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The impact of climate change on the Polish economy

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Aim of the dissertation

The aim of my doctoral dissertation is to prove main hypothesis stating that the climate change will significantly impact polish economy, changing the labour market, sectoral structure and the availability of capital. This hypothesis is supported by five auxiliary hypotheses on different channels of impact - the first hypothesis is related to the frequency of extreme events - fluvial floods and windstorms, the second states that sea-level rise will affect polish economy. Third auxiliary hypothesis is related to the changes to migrations induced by the climate change and fourth describes the relationships between climate change, heat waves and mortality and labour productivity. The last auxiliary hypothesis states that the effects of all these changes combined will be larger than the sum of the impacts exerted by individual channels.

To test these hypotheses, I will build on existing literature and data, complementing to the existing research when necessary. In particular, I present improvement to the estimates of direct losses from fluvial floods through extending the standard physical modelling to include the spatial distribution of value added. Furthermore, I apply the method of estimating future wind losses to Polish conditions, using the climate model simulations and national data, what has not been done before. Moreover, I build the gravity model on the global data on migrant stock, including the climate change variables to construct estimates of future inflow and outflow of migrants to and from Poland. The applied general equilibrium model presented in the unique way merges computable general equilibrium (CGE) and dynamic stochastic general equilibrium (DSGE) frameworks, as well as includes in one model both overlapping generations consumption block and multisectoral production function.

Although the literature on the impact of climate policy on the economy is relatively vast, it usually focuses on negative short-term effects, such as a decline in GDP related to reductions in greenhouse gas emissions following the strict climate policy. The impact of climate change on health and human capital is much less researched and the literature in this area is less abundant. On the other hand, there are numerous publications describing the impact of climate change on the amount of losses caused by extreme climate events, but there are few estimates of indirect changes in the economy induced by these losses. Furthermore, while the effects of climate change on health and life expectancy are relatively well described, there is no literature analyzing the impact of these phenomena on the economy. This dissertation will contribute to filling all these gaps.

In line with the above, the main research hypothesis to be tested is:

Main hypothesis:

Climate change will affect Polish economy in several dimensions. It will lead to GDP losses, cause shifts in sectoral structure and affect employment.

In addition to this main hypothesis, there are five auxiliary hypotheses that contribute to the test:

1. Climate change will contribute to increase in the frequency of extreme events (fluvial floods and storms) that will increase the expected value of losses causing shifts in the structure of the economy.
2. Climate change will cause sea-level rise, leading to displacement of people and destruction of capital.
3. Global climate changes will intensify migrations, shifting the availability of labour force in the Polish labour market.
4. Increase in the frequency of heat waves will affect mortality and surge in ambient air temperature will diminish labour productivity.
5. The influence of all these effects combined will be significantly more significant the the isolated direct impact of these events.

Literature background

Climate change is becoming even more pressing problem for the global economy. The number of estimates of the climate change costs for the economy is huge and diverse, as the uncertainty around key channels is tremendous. Fourth IPCC report (Kunreuther et al., 2014) argues that there are four main channels of uncertainty affecting the estimated impact of climate change on the economy. The first is the measurement of greenhouse gas emission - currently the emission of most greenhouse gases (including carbon dioxide) is estimated and we do not know what is the *true* size of this emission. Secondly, the link between the concentration of greenhouse gas and the climate change is not yet fully understood with large uncertainties related to feedback loops, tipping points etc. They are so large, that Weitzmann (2009) even argues that if we face positive likelihood of catastrophic impact, than every magnitude of mitigation effort is justified. These catastrophic impacts constitute large part of the expected value of losses and small changes in probability of such events can turn any cost-benefit analysis of climate change upside-down. Such unknown, but potentially catastrophic impacts are the reason for which we should act now to prevent climate change. Third important source of uncertainty is the scale of adaptation and how climate change will translate to economic losses. For instance, the influence of climate change on agriculture depends on the decision shaping the structure of crops as the yields of wheat, maize and potato will change differently. Also, the modelling of the link between agricultural droughts and crops are still at its early stages (Piniewski et al.,2018). Another example are floods, in which adaptation allows for decrease of losses caused by 100-year flood in Poland by 42% (Alfieri et al., 2015). Fourth source of uncertainty is the accuracy of overarching model, which translates direct impact estimated using micro-based approach on the overall consequences on the economy.

First channel, through which climate change will affect the economy is the change of the productivity of agriculture. According to Schlenker & Roberts (2009) or Lobell & Burke (2008), the negative influence of temperature on crops dominates the positive impact of increased rainfall due to the importance of temperature extremes during the certain phase of the growth cycle (Welch et al., 2010). Moreover, even though rainfall is somewhat less important, extreme values of total rainfall during the season can damage crops significantly, especially if heavy rainfall is concentrated over the small number of days (Fishman, 2016). These are just a few examples of how climate change will affect agriculture. In case of Poland (with specific analysis of relevant agriculture products) such analysis was prepared recently by Kundzewicz et al. (2017). They conclude, that even though the impact of warming on yields can be positive, it can be outweighed by negative consequences of increase in extreme climate events, such as floods or droughts, projected by the climate models. Nevertheless, even though adaptation in agriculture sector is important part of the adaptation to climate change as such, its impact on GDP and employment would be relatively modest. Furthermore, the ultimate direction of the impact of climate change on crops in Poland is difficult to determine.

Second impact, that is of growing importance in the literature is the influence of even longer heat waves and resultant heat stress on work intensity and cognitive performance (Graff Zivin et al., 2018). Sudarshan et al. (2015), using the data from Indian manufacturing sector show that the manufacturing output in high temperature environment decreases by as much as 3% per 1 Celsius degree increase in temperature, mostly through reduction in workers productivity and increased likelihood of absence. Hsiang (2010) proved that this effect can be elevated to macroeconomic level as economy-wide response patterns are consistent with micro-level studies on temperature and labour productivity. Similar result was obtained by Park & Heal (2014), who even extended the conclusions to the observation that the distribution of wealth in the world may be driven by temperature due to this simple physiological relationship. In that context, climate change may increase the between country inequalities, because poorer ones will be more affected. Furthermore, it can increase within-countries inequalities, because less productive labour would be substituted by energy and capital. These effects can be, to some extent, alleviated by air conditioning, but at a substantial cost of energy used for cooling (Sudarshan et al. ,2015).

Third important channel is energy demand. Although there will be some reductions in the demand for heating, especially in cooler climates, it will be outbalanced by the increase for air conditioning (Davis & Gertler, 2015). Transmission lines will experience efficiency losses while working in higher temperatures (Jaglom et al., 2014). Warmer river-waters will affect the cooling possibilities for nuclear power plants, affecting the prices of energy (Linnerud et al., 2011) and droughts may lead to shift from hydropower power plants towards more carbon-intensive energy sources (Muñoz & Sailor, 1998). Given that energy sector is one of the most important greenhouse gas emitter, these problems needs to be integrated into long-term planning of development of energy systems.

Climate change will affect also trade patterns. Even though global wind patterns and ocean currents do not play as important role in determining the costs of transport as they used to a few ages ago (Feyrer & Sacerdote, 2009}, climate change will likely affect the international division of production, as the competitive advantage in agriculture will shift away from the equator. Changes in trade patters will be required by more intensive migration. Furthermore, the more frequent and severe extreme events will affect import, because products needed to rebuild destroyed infrastructure need to be sourced domestically (Hsiang & Jina, 2014). Nevertheless, also in this case, the estimation of potential impact of climate change is very difficult and such estimates are, by construction, quite imprecise.

The next, and perhaps the most important for countries such as Poland, channel for the impact of climate change on the economy will be changing the frequency of extreme climatic events. In the literature, the changes to flood risk are calculated directly on the basis of model simulations. The starting point are the global models (GCM - General Circulation Model), which provide the boundary conditions for regional models (RCM - Regional Climate Model). Regional models allow to accurately reflect land coverage, which is an important factor shaping the local microclimate and significantly influences the projections (Rummukainen, 2010). A fairly large sample of simulations using this type of model was created as part of the ENSEMBLES project, funded by the European Commission under the Sixth Framework Program. Examples of the use of this type of data to estimate changes in the probability of extreme phenomena can be found in the works of Tramblay et al. (2012) or Goodess et al. (2003). Knutson et al. (2008) used this type of data to show changes in hurricane probability in the United States.

The literature on the impact of climate change on flood losses in Europe is relatively abundant. For instance, Rojas et al. (2012) use data generated by twelve pairs of General Circulation Model (GCM) and Regional Climate Model (RCM) linked to the LISFLOOD hydrological model. On the basis of daily river discharge, they fit Gumbel distribution and found that the uncertainty along the climate projections is huge and sometimes it leads even to contradicting predictions of different models. For Poland, they report robust decrease in expected flood hazard, that can be attributed to the higher winter and spring temperatures, that will reduce the risk of snowmelt floods. In summer, however, the risk of flood will increase due to the higher precipitation. Similar results are presented in earlier study by Dankers & Feyen (2008)-- as northern part of Poland is more endangered by snowmelt floods and southern - by summer floods caused by intense precipitation, the probability of floods will increase in the southern part of Poland and decrease in the northern part. Alfieri et al. (2015) show that maximum annual daily precipitation will increase, but mean will fall in southern Europe and rise in north-eastern part of the continent. However, due to the interplay between various hydrological phenomena, peak discharges will increase in central and eastern Europe and decrease in Spain, Scandinavia and Baltic states. Poland, Germany and France will be particularly affected. In particular, for Poland, the frequency of today 100-year exceed event will increase until 2070 by 80-90%, what means that return period will be reduced to about 50-years. Similar study by Roudier et al. (2016) shows increase in both heavy precipitation (by 20-30%) and likewise surge in probability of current 100-years flows. Such results were obtained even for areas in which precipitation is projected to fall. In general, across Europe, the increase in frequency of flood is expected, where they are predominantly rain-fed and decrease in areas, where snow-melt flood regime dominates - in Scandinavia, Finland, northern parts of Russia and Alps. These findings are also consistent with similar study for Poland by Piniewski et al.

(2017), where mountains were the only parts of Poland with projected decrease in flood frequency and intensity.

Another phenomenon related to climate change and affecting the economy through changes in health are changes in the frequency of cold and heat waves. In this case, projecting the changes is slightly easier because they result directly from the simulation of climate models. Consequently, there is no need to translate climate change into the probability of flooding, as in case of other extreme events. As predicted by climate models, the frequency of heat waves by 2100 will increase fourfold compared to the years 1971-2000, and their length and intensity will also increase (Lhotka et al., 2017). In general, the number of channels through which climate change will affect economy is vast and it is difficult to enumerate all of them. However, more elaboration on the societal and economic impact of climate change can be found in Carleton & Hsiang (2016).

Economic models, and, in particular, general equilibrium models are quite commonly used tool in the economic assessment of the climate change. For example, Berrittella et al. (2007) includes water as a production factor to the CGE model and show that introduction of water scarcity to the model can decrease GDP by as much as 3.5% of GDP in North Africa. Koopman et al. (2017) show that while industry sectors can adapt to the climate change by using more water efficient technologies, in case of agriculture this is not possible. Using the CGE model, they conclude that agriculture in Netherlands will lose 2.2% of its output in 2050 due to change in climate conditions (2.9°C increase in summer temperature and 19% reduction in summer precipitation). In case of industry, the change in output is very small and overall GDP decreases by about 0.02%. CGE models were also widely used worldwide for the general assessment of the impact of various aspects of climate change on the economy. For example, Robinson et al. (2012) use the dynamic CGE model coupled with sector-specific hydrologic, crop and road model to assess the impact of climate change on the economy. Using the simulation from the Global Circulation Models (GCMs), they argue that, in the absence of adaptation investments, Ethiopian economy would be, in 2050, about 10% lower than in the baseline with historical climate. Chalise & Naranpanawa (2016) use the CGE model to explore economic impact of change in land use in Nepal in response to climate change. They argue that allocation of land to more climate-resilient kind of crops can significantly reduce the negative economy wide impact of projected climate changes. In global study, Bosello et al. (2012) argues that 1.9°C temperature increase will lead to about 0.5% decrease in global GDP, but with substantial regional variation.

While describing the economic models used for climate change impact assessment, so-called integrated asessment models are one of the most important tool. They were pioneered by William Nordhaus who received for these works Nobel Memorial Prize in Economic Sciences in 2018. These models links the losses to the climate change through damage functions (Nordhaus, 1992). The examples of newer work in these area are Hope(2006) or Rehdanz & Maddison(2005), who estimate the global impact of 2.5°C and 1°C w warming in 2050 at about 0.9% and 0.4% of global GDP respectively with huge uncertainty (Tol, 2012). There is also significant number of studies aiming at the assessment of the cost of just one component of climate change. For instance, the global influence of sea-level rise with 3°C warming in 2050 without adaptation is estimated to 4% (mostly in southeast Asia) (Schinko et al., 2020), of agriculture developments to 3% (Nelson et al., 2014) and of extreme events to 0.5% of GDP until 2100 (Stern, 2006). The overarching impact of all climate change phenomena can be estimated through plugging the sectoral losses (estimated based on physical variables) into the global general equilibirum model. In that case, the global GDP losses from 3°C warming are roughly equal to 3% of GDP. In case of Poland, this is 0.5% of GDP (Kompas et al., 2018). These results show how large is uncertainty around the projected climate change impacts.

Methods

I used several methods to achieve the abovementioned goals and verify research hypotheses. I start with the review of existing literature on projected climate change and its impact on the economy. This serves as the basis for research hypotheses and introduction for further considerations. In the first chapter, I show the variety of tools used by economists to assess the relationship between climate change and the economy to justify the research hypotheses, and present the overview of the literature. Second chapter describes projected climate change in Central Europe, with particular emphasis on Poland, based on existing literature. I present how climate change will affect the frequency of extreme events, such as river floods and storms. Moreover, I show that despite the increase in the frequency and intensity of agricultural droughts, the impact of climate change on the added value in the agricultural sector is unclear – as Poland will be relatively modestly affected by the climate change, Polish agriculture may gain a comparative advantage and export of agricultural output can increase. Moreover, the final impact of climate change on the agriculture sector depends on changes in the structure of agricultural production and consumption - I present the literature results from IFPRI (2019), as detailed analysis of the determinants of climate change influence on agriculture would require separate book. In addition, I present the research on the frequency and intensity of heat waves, showing that they should increase in the future. In the third chapter, I turn to the research on the relationship between climate change and the economy to justify that the climate change presented in chapter two will have a significant impact on the sectoral structure, employment and GDP.

In the next step, I use climate change data from the climate models to estimate the direct economic losses. I consider the following dimensions:

1. Losses resulting from changes in the frequency of river floods: based on historical data, the distribution of losses resulting from floods is determined. The projected change in frequency results from the hydrological model results by Piniewski et. al (2017) who provide projected daily flows in rivers until 2100.
2. Losses resulting from changes in the frequency of flash floods and windstorms: inspired with the method proposed by Pardowitz (2015), I calculate the cubic exceedance of the maximum daily wind speed over the 98th percentile threshold for the given location. This method allowed the determination of changes in losses caused by wind and storms.
3. Losses resulting from sea level rise - in this case I rely on study by Paprotny & Terefenko (2017), who determine the amount of losses for a given threshold of sea level rise. I combine this data with the predicted sea level rise data from newer and more precise study by Jackson & Jevrejeva (2018).
4. The impact of climate change on migration: In this case, I estimate a panel gravity model with climate indicators (among others) as explanatory variables. Then, I use this model and projected changes in climate indices (based on climate models) to assess the impact of climate change on migrations.
5. The mortality change associated with surge in number and duration of heat waves and the loss of productivity due to temperature increase were adopted from earlier work by Gosling et al. (2018) and Kendrovski et al. (2017) respectively.

Estimates of direct losses caused by climate change along with their spatial distribution are presented in the fourth (losses caused by an increase in the frequency of extreme phenomena and sea level rise) and the fifth (changes in human capital and labor resources caused by climate change) chapters of the dissertation.

Assessment on how the processes described above will translate into the changes to the economy as a whole is the next step of the work. I use the general equilibrium model for that purpose. In the literature on the impact assessment, such tools are used quite often – the computable general equilibrium (CGE) model is the *state-of-art* method used to examine how the climate policies will affect GDP, employment, etc. Such tools are often combined with optimization models of the energy or transport sector to obtain more consistent and more accurate estimates or to simulate detailed sectoral policies. I decided to focus to the economic effects of climate change - such analyzes are much less common in the literature than in the case of climate policy as such. While there is some literature on the losses from the extreme events based on general equilibrium models or integrated assessment models, research that would also take into account losses in human capital resulting from climate change is limited to a few studies in which such developments are modeled with standard CGE models (e.g. Hasegawa et al. 2016 or Bosello et al. 2006). To my knowledge, such estimates for Polish data are not yet available.

In this dissertation, to assess the economic effects of climate change, I employ the Overlapping Generations (OLG) model. This model is adapted to climate policy analyzes as follows:

1. There are two types of physical capital. This approach is inspired by the work of Hallegate et al. (2007), and allows for taking into account the fact that extreme phenomena destroy not only capital with marginal productivity, but rather capital with average productivity.
2. Includes an extensive module of the labor market with job search in line with the classic work of Mortensen, Pissarides (1994).
3. The overlapping generations (OLG) structure allows for a different modelling of migration (which affects mostly the working generations) and mortality due to the heat waves (affecting oldest generations and retirees).

The model was calibrated based of macroeconomic data published by the Central Statistical Office (GUS) and Eurostat (macroeconomic data). The data for the calibration of behavioral parameters was sourced from literature, while the magnitude of climate-induced shocks was determined based on the results of the fourth and fifth chapter.

The general equilibrium model (DSGE) is described in detail in the sixth chapter, while the results of model shown in seventh chapter of the dissertation.

Main results

The results described in the dissertation are in the areas of direct influence of the climate change on the economy and indirect economic effects with the use of CGE model. In particular:

1. In general, expected value of losses from fluvial floods will increase towards 2050 in almost whole country, both in RCP4.5[1] and RCP8.5[2] scenarios, while in the latter the change is much greater. In the second half of century, the expected value of losses slightly fall due to the increased evapotranspiration, but they are higher than in the *no-climate* scenario. At the country level, the losses expressed as a percentage of GDP will rise by 47% in RCP4.5 and 83% in RCP8.5 until 2050. Towards the end of century these numbers will become 32% and 51% respectively. The absolute value of the losses is highly dependent on the assumption on GDP (and parallel value of assets) growth.
2. The mean wind speed in Poland will increase and so will losses caused by windstorms. In contrary to floods, the whole country will be relatively similarly affected, but mountainous and seaside areas will be affected to greater extent. Nevertheless, the country-level increase in damages is much smaller than in case of fluvial floods – 6% and 16% until 2050 and 29% and 32% until 2100 in RCP4.5 and RCP8.5 scenarios respectively. However, these results are highly dependent on the climate models used and uncertainty bands around these numbers are relatively wide.
3. The long-run effect of sea level rise will be similar in nature to the influence of the increase in frequency of extreme events, though magnitude is going to be much lower - almost negligible in 2050 and 0.01% of GDP in RCP4.5 and 0.02% of GDP in RCP8.5 in 2100. These numbers are

[1] RCP4.5 scenario is climate scenario in which the *radiative forcing* reaches 4.5 W/m^2 in 2100. This is roughly equivalent to increase in global land surface temperature to 2°C.
[2] RCP8.5 scenario is climate scenario in which the *radiative forcing* reaches 8.5 W/m^2 in 2100. This is roughly equivalent to *business-as-usual.*

however, still one of the most significant in Europe, according to Hinkel et al. (2010). However, these losses can still be minimized through relatively inexpensive coastal protection (Paprotny & Terefenko, 2017).

4. The increase in temperature in the moderate climate zone can raise the number of immigrants leading to surge in GDP as the temperatures in summer in southern countries will become unbearable, especially towards the end of century (2080-2100) in RCP8.5 scenario. As a result, in RCP8.5 scenario, a steady increase in the number of immigrants is projected, towards 500 thousands in 2100. This is not the case in more moderate RCP4.5 scenario, as the negative influence of precipitation will outweigh the positive influence of temperature and net migration will be negative, leading to loss of GDP potential. These changes are, however, relatively minor, below 100 thousands, over the whole century.
5. The influence on labour productivity is negative, but highly uncertain (0.1%-0.9% in RCP4.5 and 0.5% - 4% in RCP8.5 in 2080). Consequently, fall in labour productivity will contribute to the negative impact of climate change on polish economy.
6. The effect of increased mortality caused by heat waves on the economy is projected to be relatively small because it will affect mostly elderly people that are already out of labour force. However, it must be kept in mind, that the overall effect of changes to health on healthcare sector were not examined, but this pressure can significantly alter the influence of future heat waves on the Polish economy.
7. As a result of changes in the frequency of extreme events (including sea level rise, increase in the frequency of fluvial floods and rise in the frequency and wind speed), GDP will decrease by 1.2% on average in RCP4.5 and 2% in RCP8.5 over the 2051-2100, with main contribution from consumption, which will decrease in comparison to the baseline by 6% on average in RCP8.5 and 4% in RCP4.5 scenario in second half of the century. The fall of investment and government consumption as a result of climate change induced increase in losses is smaller and equal to about 4% in RCP8.5 and around 2.5% in RCP4.5.
8. The influence of migration on economic outcome is smaller than in case of extreme events, but of similar magnitude. As a result of additional incoming migrations in RCP8.5 scenario, GDP will increase in 2050 by 0.1% and 0.8% in 2100. GDP *per capita* is expected to fall by 0.1% and 1.1% respectively. The impact of changes expected in RCP4.5 scenario is similar until 2060. After that, the trajectory is becoming different to what is observed in case of RCP8.5, due to the outflow of migrants from Poland. Nevertheless, these changes are very small and do not exceed -0.1% in case of GDP and 0.2% in case of GDP *per capita*.
9. The influence of labour productivity and shocks to mortality mirrors the shock to migration with significant negative contribution of consumption and smaller addition of changes to government consumption and investment. The maximum impact of these effects of climate change do not exceed 0.5% of GDP in RCP8.5 and 0.1% in RCP4.5 scenario. Furthermore, towards the end of XXI century, the influence of climate induced mortality and labour productivity shock on GDP *per capita* becomes positive, as the population is lower than in the baseline, especially within the retired generations.
10. In total, climate change will decrease GDP by 0.5% on average in 2021-2050 and by 1.5% in 2071-2100 in RCP4.5 scenario. In RCP8.5, these numbers are equal to 0.8% and 3.2% respectively. Changes to consumption will be even greater - as Poland is relatively moderately affected by the climate change, the trade balance should improve, decreasing the observed GDP loss. Also, due to the positive net migrations resulting from the climate change, the labour supply will be higher in RCP8.5 scenario than in the baseline (no climate change) and RCP4.5 scenarios. These changes are larger, than the individual sum of impacts.

In general, I proved all the auxiliary and main hypotheses. Also, my dissertation is one of the first such comprehensive evaluation of the impact of climate change on the Polish economy. Even though in comparison to the countries located in warmer climate zones, Poland will be relatively moderately affected by the climate change, losses are still significant and larger than the costs of low-carbon transformation, as estimated e.g. by McKinsey&Company (2020), who show they will amount to about 1-2% of GDP. As the losses to the consumption will be even greater, the mitigation efforts are profitable from purely *cost-benefit* perspective. If the impact on agriculture and biodiversity, omitted in this dissertation, would be taken into account, this conclusion would be even stronger.

The recommendations for governments and policy makers are clear - climate change will exert pressure on the economy and actions shall be made to prepare and to adapt. In particular, adaptation to floods and windstorms is particularly important, as the negative influence of changes can significantly decelerate capital accumulation. Furthermore, the inflow of migrants in RCP8.5 scenario may lead to social tensions, as it would negatively affect consumption and GDP *per capita*. Nevertheless, it must be kept in mind that the impact of droughts on agriculture and changing water conditions was not assessed due to the data limitations and uncertainty along the scale of potential adaption in the agriculture sector and change in the structure of crops. However, the climate change may affect agricultural production both directly - through changes in the length of vegetation season, temperature and precipitation and indirectly, through changes in comparative advantage of certain areas. In case of Poland, climate change may even lead to surge in production due to the necessity to feed other nations (Robinson et al., 2015).

Final remarks

The aim of my dissertation was to perform rigorous assessment of the impact of climate change on the Polish economy, using different methods and achieving comparable results, that can be plugged as shock into the general equilibrium model. This model is then used to verify the main hypothesis and fifth auxiliary hypothesis. Flood impact, windstorm losses and sea-level rise costs were calculated in unified manner, allowing for comparisons of the different channels and proving first and second auxiliary hypothesis. Also, inclusion of the climate impact on human capital and productivity to the DSGE model with OLG household structure is first exercise of its kind for Poland and allowed me to verify third and fourth auxiliary hypothesis of this dissertation.

I contributed to the literature in several areas. Firstly, I present the improvement to the estimates of direct losses from fluvial floods through extending the standard physical modelling to include the spatial distribution of productivity. Secondly, I apply the method of estimating future wind losses to Polish conditions, using the climate model simulations and national data. Thirdly, I build the gravity model on the global data on migrant stock, including the climate change variables to construct estimates of future inflow and outflow of migrants to and from Poland. Fourthly, the applied general equilibrium model used for the overall assessment of the impact of climate change in unique way merges computable general equilibrium (CGE) and dynamic stochastic general equilibrium (DSGE) frameworks, as well as includes in one model both overlapping generations consumption block and multisectoral production function.

Some important issues are still set aside mainly due to their complexity and their loose connection to other parts of this dissertation. In particular, I argue that the impact of climate change on agriculture in Poland is dependent mostly on dietary shifts and international competitiveness and, according to current research results, with proper adaptation strategy, this sector may even gain from the climate change (IFPRI, 2019). Also, I do not elaborate on the impact of mitigation policies and reduction in greenhouse gas emission on the economy, as this topic is already widely covered in the literature - Bukowski & Kowal (2010), Boehringer & Rutherford (2013) or Zachłod-Jelec & Boratyński (2016) are just few examples of such studies. According to their results, the costs of mitigation are lower than the climate change impacts, even though Poland is relatively moderately affected by the climate change. Furthermore, the general equilibrium model used in this dissertation is small open economy model - so I abstract from the impact of climate change in other countries. As Poland will be less affected by the climate change than other regions of the world (especially those located in warmer climate zones), its competitiveness may increase as a result of the climate change. However, this process is not modeled *explicitly*. The political economy of the process and how climate change will shape the political landscape in Poland, is interesting area of future research, especially once the overall impact of climate change on the economy is known.

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