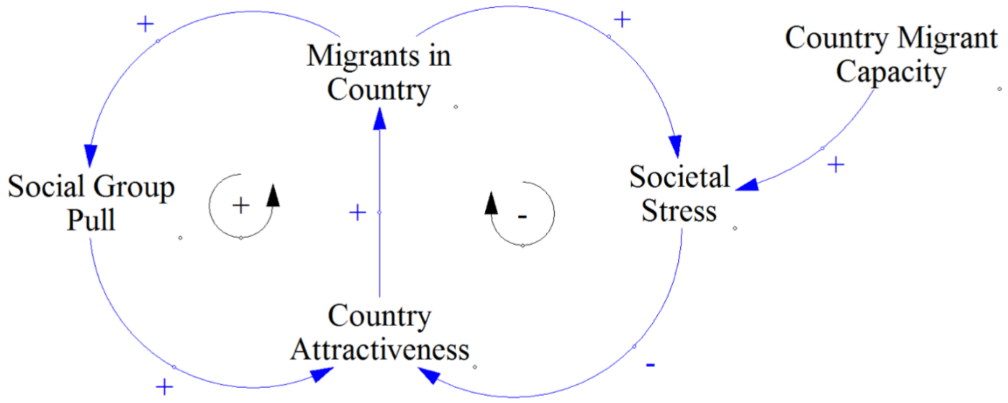

Figure 2 Causal Loop Diagram

Distribution of Migrants Across Countries

The model is built to run the same stock flow structure (Figure 3) for multiple countries (37 in this case), where the outflow of one country adds to the inflow of other countries. When migrants leave a country, they are distributed among that country's neighboring countries. The distribution key that is used is based on the ratio between the attractiveness of a neighboring country, and the sum of the attractiveness of all the neighboring countries of that country. This way, the most attractive neighboring country will receive the most migrants, and the least attractive neighboring country will receive the fewest.

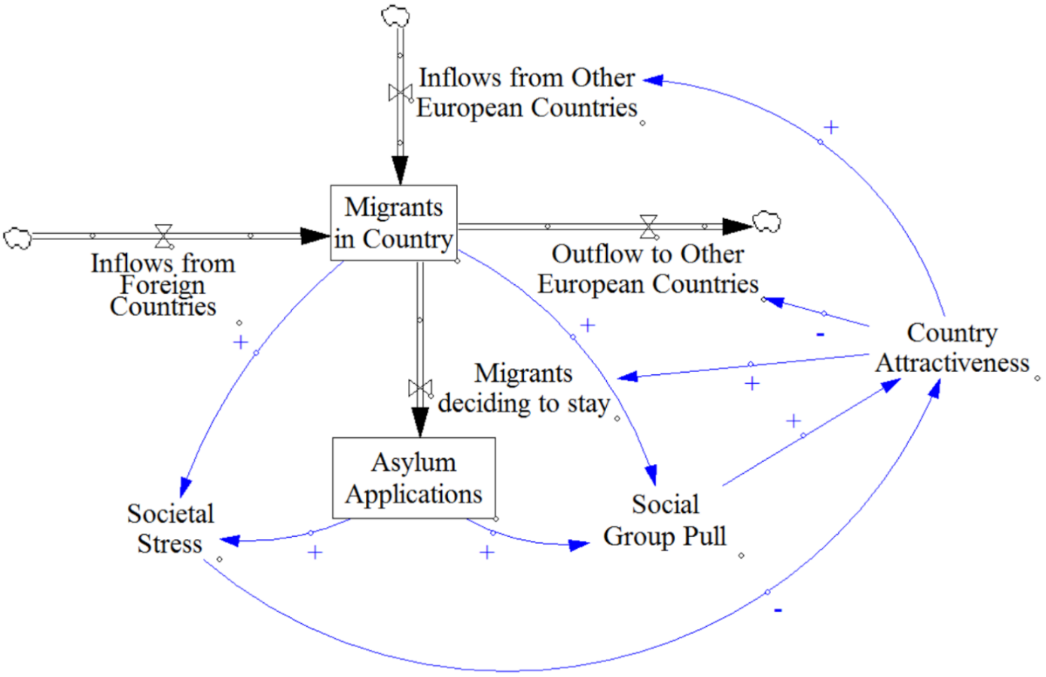

Figure 3 Stock-Flow Structure and Feedbacks

Model

This section contains a detailed description of the model's structure, equations, and assumptions. The basic structure of the model is a simple stock flow diagram, but most variables need to be subscripted for all countries. The exact formulation of each variable can be found in the appendix.

Hence, the first step in building this model is creating a subscript range for all 37 countries, called *countries*. To allow for accessing data arrays, a subrange called *countrycolumns* should be created, also containing all 37 countries. A complete country list can be found in the appendix. In addition, a subscript range for the country data is required, containing GDP, population, transitablitiy, democracy index, and ground transportation network quality. We call this subscript range *countrydata*.

Variables that need to be subscripted across *countries* are marked with a *. Variables that need to be subscripted across *countries* and *countrycolumns* are marked with **. Variables that need to be subscripted across *countrydata* are marked with ^. Variables that require subscripting across *countrydata* and *countries* are marked with ^*.

Some variables are based on data, which is specified in the *country data matrix^** (GDP, population, transitability, democracy index, and quality of ground transportation network). In addition to this, the model requires a *base country adjacency matrix***, where a 1 denotes that countries are neighbors, and a 0 denotes that they are not.

The migrants in a country are represented by two stocks: *migrants transiting country** and *new residents**. *Migrants transiting country** can increase through *migrants entering Europe** and *migrants entering country from another country**, and decrease by *migrants leaving country to another country** and *migrants deciding to stay in country**. The *new residents** can increase by *migrants deciding to stay in country**.

*Migrants entering Europe** needs to be externally specified by migrant inflow data, by means of *border country inflows**. *Border country inflows** is zero for all but Greece, Italy, and Spain, whose inflow is specified by external data.

*Migrants deciding to stay in country** is equal to a third order delay of the sum of *migrants entering Europe** and *migrants entering country from another country** with a delay equal to the *travel time**. We choose a third order exponential delay because we expect there to be some variability in the migrant flow rate through the delay – consider random border crossing checks, different processing times for families vs. individual travelers, etc. The *travel time** is equal to the *default travel time* (constant), multiplied by the relative ground transportation network quality from the *country data matrix^**, and the *seasonal influence*, which is modeled through a sine curve to account for a seasonal effect on travel time. While real data could be added to the model to reflect real travel conditions, we felt the sine method gives a good generic approximation of weather conditions. The sine curve function is implemented as (sin((Time*3.141-84)/26)*0.3+0.7) and is tuned to fit the external migrant inflow data.

*Migrants in country** is equal to the sum of *migrants transiting country** and *new residents**. *Societal stress** is equal to the ratio of *migrants in country** and *migrant capacity**. *Migrant capacity** is the population of each country, multiplied by the ratio of its GDP and the average GDP of all the countries. This accounts for the assumptions that country size, and country welfare are the major contributions to its migrant capacity.

*Country attractiveness** is equal to the sum *residence attractiveness** and *transit attractiveness**, where *residence attractiveness** is given a weight of two because it makes sense to assume that migrants will prefer a country with high residence attractiveness over a country with high transit attractiveness. *Residence attractiveness** is a relative variable based on the average of the relative GDP, population, and democracy index data from *country data matrix^**, divided by (1 + *societal stress**). In a similar fashion, the *transit attractiveness** is specified as the average of the relative quality of ground transportation network, and transitability, divided by (1 + *societal stress**). Using this approach, a rise in societal stress will make a country less attractive.

The *migrant settling rate** is equal to the *residence attractiveness** divided by the maximum *residence attractiveness** at each point in time, divided by (1 + *societal stress**). Hence, most migrants will choose to stay in the most attractive country, given that the societal stress is not too high.

The *neighbor attractiveness** is equal to the sum of the *country adjacency matrix** and the *country attractiveness**. The *country to country reception percentage matrix*** is modelled as the *country adjacency matrix**, multiplied by the ratio of *country attractiveness** and *neighbor attractiveness**. This creates a matrix where the exact flows of the migrants from and to each country are specified.

Now, *migrants leaving country to another country** can be specified as (1 - *migrant settling rate**), multiplied by a third order delay of *migrants entering country from another country** and *migrants entering Europe**, with a delay time equal to the *travel time**. Finally, *migrants entering country from another country** is equal to the sum of the array *country to country reception percentage matrix*** multiplied with the array *migrants leaving country for another country**.

Subscripts

The described model operates on a country level. To achieve the desired geospatial, pan-European system, this model is subscripted across 37 major European countries (minor countries like Monaco, Liechtenstein, Andorra etc. were not considered). The full list of countries, as well their ISO 3-digit country codes, is listed in the appendix for reference.

Data

Two primary sets of static external data are imported from an Excel file for easy data management. The *Country Adjacency Matrix* is a symmetric, 37x37 array of 1s and 0s, indicating for each pair of countries whether they share a border (=1) or not (=0). This matrix was produced through visual review of a map, but could also be generated automatically with a suitable Python script. In total, 72 borders were recorded, for a total of 144 possible border crossing possibilities.

The Country Data Matrix is a 5x37 matrix holding the following data points for each country in the subscript:

Data Point	**Unit**	**Scale**	**Source**
GDP per capita	USD	(continuous)	IMF, 2016
Population	Persons	In thousands	CIA, 2016
Transitability	Dmnl	1-3	Own estimation
Democracy Rating	Dmnl	0-10	EIU, 2016
Ground Transportation Quality	Dmnl	0-10	WEF, 2015

To prevent difficulties stemming from different magnitudes, scales and units, the data is only used under normalization in the model.

The *Border Country Inflows* (implemented with lookups) represent the numbers of migrants entering Europe through the border countries. In the current setup, these are Spain, Italy and Greece. For the purposes of validation and model behavior demonstration, historical inflow data (UNHCR, 2016) is used. Alternatively, projected future migration inflows could be implemented to forecast future migrant distributions.

The exact data used can be viewed in the appended Excel file and the Vensim model.

Verification

The model was initially built to run for a limited set of countries (the Balkans), making model behavior and debugging more comprehensible. After several successful runs and tests with this simplified model, it was possible to extend the model with the remaining European countries. A unit check was conducted and successful.

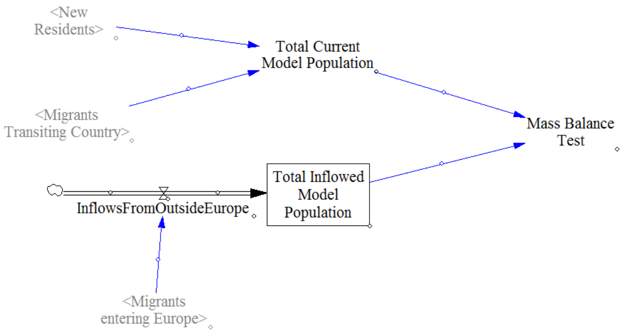

Figure 4 Mass Balance Test

An extreme value test on the travel time was conducted successfully. A travel time of one year causes most migrants to stay in the Southern European countries, and only a few reach the Northern European countries.

Of special note in the validation of the model is the Mass Balance Test (Figure 4). The chosen implementation of the model means that at every time step, large number of migrants leave the model (when leaving countries) and enter the model (when entering one of the neighboring countries). Therefore, it is relevant to conduct a so-called Mass Balance Test to ensure there are no “leaks” in the model. In this test, we compare the total number of migrants currently flowed into the model from outside Europe with the current total model population. Plotting this Mass Balance Test (Figure 5) shows minute deviations due to numerical calculation errors or rounding. This test confirms that the model has no leaks and conserves mass over the entire model run.

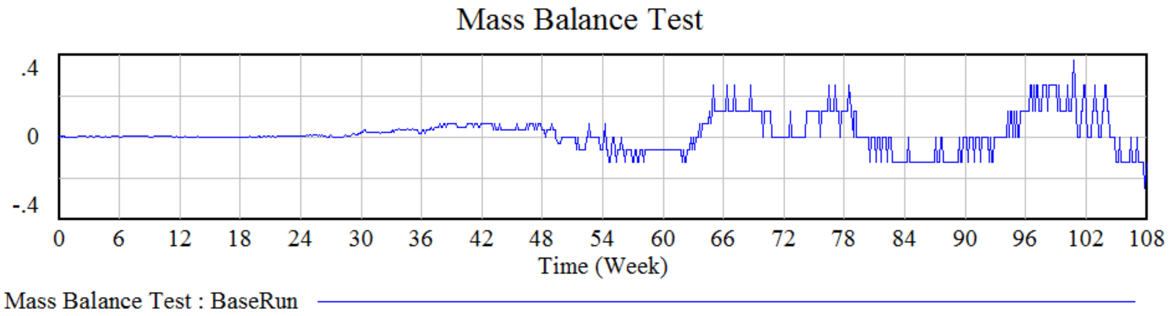

Figure 5 Mass Balance Test Plot

Base Model Validation

After ensuring the model does not “leak” (that is, create or destroy flow units unintentionally), we test that the model’s behavior is what we expect it to be. Specifically, two validation tests are performed: a base model run with which to perform face validation with migration experts, and an external validation wherein model performance is contrasted against historical data.

Key Performance Indicators

We identify three main benchmarking variables in our model:

- Migrants Transiting Country: the number of migrants currently travelling through a given country
- New Residents: the total number of migrants who have chosen to stay in a given country
- Societal Stress: the current migration-derived stress level in a given country, calculated as the ratio of the total number of migrants in a country over the migrant capacity of the country

In the following examples, we will use these KPIs to show model behavior. We will only show plots for selected countries to reduce plot clutter.

Model Behavior

Before applying any exemplary policies to the model, it makes sense to perform a “base run” to examine standard behavior, and to gain a feeling for the validity of the results. Supported by experts from the national police, face validation of the model behavior was performed based on this base run.

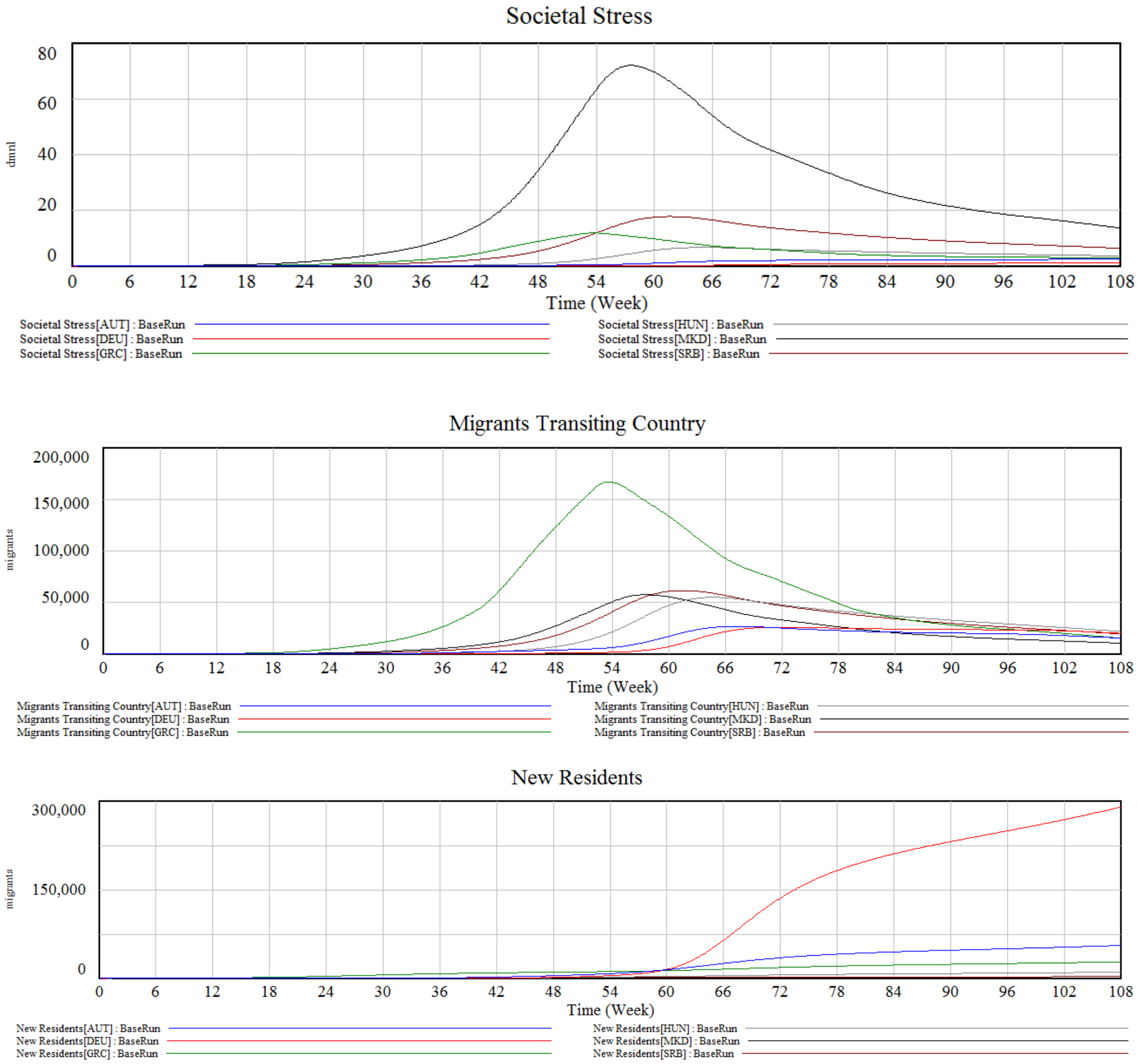

Figure 6 Base Model Plots

As expected, Germany and Austria received significant amounts of new residents. Greece also takes a large number of new residents. The Balkan countries only take very few migrants, as they are, by the metrics used here, unattractive places to live. Societal stress peaks in Macedonia, as a huge number of migrants passes through this small country almost simultaneously. Similar patterns can be seen in Serbia and Greece. However, as these countries are unattractive to stay in, most migrants quickly move on, with a corresponding decrease in societal stress. In contrast, the stress levels in Austria and Germany continuously climb, as many migrants choose to settle there – enacting a permanent penalty on societal stress. Overall, the model produces realistic behavior.

Comparison to Historical Data

While it is essentially impossible to find quantitative historical data for societal stress (barring the use of some proxy such as the tenor of newspaper articles, or social media posts), data on asylum applications (which may be considered correspondent to new resident levels) is available. A comparison of simulation output data for new residents and historical asylum applications data for 2013-2015 from Africa and the Near/Middle East (UNHCR, 2017), where available, shows a good relation between model and data.

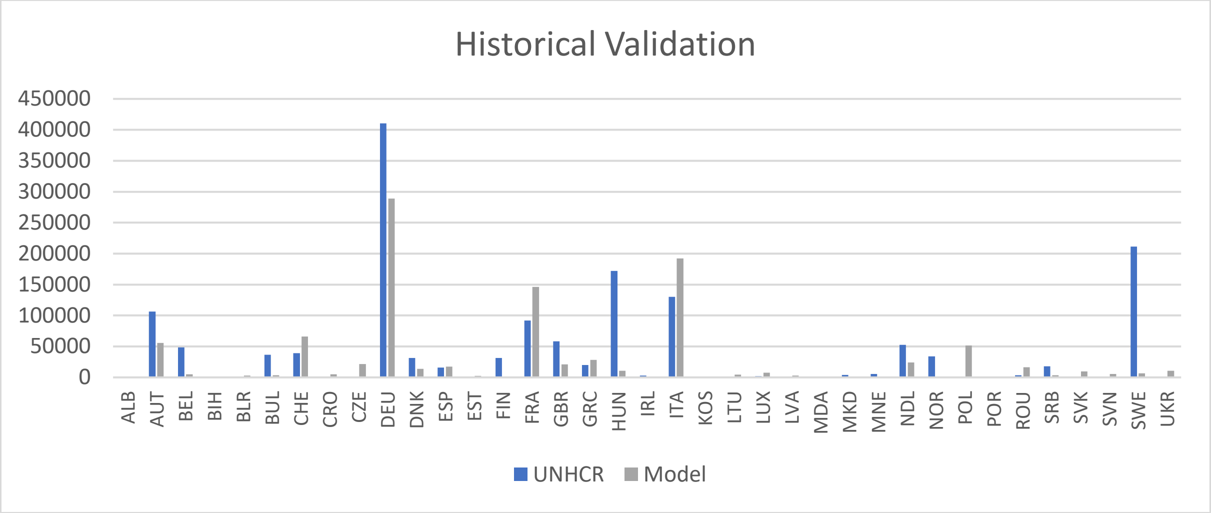

Figure 7 Model validation with historical external data

Countries which received many asylum applications in real life should see a large number of new residents in the base model run. We see above that attractive Western and Northern European countries actually received many more migrants than the model gives them. This shows that the “pull” exerted by highly attractive countries in the model is not strong enough. Sweden and Hungary stand out. Sweden is extremely receptive of migrants, which may explain why their real-life numbers so significantly exceed the model prediction. Hungary on the other hand was one of the main “thoroughfares” for migrants transiting from Greece across the Balkan to Northern Europe. Clearly, factors are at play here that skew the quantitative model results.

Nevertheless, we believe the model to be behaviorally valid, as evidenced by the two tests. Highly attractive countries like Italy, Germany or France in mainland Europe do take in many more migrants than traditionally unattractive countries like Macedonia, Kosovo or Latvia. We therefore posit that the model behavior corresponds to the dynamics observed in reality, but that some calibration could improve the model’s accuracy. Thus, the model may be used for exploratory modelling, and could also be employed in more quantitative stages of the policy process pending improved calibration.

Figure 8 Balkan route. Source: FRONTEX 2016

Policy Examples

The strongest suit of the presented model is not the base run behavior, but the fact that it is versatile and extensible enough to allow testing of a variety of different possible national migration response policies. Crucially, multiple policies can be tested together to establish their interaction. As was seen during the last migration crisis, it is likely that countries will (at least initially) enact migration policies on a national level with little regard for impact on the system as a whole. Three exemplary national migration policies are described, implemented and discussed. A fourth policy set combines the three single policies to showcase the model’s capability for exploring the temporal and geospatial interaction of national policies.

The three individual policies are implemented in a separate Vensim model file and can be activated through switches. Care should be taken to only activate one at a time. The combined policies model is another separate model file for cleanliness.

Border Walls

Description

During the 2013-2015 migration crisis, multiple European countries installed some kind of fence or wall on parts of their borders (UNHCR, 2016), both to control and prohibit border crossing. While the immediate consequence of these measures seem obvious, the wider effect on migration flows is less clear. It may therefore be valuable to investigate the impact of such localized policies on the system as a whole.

Implementation

As an example case, a border fence policy is implemented in Hungary, analogously to that country's actions in 2015 during the height of the European migration crisis. At that time, the border between Hungary and its neighbors Croatia and Serbia was effectively closed off through fences and security patrols. In the context of the presented model, this is implemented by setting the values for ([HUN],[SRB]) ([HUN],[CRO]) and their reciprocals in the symmetric Country Adjacency Matrix - the values indicating whether the countries share a border - from 1 to 0. This effectively closes their common borders, as a fence would. To reflect the time delay in the implementation of such a policy, a time-based trigger is used to switch from the original Country Adjacency Matrix to a modified one with the border fence alterations. The point in time of implementation is exemplarily set to 40 weeks after model run begin.

Results

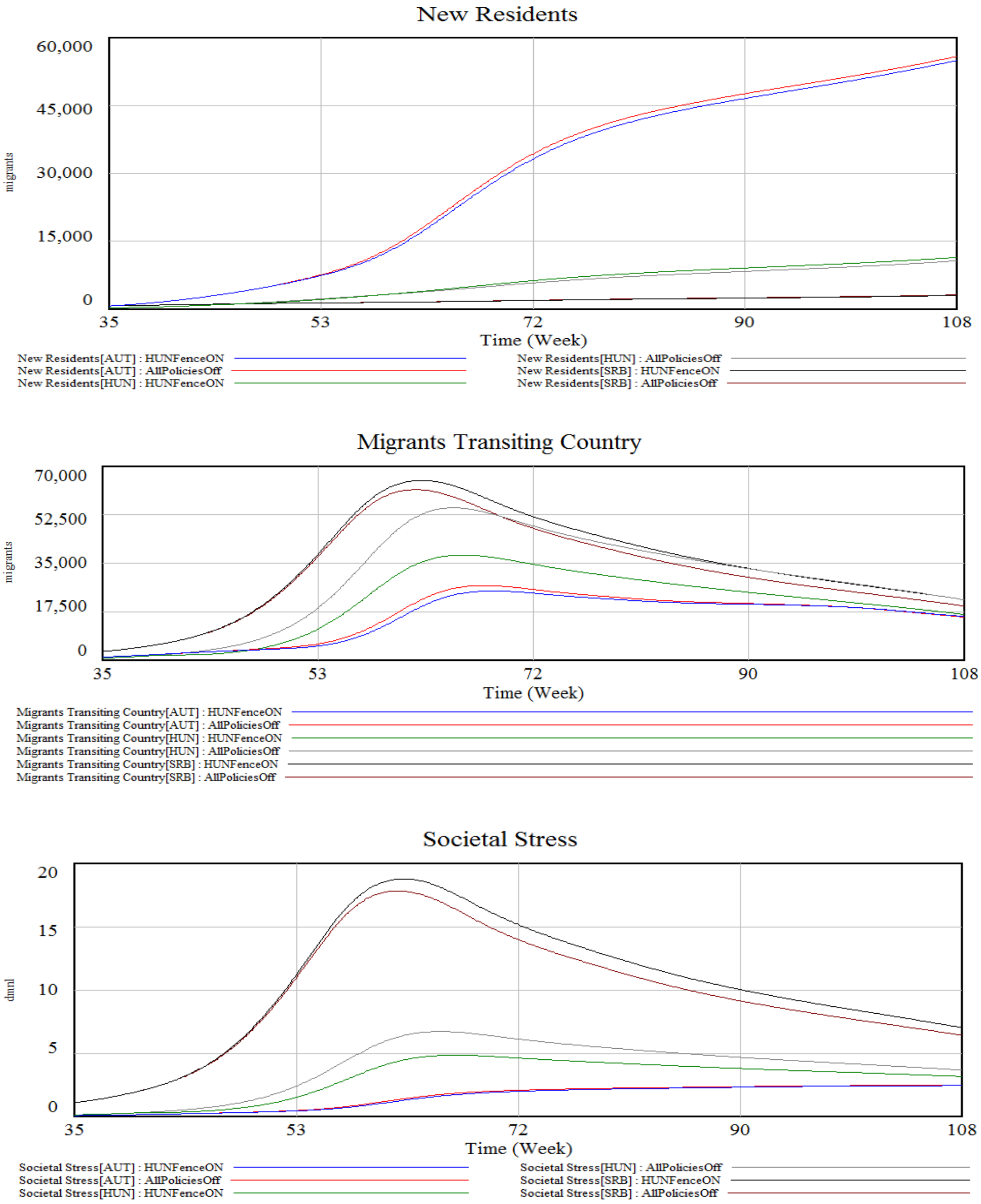

Figure 9 Hungary Border Fence Plots

Interpretation

The moment of policy implementation can clearly be seen in Hungary's plots, as Societal Stress In Serbia, which lies south of the border fence, sees an increase in Societal Stress - This could be considered analogous to a stagnating or halting "traffic jam" of migrants in Serbia confronted with a closed border. As expected, the number of migrants in transit in Serbia, south of the border fence, is essentially unaffected, but in Hungary, the new residents total also only slightly decreases. This may be due to migrants flowing around the border fence into Hungary through other countries.

Bus Transports

Description

Another option for migrant flow control, besides building fences, is expediting migrants across national territory - passing off the problem to neighboring countries. Such a policy was implemented in Austria in 2015, when migrants were bussed virtually directly from the Austro-Hungarian border to the Austro-German border. The effect of such a localized policy can be investigated in the context of the entire system.

Implementation

In the context of the presented model, a bus connection between two borders can be considered a direct border between those two countries. The travel time is negligible. As it is likely that incoming refugees at the first border would directly be herded onto busses without any chance to consider staying in that country, this border effectively becomes closed - migrants are “tunnelled through” the country in question. Using the example of Austria discussed above, the ([HUN],[DEU]) border value becomes 1, while ([HUN],[AUT]) becomes 0 (symmetrical values are also adjusted accordingly). This has the intended effect of moving migrants directly from the Austro-Hungarian border to the Austro-German border without giving them the chance to stay in Austria itself. Again, this modified country adjacency matrix is time-triggered (at $t = 60$ weeks).

Results

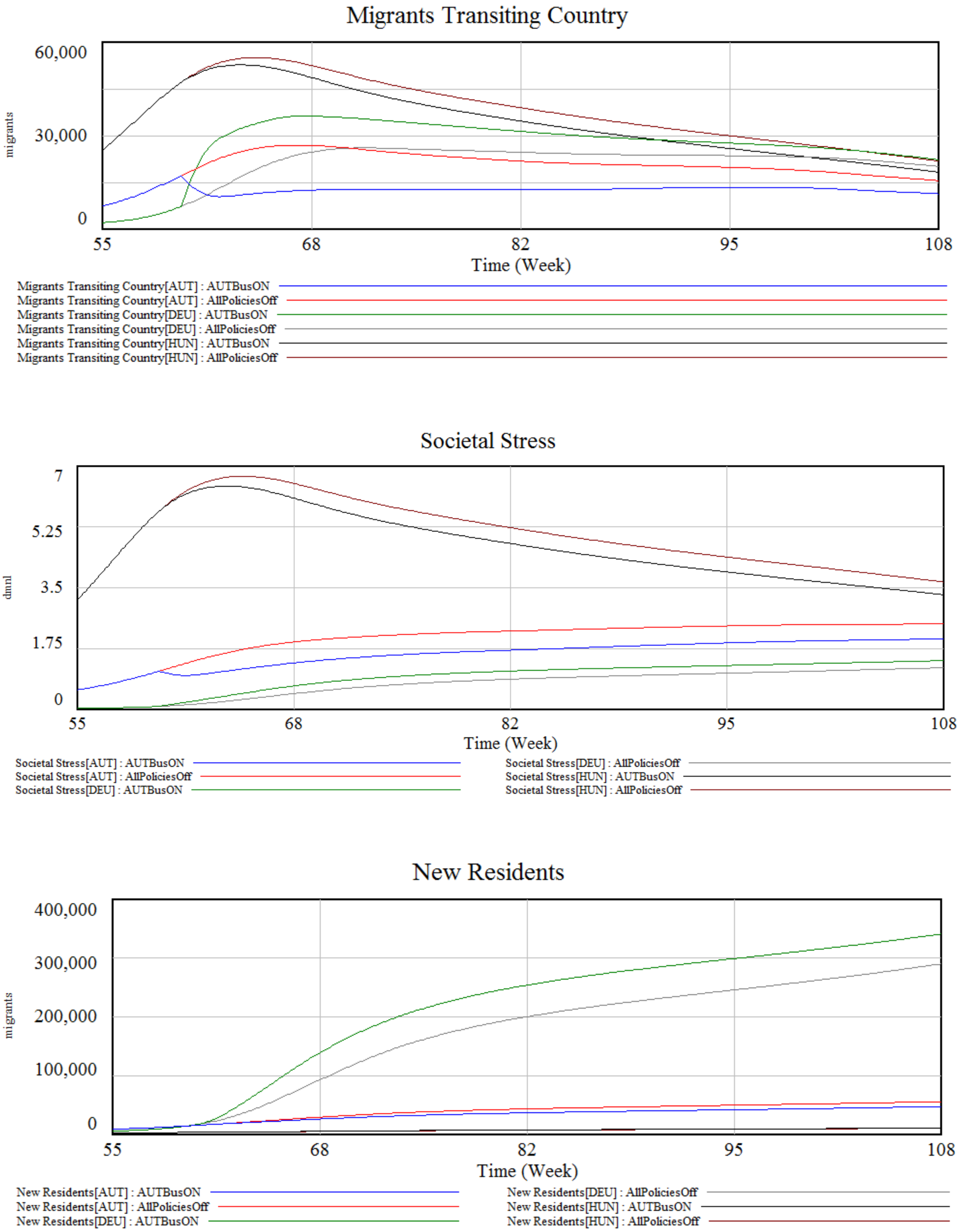

Figure 10 Austria Bussing Plots

Interpretation

As the policy is implemented, a large number of transiting migrants are pushed from Hungary directly into Germany, reducing Societal Stress in Austria and Hungary, with a corresponding increase in

Germany. Surprisingly, the number of New Residents in Hungary experiences little impact, even though Germany is now just one border away and should exert significant pull. It is possible that this is because the policy essentially replaces Austria, a quite attractive residence country, with another quite attractive residence country (Germany) and this has little impact on the migrant flow distribution.

Refugees Welcome

Description

The EU's Dublin Protocol regulates migration and asylum procedures across the EU, with the intent to distribute migrant load across the various member states. However, countries can voluntarily ignore the Dublin Protocol guidelines. In August 2015, Germany did just this by officially declaring it would process all asylum applications made within its borders, regardless of prior applications in other countries, or previous registrations. This effectively made Germany an (even more) attractive country for migrants entering Europe.

Implementation

In our model, dynamic Societal Stress is dominant factor governing the attractiveness of a country. By artificially setting Germany's Societal Stress to one-tenth of its true value, the country's attractiveness is magnified. This new calculation is triggered at simulation time t = 80 weeks through a switch function, reflecting the implementation time of the policy.

Results

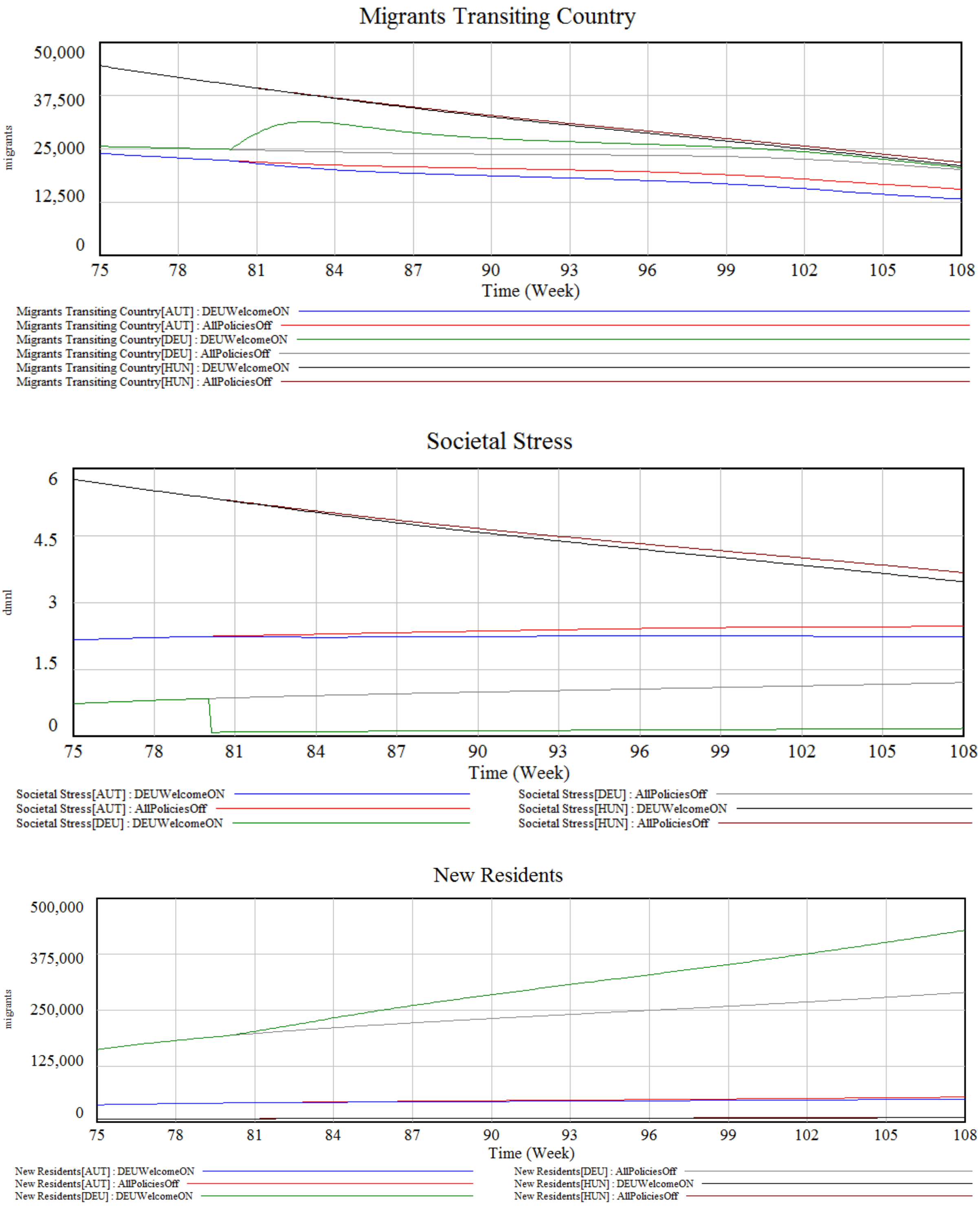

Figure 11 Germany Refugees Welcome Plots

Interpretation

Germany's "Refugees Welcome" policy certainly has the intended effect – both Migrants In Transit and New Residents increase markedly. A corresponding inverse effect on nearby countries is observed, as Germany draws transiting migrants away from them.

Policy Combinations

Description

National government policies do not take effect in an isolated sand box, but in an interwoven dynamic system. Similarly, they do not occur solitarily – other countries may be executing their own independent policies concurrently. This was seen clearly during the European migration crisis, when various countries enacted various policies at various times, with only limited coordination (ODI, 2016). Exploring the interaction of multiple national policies across space and time is the true value of the presented model. To demonstrate this, the three previously discussed policies are enacted sequentially in the same model run.

Implementation

As each separate border policy requires a customized Country Adjacency Matrix, a new matrix combining bussing in Austria and border fences in Hungary is created. This is performed analogously to the individual policies shown above. Through time-based switches in the model, the correct adjacency matrix is loaded for each phase. The activation times remain the same as above:

- t=40weeks: Hungary closes borders to Serbia and Croatia
- t=60weeks: Austria starts bussing migrants from the Hungarian to the German border
- t=80weeks: Germany declares “Refugees Welcome”, Societal Stress significantly decreases

Results

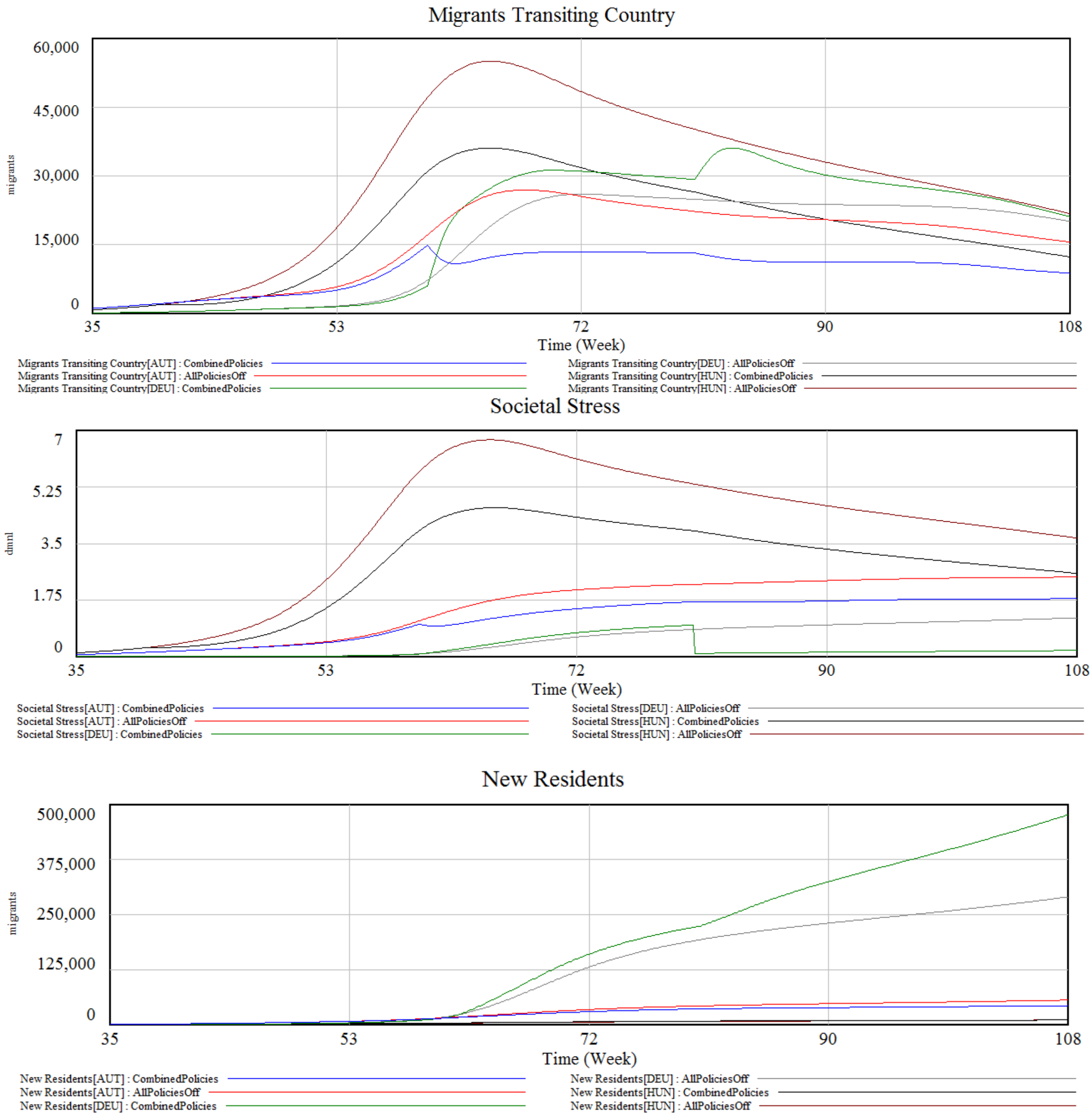

Figure 12 Combined Policies Plots

Interpretation

The behavior generated by the combined policies is within expectations. The effects of the three policies are easily recognizable, as well as their interactions. All three policies individually move more migrants towards Germany, and the combined model confirms this behavior, as New Residents in Germany increases markedly over the base model. This indicates that the model responds behaviorally correctly to policy combinations.

Discussion

At the beginning of this paper, we posited that a geospatial system dynamics model of migration in Europe could be useful for exploratory policy analysis and crisis management. We then presented such a model, implemented through vector operations and subscripting. We applied various separate policies to the model to demonstrate its usefulness, and showed how the model can just as easily handle multiple different policies being implemented in different countries across Europe at different times. This indicates that the model is indeed useful for exploring the temporal and geospatial interaction of government migration policies.

However, the model is not without flaws. The choice of scope excludes several aspects of migrant movement (deportation to home country, forced relocation under Schengen/Dublin Accords, etc.). Additionally, the model has not been calibrated with historic data, and therefore shows some discrepancies when it comes to assessing hard numbers. However, we believe the model to be behaviorally correct. Furthermore, the static nature of data structures in Vensim makes the preparation of complex multi-policy simulation runs somewhat tedious, but feasible.

Based on these characteristics, we see potential for this model in early-stage, exploratory policy analysis or crisis management. It is possible to set up complex simulation runs, featuring distinct national migration policies implemented at specific times for different countries, with very quick feedback in easily understandable plots. Especially in the context of crisis management, this lightweight model is “good-enough” to quickly visualize to problem owners just how interconnected and complex the European migration system is.

Ongoing and Future Research

Numerous possibilities exist for future research and improvement. The scope of the model should be extended to include processes and effects such as undocumented residents, the asylum process, political interventions like Schengen-Dublin or different migrant nationalities. This could be accomplished by adding another ([Undocumented], [Documented]) subscript layer. Similarly, migrant nationalities could be reflected through a ([Syria],[Iraq],[Libya],…) subscript layer. This would also allow for more accurate modeling of social dynamics – it is plausible that migrants would more likely go where countrymen and -women have gone. However, this would significantly increase model complexity and run-time.

The model is also ripe for improved interactivity, both for defining policies for exploration (input) and for visualization (output). However, these extensions would likely be easier to implement in a scripting or object-oriented computer language such as Python or Java due to greater freedom in design and data handling. The Exploratory Modeling and Analysis Workbench (Kwakkel, 2017) may prove useful here.

Reflection

The main learning experience for us was that, given perseverance, there is always a way. While trying to implement our vision of an adjacency matrix-driven SD model, we went through numerous iterations of clunky, bloated functions before finally discovering the presented vector operations. While our usage of subscripts is probably unorthodox, model behavior and feedback from our partners at the national police force are encouraging. In retrospect, it would have been useful to have more control over Vensim’s data structures – being able to dynamically get/set values in matrices and subscripts could make our model easier to use and more powerful. Tools such as PySD might allow more efficient implementation of policy experiments.

Nevertheless, we believe geospatial SD models can be used alongside other techniques (ABM, graph theory, et al.) to explore future scenarios of migration, though a transition to more flexible software may be required for full effect. There are significant nonlinearities in migration, which are more easily captured using system dynamics than many other paradigms. Thus, we see the contribution of our work primarily in showing how subscripting in Vensim can be used to make models which can quickly and effectively show the temporal and spatial interactions of heterogenous government policies.

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Appendices

- Models:
    - *GeospatialMigrationDynamicsBaseModel*
    - *GeospatialMigrationDynamicsSeparatePolicies*
    - *GeospatialMigrationDynamicsCombinedPolicies*
- *GeospatialMigrationDynamicsXLSConstants* (Excel file containing country data and country adjacency matrices for policies, referenced by models)
- *GeospatialMigrationDynamicsSubscriptCountriesElements* (Word file containing list of all countries implemented in model together with their subscript codes)
- *GeospatialMigrationDynamicsModelVariableDefinitions* (Excel file containing all model variable definitions)