Urban Systems and Transportation
Final Project

Regional Transfers to Fund Resilient Local Communities

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Abstract

Nature is the source of life and at the same time posing significant risks to humankind. In a changing climate, awareness and resilience to risks are paramount for modern societies. In order to build resilience, societies as a whole must reallocate resources. This project investigates the impact of different risk-based transfer schedules for tax income between the first-level NUTS regions in the United Kingdom on overall welfare.

Our report shows that efficient redistribution through tax systems can significantly increase the United Kingdom's welfare. At the same time, careful consideration of feedback loops and multiplier effects of measures over several years remain the most crucial challenge in designing policy measures—the four models tested yield contradicting results when accounting for different real-world effects. Additionally, the models showed different sensitivities to core indicators. Two aspects are therefore highlighted: Firstly, careful design of policies is paramount because small parameter changes can significantly affect welfare. Secondly, more research is needed to understand the interplay of several feedback loops and parameters better.

To reach these conclusions, in the first step, temperature, flood, rain and CO2 emission risks on assets such as motorways, rail infrastructure and ports are quantified. In the second step, four different models for the redistribution of tax income are developed and evaluated for various parameters, taxation patterns, and time spans.

Contents

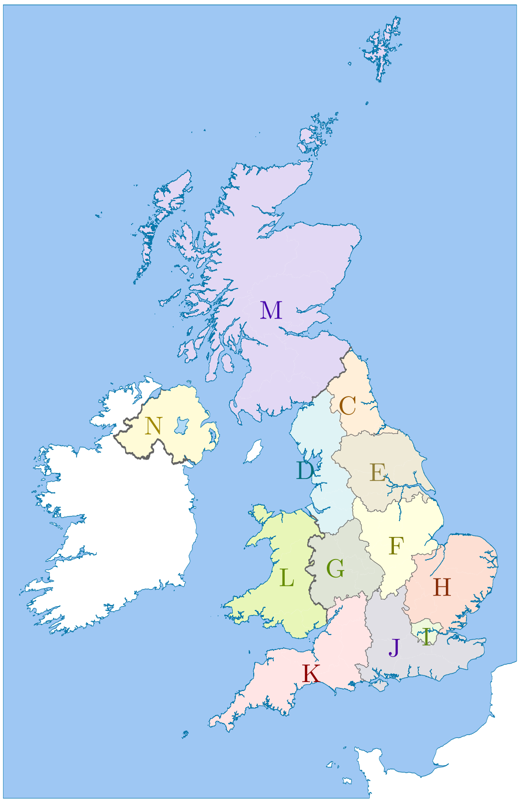
1 Introduction

As part of the autumn semester 2022 course *Urban Systems and Transportation* at ETH Zurich [1], we have executed research looking into the effects of climate change related exposures on regions of the United Kingdom (UK), defined and calculated local and external economical costs, and build a model which simulates the reaction of individuals and firms to transfers. The model explores different transfer strategies and are evaluated by the metrics and welfare function.

The model uses a similar approach to the paper ”The Economics of Density: Evidence From the Berlin Wall” by Ahlfeldt et al. 2015 [2]. External effects are being observed by a change of residential and economic activity within the city of Berlin. The set up model by Ahlfeldt et al. corresponds to the observed reality. This concept of allocation of residents is applied in our model.

Strategies for regional transfers to fund resilient local communities are important to be able to cope with risks associated to the change in climate. Without regional transfers, some regions may be unable to manage the negative effects. Not every transfer schedule improves overall welfare as can be seen in our findings. The *right* schedule has to be found.

In accordance with the given assignment specifications for the final project, we have decided to focus on the UK and build an economical cost model based on risk factors for climate change exposures, as well as regional assets, such as transportation and infrastructure. We will focus on the regional first level NUTS (nomenclature d'unités territoriales statistiques)[3, 4], as seen in the map and list of statistical regions in Figure 1.



Legend:

- **C** North East England
- **D** North West England
- **E** Yorkshire and the Humber
- **F** East Midlands
- **G** West Midlands
- **H** East of England
- **I** London
- **J** South East England
- **K** South West England
- **L** Wales
- **M** Scotland
- **N** Northern Ireland

Figure 1: ITL - statistical first level NUTS regions in the UK [5]

2 Data Collection

2.1 Risk Data

Risk data was gathered in order to define the exposure of climate changes occurring in relation to different sets of assets. An overview of the risk data is represented in Table 1.

Region	Temperature Increase [$°C$]	Rain [mm]	Flood Risk [%]	CO_2 Emissions [$ktCO_2$]
North East England	1.310216618	34.64543189	0.16	14821.2
North West England	1.234132058	47.9029482	0.11	41921.9
Yorkshire and the Humber	1.563126672	33.81479328	0.69	36938.7
East Midlands	1.05967585	28.5870585	0.22	30197.7
West Midlands	0.931622388	31.71592436	0.07	31551.8
East of England	1.586752957	26.11977272	0.08	36562.2
London	1.703314869	29.98249621	0.10	28369.3
South East England	1.370755049	35.48214576	0.14	40399.6
South West England	0.718199346	45.66582055	0.17	30372.1
Wales	0.710093123	58.76975534	0.11	27303
Scotland	0.83530936	54.7447184	0.07	37944.7
Northern Ireland	0.490934677	39.6731276	0.07	21145.7

Table 1: Risk data

2.1.1 Temperature Increase

United Kingdom Climate Projections User Interface (UKCP UI) provides tools and data of the latest updates for climate projections, enabling users to follow future climate trends in the UK. The service provide regional, global, probabilistic, marine and derived projections. Their website offered the possibility to download data observed from weather stations from HadUK-Grid. We downloaded annually mean temperature data and compared the average temperature for the first 10 years of the data set with the average temperature for the last 10 years. The value for the increase is the difference. [6]

2.1.2 Rainfall

As UKCP UI provide data on climate projections, we used the same data set as for temperature for gathering data of the monthly rainfall in mm from 1962-2020 and calculated the standard deviation using the N method for each region of the UK. [6]

2.1.3 Flood Risk

The gov.uk official statistics website offers data on floods and flood risk and it provides the possibility for reviewing the long-term flood risk exposure for each postal code in the UK. The data contains a percentage value for the probability for a flooding event in the next year. The underlying data set has been extracted. An additional data set mapping the millions of postal codes to the NUTS regions was used to derive the average flood risk in each region. The Jupyter Notebook can be found in the additional materials in the folder containing the raw data for the flood risk. [7, 8]

2.1.4 CO_2 Emissions

Regional CO_2 emissions data from 2005 to 2019 could be directly sourced and downloaded from the official gov.uk statistics website. [6, 9]

2.1.5 Fire Risk

Regional fire risk data was difficult to find. The only usable data we could access was charts denoting the fire number and burnt area per year for England, North Ireland, Scotland and Wales. These were manually transcribed, but due to the data limitations these were not used in the model. [10]

2.2 Asset Data

Asset data were gathered to define a set of available resources with economical value in the UK regions as well as population data. The value of the resources available and risks related to climate change on the specific asset will define what costs an exposure will inflict. An overview of the asset values is represented in Table 2 and Table 3.

Region	GDP [$Mil\ GBP$]	Motorways [$Miles$]	Road/Rail [$Travel\ Time$]	Ports [$MT/year$]	Energy Generation [GWh]
North East England	61'951	36	61'657'549	58.694167	11'225.23452
North West England	208'183	408	7'367'456	155.04227	30'849.95213
Yorkshire and the Humber	142'008	277	143'685'100	174.13554	23'140.64123
East Midlands	126'289	124	111'908'409	1.606792	20'373.79294
West Midlands	156'685	277	155'010'154	0	24'964.55347
East of England	182'910	165	156'729'025	164.128696	26'251.03469
London	503'904	37	414'114'448	156.406244	37'696.37193
South East England	318'142	410	239'648'890	798.040509	38'595.71372
South West England	158'524	204	130'160'289	49.429954	23'696.68911
Wales	75'695	88	69'730'892	184.635805	28'608.34494
Scotland	161'954	295	142'116'000	181.810821	49'969.43158
Northern Ireland	48'478	70	53'074'280	177.186172	9389.178643

Table 2: Asset data, Part 1

Region	Agriculture [$Hectars$]	Population [#]	Area [km^2]	Population Density [$population/km^2$]	Wage [$GBP/week$]
North East England	641'820	2'680'763	8592	312.0068669	575.2
North West England	1'066'920	7'367'455	14'165	520.1168373	602.3
Yorkshire and the Humber	1'204'530	5'526'350	15'420	358.3884565	579.1
East Midlands	1'204'620	4'865'583	15'627	311.3574582	594.1
West Midlands	942'730	5'961'929	12'998	458.6804893	617.5
East of England	1'412'160	6'269'161	19'120	327.8849895	632.4
London	12'690	9'002'488	1569	5737.723391	804.9
South East England	1'174'100	9'217'265	19'095	482.7056821	664.3
South West England	1'853'350	5'659'143	3800	237.7791176	611.3
Wales	1'741'260	3'169'586	20'779	152.537947	598.1
Scotland	5'984'840	5'466'000	77'933	70.13716911	640.5
Northern Ireland	1'055'430	1'895'510	14'130	134.1479122	591.6

Table 3: Asset data, Part 2

2.2.1 GDP

GDP was used as a measure of the size of the regional economies. ons.gov.uk provide estimates of regional GDP for all ITL regions data sets available for download. [11]

2.2.2 Motorway Infrastructure

gov.uk publish data and statistics on road conditions, including motorway data. We collected data about miles of motorway in the UK regions. Northern Ireland was lacking in the gov.uk data set and was collected by multiplying the miles of each motorway from Wikipedia. [12, 13]

2.2.3 Port Infrastructure

gov.uk publish port and domestic waterborne freight statistics produced by Department of Transport. We gathered the data for all freight (million) gross tonnage traffic by port and year and divided them by the region of placement. [14]

2.2.4 Energy Generation

The electricity generated in each region was collected from gov.uk publication for energy trends. In the data set we accessed there was a total value for England and not divided into regions. Therefore, we distributed the total

GWh energy generation on the regions based on population, assuming that the amount of energy generated for a region is in correlation with the population. [15]

2.2.5 Agricultural Land Use

Land used for agriculture were gathered form eurostat Data Browser for Farm structure and Farm land use for NUTS 2 regions in the UK. The values for hectares Farm land were added together for the NUTS 1 regions. [16]

2.2.6 Population

The population for each region were selected from Statista in absolute numbers. The population density was derived by dividing the absolute numbers by the area of the region. [6, 11, 6, 4]

2.2.7 Area

The area was collected as km^2 from the Wikipedia page for International Territorial Level NUTS 1 regions of UK. [4, 11, 6]

2.2.8 Income

The median weekly income for full-time employees in UK by regions was collected from Statista. [17, 18]

3 Monetary Value and Risk Estimation

3.1 Valuation of Assets

The value estimations is represented in Table 4.

Region	Ports	Motorway Infrastructure	Agricultural Land	Energy Generation
North East England	17’494’388’777	1’080’000’000	393’698’856.21	2’254’622’029.91
North West England	46’211’913’158	12’240’000’000	654’459’480.33	6’196’305’435.18
Yorkshire and the Humber	51’902’854’958	8’310’000’000	738’870’841.16	4’647’867’213.54
East Midlands	478’920’570	3’720’000’000	738’926’048.06	4’092’137’432.56
West Midlands	0	8’310’000’000	578’280’082.76	5’014’205’457.23
East of England	48’920’214’122	4’950’000’000	866’233’175.64	5’272’599’069.60
London	46’618’459’373	1’110’000’000	7’784’173.89	7’571’429’391.10
South East England	237’864’027’008	12’300’000’000	720’204’772.49	7’752’064’887.67
South West England	14’733’096’604	6’120’000’000	1’136’863’567.91	4’759’551’097.28
Wales	55’032’564’903	2’640’000’000	1’068’106’432.28	5’746’071’907.04
Scotland	54’190’549’914	8’850’000’000	3’671’161’170.74	10’036’510’241.68
Northern Ireland	52’812’126’611	2’100’000’000	647’411’398.54	1’885’844’698.04

Table 4: Valuation of assets in GBP

- Value of ports: gov.uk post data about the the total value of goods traded through UK ports in 2014. The value was 29.2% of the GDP in 2014 and for simplicity there was made an assumption that this ratio is constant. Hence, the total value of all ports in our data set was assumed to be 29.2% of the total GDP. We calculated the share of tonnage for each region and then multiplied it by 29.2% of total GDP. [19]
- Value of motorway infrastructure: We found the average cost per mile of new motorways in the UK from a BBC article. This value of 30 million pounds was multiplied by each regions value for miles of motorway. This gave an estimation of the value of motorways in each region of the UK. [20]
- Value of agricultural land: gov.uk post data about total income from farming in the UK, where we found that in total agriculture’s’ contribution to the UK economy was £11’222 million in 2021. We used this total value for calculating the mean value of 1 km^2 agriculture land, and then we multiplied with each region square meters to get an value estimation for agriculture land in each region. [21]
- Energy generation: Statista provide electricity prices from 2010 to 2020. We used the average energy price for 2020 in GBP per GWh and multiplied with the total energy production in GWh for each region, resulting in an estimation of the total energy value for each region. [22]

3.2 Risk Estimation and Valuation

To quantify and therefore compare the different risk categories, we connected the different categories to the identified assets and calculated the resulting risk valuation. The calculation steps are explained in the following. First, every team member independently estimated the effect of each identified risk on the given assets which are explained in Section 2. The identified risks are the following:

- Temperature increase risk
- Rain risk
- Flood risk
- Emissions risk (CO2 cost [23])

The scale used for the influence estimation reaches from 0 - no influence to 3 - very high influence. The calculated influence is then the average of the different estimations. To check the validity of the estimations, each standard deviation is calculated. The influence values were then scaled to an overall scale of 0 to 1, meaning that the highest value of the whole table is 1 while the lowest for the whole table is 0. The calculated influences can be seen in Table 5.

	Road/Rail Infrastructure	Ports	Energy Generation	Land use of Agriculture
Temperature increase	0.2	0.33	0.53	1
Rain	0.67	0.4	0.47	1
Flood risk	0.87	0.93	0.67	0.87
CO2 emissions	0.13	0.13	0.4	0.4

Table 5: Mean values of influence estimations

The standard deviations are based on the original estimation scale of 0 to 4 and can be seen in Table 6.

	Road/Rail Infrastructure	Ports	Energy Generation	Land use of Agriculture
Temperature Increase	0.8	0.63	0.49	0
Rain	0.63	0.4	0.8	0
Flood risk	0.49	0.4	0	0.88
CO2 emissions	0.49	0.49	1.17	0.75

Table 6: Standard deviation of influence estimations

Analyzing these values, it is visible that the standard deviation for CO_2 emissions influence on energy generation is high (above 1), referring to more spread data values. This could be a result of a different understanding of the influence of emissions in relation to energy generation, and further this makes the data less reliable. The interpretation can either be that the emission is necessary to produce energy or that it has a negative effect on energy generation. All values, also the questionable ones, are considered in the subsequent steps of the calculation.
To achieve an equal non-monetary valuation without units of each risk as a basis for the monetary evaluation, we scaled each risk category to a value between 0 and 1. This value is seen as the relative probability of occurrence. Table 7 shows the scaled values for each region.

Region	Temperature Increase	Rain	Flood Risk	CO2 Emissions
North East England	0.769215746	0.589511249	0.231884058	0.353543136
North West England	0.724547223	0.815095246	0.15942029	1
Yorkshire and the Humber	0.91769684	0.575377472	1	0.881131342
East Midlands	0.622125638	0.486424664	0.31884058	0.720332332
West Midlands	0.546946666	0.539664053	0.101449275	0.752632872
East of England	0.931567607	0.444442427	0.115942029	0.872150356
London	1	0.510168811	0.144927536	0.676717897
South East England	0.804757285	0.6037484	0.202898551	0.963687237
South West England	0.421648022	0.777029278	0.246376812	0.724492449
Wales	0.416888936	1	0.15942029	0.651282504
Scotland	0.490402201	0.931511763	0.101449275	0.905128346
Northern Ireland	0.288223091	0.675060282	0.101449275	0.504407004

Table 7: Scaled risk data

The next step was to aggregate the asset valuations using the multipliers to calculate a monetary estimation for risk. The risk value rv is computed using Equation 1 with assets a and risks r for regions i using the given parameters risk probability rp, asset valuation av and influence factor *if*.

$$rv_{r,i} = rp_{r,i} * \sum_a if_{r,a} * av_{a,i} \tag{1}$$

This results to a valuation of each risk in the given regions. For the further model, we aggregated the monetary valuations to simplify the complexity of the whole model using Equation 2.

$$rv_i = \sum_r rv_{r,i} \tag{2}$$

4 Model

The model uses the following structure to estimate the welfare after transfer payments and reallocation of people. Index i denotes the ITL region. The model runs multiple times (t = 10). Each run represents one year. The reason is, a change in population though reallocation of people due to a change in attractiveness with the transfer payments the properties of the region are changing. A changing population has an affect on risk per capita Equation 3 and population density Equation 4 with consequences to all following equations. At each consecutive run the newly crated population allocation in the UK is used to calculate the resulting welfare of the transfer schedule.

For t $\in$ **[0,10]:**

The risk per capita is calculated by Equation 3. The total estimated risk in Equation 2 is divided by the population in the respective region:

$$rpc_{i,t} = \frac{rv_i}{population_{i,t-1}} \tag{3}$$

↓

The population density is provided by Equation 4, regional population over regional area:

$$pd_{i,t} = \frac{population_{i,t-1}}{area_i} \tag{4}$$

↓

The following correlation Equation 5 of wages $w_{i,t}$ and population density $pd_{i,t}$ is used to estimate the wage $w_{i,t}$ in each region per year (see Figure 6):

$$w_{i,t} = (0.0359 * pd_{i,t} + 598.74) * 52 \tag{5}$$

↓

A transfer payment scheme is used to reallocate money from one region to another according to an underlying principle. All transfer schedules have in common that a tax between 0% and 100% is applied to the income. Every rate is tired out. Take, for instance, transfer schedule 1 as in Equation 6: The transferred amount depends only on the regional per capita risk level. See further down for other transfer schedules:

For tax $\in$ **[0,100]%:**

$$t_{i,t,tax} = tax * \sum_i w_{i,t} * \frac{rpc_{i,t}}{\sum_i rpc_{i,t}} - tax * w_{i,t} \tag{6}$$

↓

The attractiveness of a given regions is provided by Equation 7. Factor b_i, wage, transfer payment, and risk per capita in the region is taken into account:

$$v_{i,t,tax} = \frac{b_i * (w_{i,t} + t_{i,t,tax})}{rpc_{i,t}} \tag{7}$$

↓

Equation 8 gives a comparison of the attractiveness of regions and makes them thereby comparable:

$$\Pi_{i,t,tax} = \frac{v_{i,t,tax}}{\sum_i v_{i,t,tax}} \tag{8}$$

↓

The attractiveness of a region $\Pi_{i,t,tax}$ leads to a population allocation accordingly with Equation 9. H_{total} corresponds to the total population of the UK:

$$H_{i,t,tax} = \Pi_{i,t,tax} * H_{total} \tag{9}$$

$$\downarrow$$

The productivity of the region is given by Equation 10 by scaling the population with regional productive factor pf_i, where $pf_i = GDP_i/population_{i,t=0}$:

$$A_{i,t,tax} = H_{i,t,tax} * pf_i \tag{10}$$

$$\downarrow$$

Total welfare W is the sum of all regional productivities given by Equation 11:

$$W_{t,tax} = \sum_i A_{i,t,tax} \tag{11}$$

Next tax
Next t

4.1 Determination of Parameter b_i

To implement the model and make it run following steps were required. First, the unknown factor b_i in Equation 7 has to be estimated. We have the assumption that currently the risk is considered by people living in each region, therefore the population given by the model through Equation 9 has to be equal to the actual observed regional population in the UK. Using the Equation 3 to Equation 9 in MS-Excel with a Solver with the aim to fulfill Equation 12 under variation of b_i the b_i for each region is estimated.

$$H_i(b_i) \stackrel{!}{=} H_{actual,i} \tag{12}$$

4.2 Transfer Schedule 1

The first transfer schedule is already mentioned previously. See Equation 6 or below.

$$t_{i,t,tax} = tax * \sum_i w_{i,t} * \frac{rpc_{i,t}}{\sum_i rpc_{i,t}} - tax * w_{i,t} \tag{13}$$

The motivation for this transfer schedule is the idea that we just look at the exposed risk for each region and allocate resources accordingly. Collected funds amount to $tax * \sum_i w_{i,t}$, where every individual contributes with $tax * w_{i,t}$. The redistribution follows the ratio of regional per capita risk in comparison to overall risk $\frac{rpc_{i,t}}{\sum_i rpc_{i,t}}$. Regions with low per capita risk "subsidise" regions with a high risk per capita.

4.3 Transfer Schedule 2

$$t_{i,t,tax} = tax * \sum_i w_{i,t} * \frac{\frac{rpc_{i,t}}{\sum_i rpc_{i,t}} + \frac{pd_{i,t}}{\sum_i pd_{i,t}}}{2} - tax * w_{i,t} \tag{14}$$

Equation 14 gives the second transfer schedule. The underlying idea is that highly populated areas should be prioritized over sparsely populated areas since densely populated area can be saved on a lower per capita effort and a relocation few people is easier than of many. Financed is the scheme like the transfer schedule 1 with a collection of taxes and redistribution accordingly.

4.4 Transfer Schedule 3

$$\begin{aligned} t_{i,t,tax} = \sum_i tax * 100 * \frac{(1 - \frac{rpc_{i,0}}{\sum_i rpc_{i,0}}) - \min(1 - \frac{rpc_{i,0}}{\sum_i rpc_{i,0}})}{\max(1 - \frac{rpc_{i,0}}{\sum_i rpc_{i,0}}) - \min(1 - \frac{rpc_{i,0}}{\sum_i rpc_{i,0}})} * \frac{H_{i,0}}{\sum_i H_{i,0}} \\ - tax * 100 * \frac{(1 - \frac{rpc_{i,0}}{\sum_i rpc_{i,0}}) - \min(1 - \frac{rpc_{i,0}}{\sum_i rpc_{i,0}})}{\max(1 - \frac{rpc_{i,0}}{\sum_i rpc_{i,0}}) - \min(1 - \frac{rpc_{i,0}}{\sum_i rpc_{i,0}})} \end{aligned} \tag{15}$$

Equation 15 determines the taxes a region needs to pay respectively subventions a region gets. This means that the paid tax varies for the different region. The risk assessment is therefore scaled to a range of 0 to 100 and then the taxed are payed accordingly. Based on this, the most impacted region by risk gets the most while the safest region needs to pay the most.

5 Evaluation and Results

5.1 General Approach

The population in our model allocate according to the attractiveness of each region. Transfers affect the attractiveness of a region and therefore lead to a change in the allocation of the population. This, in turn, also alters the attractiveness of each region. It is an iterative process for each year. Hence, for each transfer model, we plotted the resulting welfare against the tax rate for 1,2,5 and 10 years after implementing the transfer schedule. Note that these are per year values, not accumulated values.
The base values are the inherent attractiveness of each region and the welfare before a transfer schedule introduced. Both are calculated by using the population and economic data. The code used to obtain results can be found in the attachments or in the public project GitHub repository[24].

5.2 Transfer Schedule 1: Compensating for the Risk

The first and easiest transfer schedule consists of the collection of a tax as the percentage of the wages in each region and redistributes the money according to the risk per capita in each region.

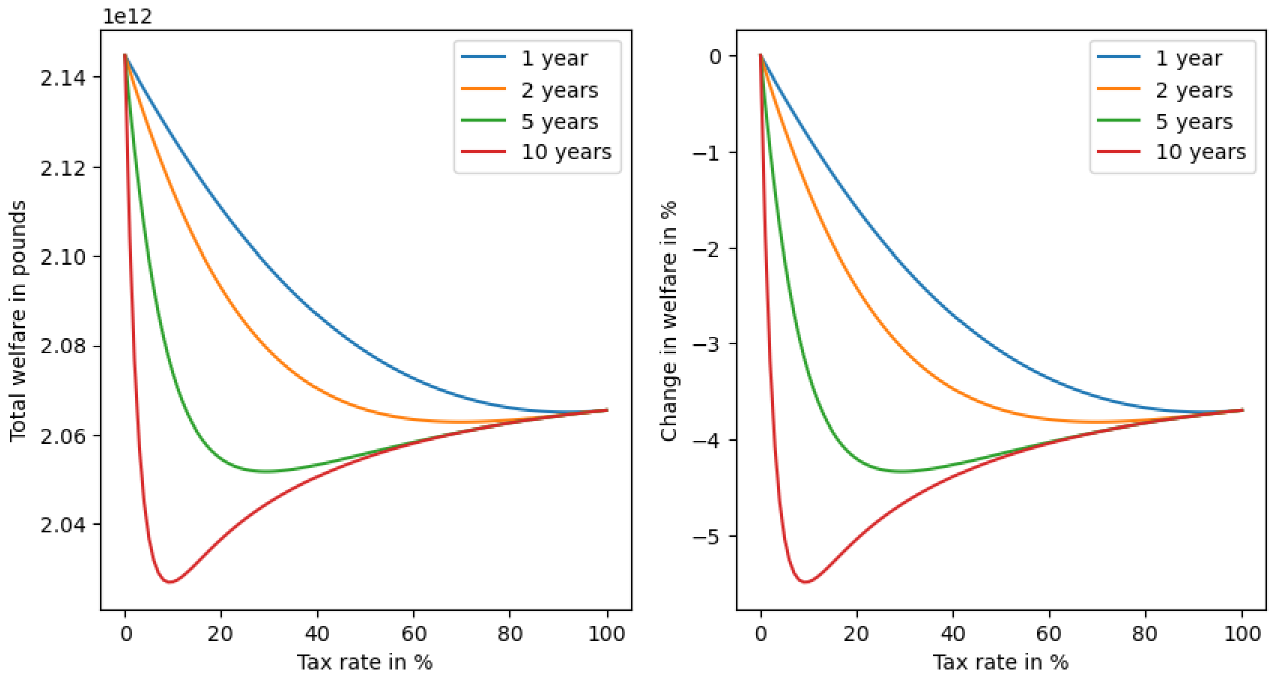


Figure 2: Absolute and relative welfare effect of transfer schedule 1

Figure 2 shows the effect of the measure on the total welfare depending on the tax, expressed as a percentage of the income. After one year, the welfare effect is a monotonously decreasing function, the function for the effect on welfare after 10 years has a minimum welfare at about five%. For each of the functions, there is a plateau where the loss in welfare stays at a constant level of about -0.8 trillion pounds. Overall, however, every taxation, when redistributed only according to the risk in each region reduces the total welfare by one to five percent depending on the considered time frame.
A possible reason for that result is that the regions in the UK with the highest risk are also the ones that are least productive, every transfer of money and in the consequence of citizens to those regions decreases the total productivity of the nation.

5.2.1 Limitations and Consequences

One can argue that the assumption of constant productivity per region is a weakness of the model because individuals might maintain their productivity when moving. Agent bases models can be more accurate in capturing dynamic with individual traits of individual citizens but those models far exceed the scope of this report.

5.3 Transfer Schedule 2: A More Efficient Transfer

Addressing the major weakness of the first transfer schedule: Producing a decrease in welfare, this model aims at redistributing the collected taxes more efficiently. The second transfer schedule transfers the money into the regions that have a high risk but also a high population density. The rationale is that the transfer most likely going to be invested into preventive measures, those are most efficient if they protect many citizens. Technically, a risk value and value for the population density is assigned to each region according to population and risk data. The values are multiplied and normalized. This normalized value for a region is the percentage of received transfers from the total transfers.
With this schedule the welfare increase increases monotonously with higher tax rates, plateauing at about 1.6 trillion pounds. The calculation for 10 years after introduction of the measure shows that tax rates of below 10% are sufficient to reach the maximum welfare increase of more than 70% for a time frame of 10 years.

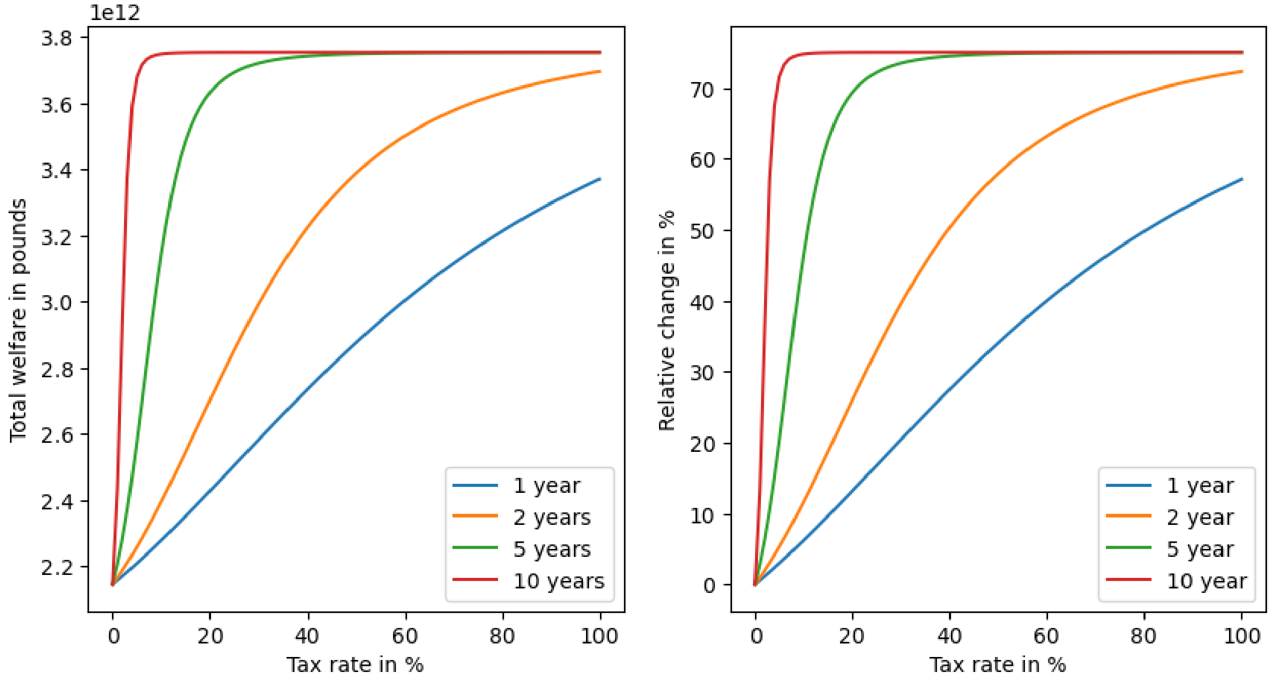


Figure 3: Absolute and relative welfare effect of transfer schedule 2

5.4 Transfer Schedule 3: Varying Tax Rates

Testing another schedule of varying tax rates which are connected to the risk for each region, a linear dependency of the welfare increase on the tax factor is detected as shown in Figure 4. An increase in the analyzed time frame shows the same multiplier effect that is observed in the previous transfer schedules. The overall impact on welfare is significantly lower than in the previous models with an increase of welfare of around 0.01% in at a tax rate of 10% with a time frame of 10 years. The linearity of the model compared to the exponential behavior of the previous models shows that the schedule brings a lower dynamic into the model and behaves more predictable. The lack of an asymptote however shows that there is no real limit to welfare growth. This shows the limitation of the model that not all factors within the dynamics of a transfer model can be considered.

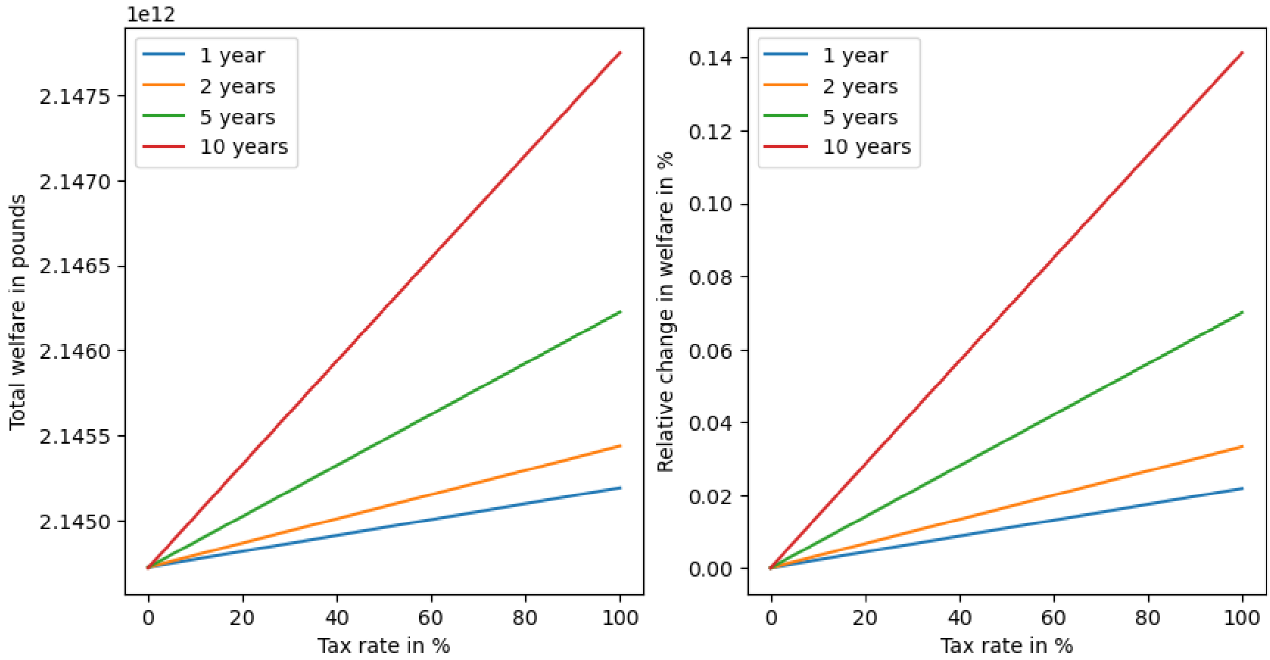


Figure 4: Absolute and relative welfare effect of transfer schedule 3

5.5 Additional Models

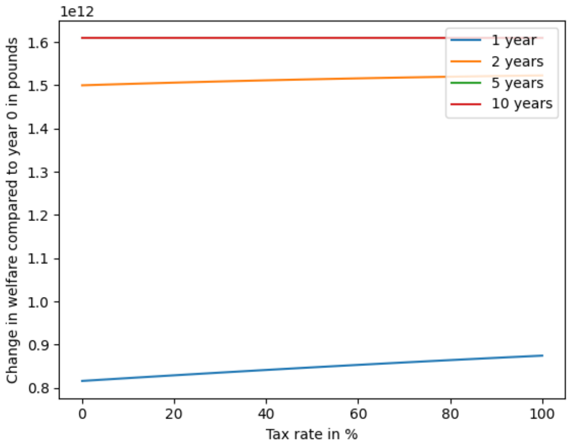
With the second transfer schedule yielding increases in welfare, one might be inclined to suggest policies similar to the transfer model. In reality, however, there are lots of feedback loops that have to be accounted for. Furthermore, in reality, there is moving stickiness, people do not easily move. Residential patterns are persistent over time regardless of whether their root cause is still effective. [25]

In the data, there is a positive correlation between population density and productivity of a region. In our model we assumed to productivity per region to be constant, therefore, if everyone would move into the region with the highest productivity, the welfare would be maximized. In the real world, this has limitations.

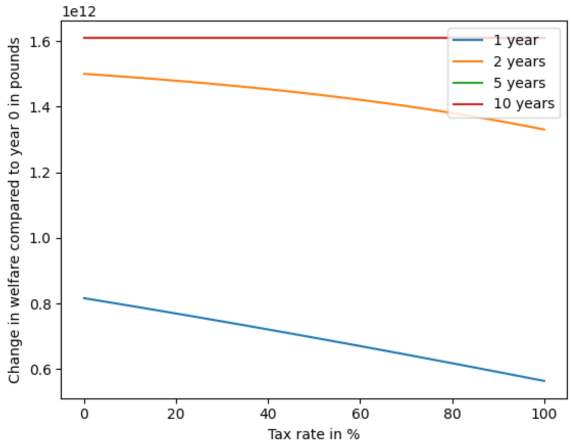
The first limitation we wanted to account for is the cost of housing in more densely populated areas. Plotting the cost of a house as a multiple of the average income in the region against the population density and applying a regression model yields a small increase in housing prices with rising population density. We constructed a model that subtracts a 30th of the purchasing price (calculated via the obtained regression function) of a house from the income per capita, as this is a usual repayment period. With this addition to the income, the first two transfer schedules were tested again. (See Equation 16 for the estimate on yearly amount spend by residents on housing and Equation 7 for the correlation of housing expense and population density; Equation 17 for the new attractiveness $v_{i,t,tax}$ in the model) This approach yields a far less dynamic model in which the tax rate affects welfare less the the housing prices. In Figure 5 one can see that the housing price becomes the dominant factor, even contradicting further results: For some year the first schedule leads to an increase and the second schedule to a decrease in total welfare.

$$h_{i,t} = \frac{(0.0014 * pd_{i,t} + 7.0373) * w_{i,t}}{30} \tag{16}$$

$$v_{i,t,tax} = \frac{b_i * (w_{i,t} + t_{i,t,tax} - h_{i,t})}{rpc_{i,t}} \tag{17}$$



(a) Welfare effect of transfer schedule 1 with housing prices



(b) Welfare effect of transfer schedule 2 with housing prices

Figure 5: Effect of the housing prices on the transfer schedules

5.5.1 Limitations

By introducing housing prices to the model, we added an additional feedback loop. This loop changes the results notably and becoming the dominant factor for the total welfare. In a real-world scenario, there are a lot more feedback loops with a potential effect on the welfare: Transfers can be spent as investment, increasing attractivity of the regions; the productivity of individuals might stay constant independent of their place of residence; investments to mitigate risks like dams could decrease the risk in the regions; and many more. This enumeration illustrates that our models, in their current state, do not suffice to justify real world transfers of the magnitude mentioned in this report.

6 Conclusion

Within the project, we developed four different transfer schedules for risk mitigation in the UK on NUTS 1 level. The three different analyzed transfers were a general tax and a distribution based on the risk per region, a distribution based on the risk and population density per region and an unequal tax redistribution based on risk. To analyze the transfer schedules' effect on overall welfare, we built a model to derive the attractiveness of each region which is then transferred into welfare. The data is based on a monetary evaluation of the risks in each region. The analysis shows that population density needs to be taken into account in order to have a positive impact on welfare. This is derived from a comparison of the first two schedules of which the first lowers overall welfare by more than 5% at a tax rate of 10% while the second - considering population - improves overall welfare of up to 70% at the same tax rate. Looking at the third transfer schedule which differentiates between different risk categories to derive individual tax rates, we see a different and almost negligible behavior in the welfare increase which reaches 0.0005% welfare increase at a tax rate of 10%. With a growing tax rate, the increase in welfare is linear and not exponential which makes the schedule less sensitive to changes in the tax rate but also less efficient in total welfare increase. These findings already show that an efficient money transfer within the UK can mitigate given risks and increase welfare. The sensitivity of welfare on the given transfer schedule is significant. An implementation of a transfer method must therefore be chosen carefully and tested in more sophisticated models. Furthermore, a multiplier effect can be detected from the different analyses. It shows that the effect of a schedule on welfare increases over time due to the dynamics of the model. The importance to find a working schedule and test it in a sophisticated model is therefore even underline since both, negative and positive consequences on welfare are amplified over time. To conclude, the analysis shows that the transfer schedule must be chose carefully to achieve a positive impact on welfare and risk mitigation. To identify a reliable schedule to implement and optimize its behavior, more sophisticated models and simulations need to be executed.

7 Appendix

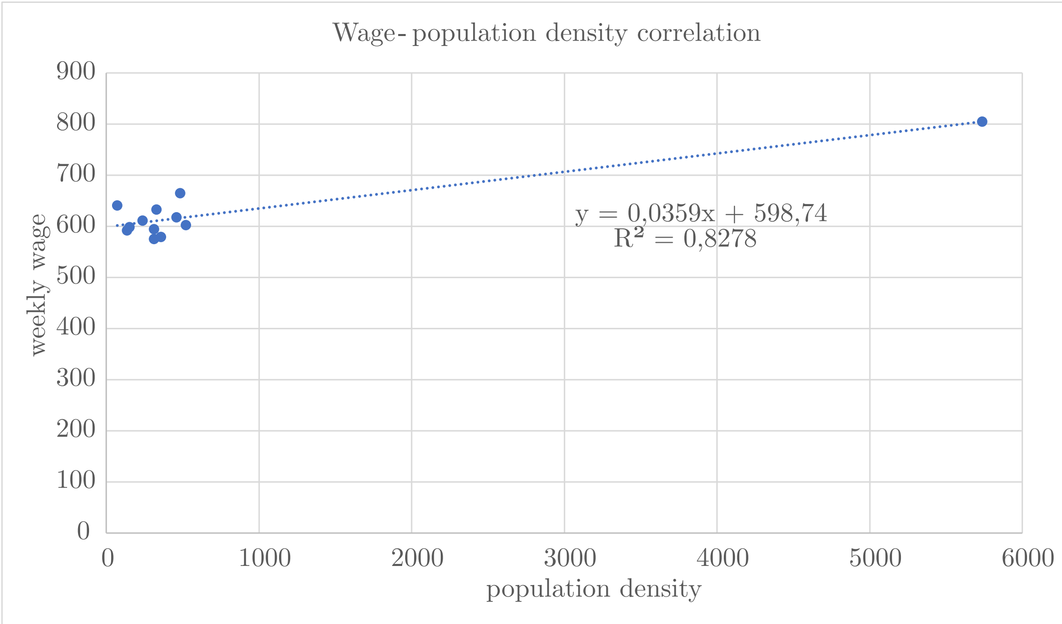


Figure 6: Wage - population density correlation

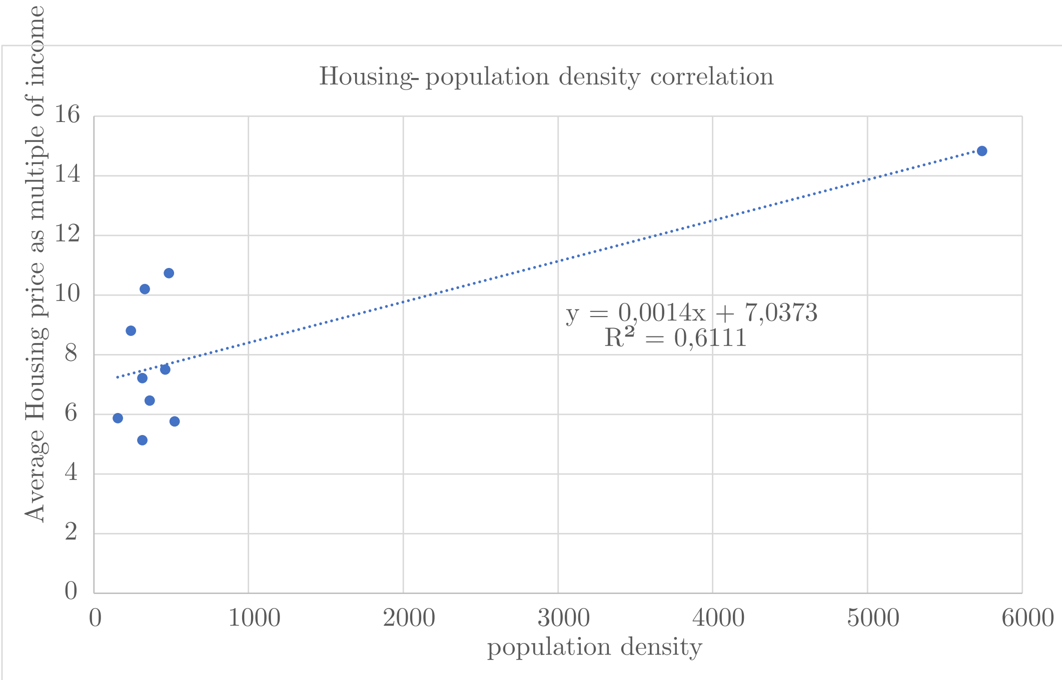


Figure 7: Housing - population density correlation

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