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D3.4 Open-access paper on the formulation and adaptation of an agent-based model to simulate generational renewal

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Abstract

This paper presents a tool to analyze the linkages between farm generational renewal and structural change of European farming regions, allowing researchers to assess the farm system's resilience. There is a strong focus on farm generational renewal both within academia and policy. However, the focus often lies on the family. This results in a knowledge gap about generational renewal of the increasing number of farms which rely on hired labour and farm almost half of European agricultural land. To begin to fill the gap, the Agricultural Policy Simulator (AgriPoliS), an agent-based model used to analyze structural change of farm regions, has been selected to extend to simulate generational renewal. The model is calibrated to the Altmark, a heterogenous farming region in Germany with both family and corporate farms. To support the model's extension and adaptation, a focus group work shop was held in the Altmark on farm generational renewal. The extension is used to simulate three scenarios, which reveal the robust and adaptive resilience capacities of the Altmark.

1 Introduction

The European agricultural sector is undergoing demographic changes, whereby the average age of farmers and average size of farms are simultaneously increasing while the number of young farmers is decreasing (European Court of Auditors, 2017). Policy makers are concerned that the continuation of these farm structural and demographic changes will threaten the resilience of European farm systems and, as a consequence, European food security. In order to combat one of the drivers of the demographic and structural change, policy makers have sought to stimulate farm generational renewal. The term "generational renewal" can be found in EU policy and literature and is defined as the goal of not only reducing the "average age of farmers in the EU … [but] empowering a new generation of farmers… " to meet the two prong objective of both increasing European agriculture's competitiveness as well as ensuring food security (European Network for Rural Development, 2014). The EU's main policy objective is to support its young farmers, defined as under the age of 40.

Since the 1990s, generational renewal has been a central focus of the EU's common agricultural policy (CAP). In the last rounds of the CAP, measures have targeted both old and young farmers through the "Early retirement" and "Setting up of young farmers" programs and the current Measure 112, known as "The Young Farmers Scheme," which offers both direct payments for young farmers as well as opportunities for start-up support from the CAP rural development funds. The EU spends a significant amount of taxpayer money to stimulate farm generational renewal. For the 2007 – 2020 CAP budget the EU has dedicated 9.6 billion euros to address generational renewal, and with the addition of state top-offs at the member state level, the

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amount totals 18.3 billion euros (European Court of Auditors, 2017). Looking forward, generational renewal remains a high-priority item, as it is one of nine objectives which will guide the next CAP budget (European Commission, 2018).

The objective of this paper is to document the creation and application of a new research tool that simulates generational renewal. Such a tool will support policy makers in their goal to enhance the resilience of European farming systems.

In the next section the paper will define what a European farm is, thereby engaging with the topic generational renewal of European farms. After it provides the theoretical background of resilience and its linkages to farm demographic and structural change. The mixed-methods approach is described in the following section where the focus group workshop is described and the agent-based model, the Agricultural Policy Simulator (AgriPoliS), is introduced. The fifth section details the adaptation of the model to simulate generational renewal in European agricultural regions. The sixth section demonstrates the application of the adaptations and extension with three scenario simulations and presents their results. The final section discusses what the results can be analyzed to assess the resilience of farm systems.

2 Generational Renewal in European Agriculture

European agriculture is diverse. From production to size to legal form, the term “European agriculture” describes both the family-owned Belgian dairy farms as well as the very large corporate arable farms in Bulgaria. However, literature shows that the term European agriculture is more commonly associated with the former than latter. Cardwell (2004) writes on the “European Model of Agriculture”, a model describing the medium-sized family farms which are dominant in Western EU countries. Calus and Van Huylenbroeck (2010) claim that family farms are essential to the concept of European agriculture. For Chiswell (2014), the next generation of farmers is family farmers. The narrow definition and concept of European agriculture is not limited to academic research. Since its beginning, the CAP has served to financially support family farms (Kostov et al., 2018). While large scale farms were not part of the European agricultural landscape when the CAP was conceived, since the expansion of the EU, in particular the New Member States (NMS) of Central and Eastern Europe, the CAP has failed to adjust its focus to serve not only the family farms, but large scale farms present in the NMS (Gorton et al., 2009).

Statistically, the preoccupation with European family farms is not wrongfully placed based on the number of family farms with family labour in Europe, some 93.7% of all farms (Eurostat, 2015). However, these farms account for only 54.3% of farmland (ibid.) with the expectation that this number will only decrease, based on the current farm demographic trend and

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structural changes. Farms using non-family- or hired- labour, often categorized legally as corporate and partnership farms, contribute significantly to European agriculture and therefore need to be considered when the employing the term "European agriculture", especially with regard to agricultural policy.

There has been much attention paid to European family farm generational renewal within the literature, while little paid to that of corporate and partnership farms. Suess-Reyes & Fuetsch's (2016) literature review on family farm succession strategies draws on 53 peer-reviewed articles, with a strong focus on Europe. The attention is with good reason, as intra-familial farm transfer is the best opportunity for young farmers to enter the sector (Lobley and Baker, 2012). While extensive studies have been conducted on hired labour versus family labour on farms in the EU (Kostov et al., 2018; Allen & Lueck, 1998) and CAP payments effects on employment (Petrick & Zier, 2011; ibid., 2012; Mantino, 2017), scholars have paid little attention to non-family farms when it comes to generational renewal. In order to ensure that the other 45.7% of European agricultural land, which relies on non-family labour, will continue to be farmed, generational renewal policies and research must focus on the breadth of diverse farms in Europe.

This paper begins to fill that gap by creating a tool that simulates generational renewal suited to European agricultural regions, not only those with family farms. For all farm types, generational renewal comes down to the question of if there are people willing and capable to work in agriculture to be part of the next generation of farmers.

3 Theoretical Framework

As the purpose of the tool is for policy makers to make ex-ante assessments of the impacts of policies and measures on the resilience of farming regions, it is fitting that resilience theory be the framework that guides the analysis of this paper. Resilience theory has been adopted and adapted across disciplines, from ecology (Holling, 1973) to psychology (Masten, 2001; Rutter, 1987) to management (Gittell et al., 2006). Meuwissen et al.'s (2018) application of resilience theory to European agriculture offers a framework for which policy makers can assess the resilience of the farm system, making it the most suited framework to apply to this research. They define a resilient European farm system as one which "maintains the essential functions of EU farming systems in the face of increasingly complex and volatile economic, social, and environmental institutional challenges" (ibid.). The framework proposes that a farm system's resilience can be understood through three types of resilience capacities; robustness, adaptability, and transformability. Robustness is defined as a system's capacity to maintain its levels of function against shocks and stresses without major adjustments to the system (Urruty

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et al., 2016). Adaptability is the capacity a system has to make internal changes in response to external forces and still maintain its functions (Folke et al., 2010). Lastly, transformability is a system's capacity to make large changes in thinking and operational logic to avoid a system collapse (Walker et al., 2004).

The processes connected to structural change are often the result of economic, institutional, and social challenges and have the potential to influence the farm system's resilience. The effects of labour shortages demonstrate the linkages between farm generational renewal, structural change, and resilience. If there is a labour shortage causing the cost of labour to increase, it can trigger farms to adapt by changing their production in a labour less-intensive direction or implementing labour-saving technology. Some farms also might not be able to adapt and will exit the system. A farm system can also become more resilient through the exiting of farms, enabling other farms to grow to economies of scale and thus enhance its potential to absorb shocks. For Appel and Balmann (2018), a "smart exit", or a farm exiting due to reasons other than illiquidity, enhances the resilience of the farm household. Adapting and transforming through production changes, new technology, and farm exits will affect farm structures, thus causing farm structural change.

4 Methodology

This paper uses a mixed-methods participatory approach of a focus group workshop to inform the extension of the agent-based model, the Agricultural Policy Simulator (AgriPoliS).

4.1 AgriPoliS

4.1.1 Model Overview

AgriPoliS is an agent-based spatial model which can be calibrated to represent a real European agricultural region and used to simulate various scenarios, including policies or shocks so researchers can observe a region's structural change over time (Appel et al., 2016; Sahrbacher et al., 2012a; Happe et al., 2008; Happe, 2004; Balmann, 1997). A full documentation of the model is in Kellermann et al. (2008) and an Overview, Design concepts and Details Protocol is documented by Sahrbacher et al. (2012b).

The agents in AgriPoliS are farms whose decisions are based on the goal of maximizing their profit or household income. Their interactions take place in a virtual region, which is calibrated using statistical regional data to capture the characteristics of the chosen farming region like its size, types of land, shares of land, number of farms, size of farms, types of farms, and so on. The agents are typical farms from the region and are selected from Farm Accountancy Data Network (FADN) data and then anonymized in an upscaling process detailed by Sahrbacher and Happe

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(2008). At initialization, the agents are stochastically assigned plots of land, ages of the farmer and farm assets, and managerial ability.

Particular to AgriPoliS is the ability to observe not only the structural change of a region over a set period of time, but the development of individual farms. At both the regional, or system, level and individual agent level researchers can observe changes in the profits, costs, labour requirements, production and investment decisions, as well as the decision to exit or remain in agriculture, all of which can result in changes to a regional farm structure. With the ability to simulate a dynamic process like generational renewal and heterogeneity of a complex adaptive system, AgriPoliS offers itself as an ideal tool to adapt.

4.1.2 Capacity to simulate generational renewal

Prior to any extensions, AgriPoliS' core version contains foundational concepts of generational renewal such as computing the opportunity costs for the farm agent to remain in the sector at the time of generational change. In this version of the model a farm manager operates the farm for 25 years before generational change takes place, if the farm does not exit due to illiquidity or the farmer's opportunity costs throughout that period. It is assumed that during generational change, the opportunity costs of the successor are higher than the current farm manager to account for the fact that the older a farmer is, the less likely their chances are to find off-farm employment (Kellermann et al., 2008). For some farms, this results in closure because the potential successor would earn more off-farm.

In Schnicke's work assessing socio-economic determinants of structural change in Hungary, Poland, and Slovakia, he adapted the model to resemble the characteristics of each farming region (2012). One of the characteristics was that many farms in those regions were without a successor (ibid.). With Schnicke's extension, the researcher could activate a switch that would result in a random 25% of family farms having no successor at the point of generational change and would therefore cease to operate. Additionally, Schnicke experimented with the effects of various distributions of farmers' ages at initialization to account for the low level of young farmers in comparison to the high level of old farmers in his case study regions.

The work of AgriPoliS' predecessors demonstrates that the model is capable of being extended to enhance its ability to simulate generational renewal. It serves as an ideal tool for policy makers because it allows not only the observance of generational renewal, but also the other complex processes which can result in structural change.

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4.2 Focus Group Workshops

In addition to the aforementioned empirical data, data was collected through the use of a focus group workshop. The focus group serves two purposes; to understand what farm generational renewal means in a region where both family and hired labour are used and to calibrate the model to the region based on this data.

The focus group followed a semi-open workshop structure with four participants of different ages and genders, representing different farm types and structures, as well as a trained moderator who facilitated the participants to discuss four topics in regard to farm generational renewal in the region; demographic change, "untrained" labour, "trained" labour, and management. The decision to use a focus group was due to the limited data on the topics (Stewart & Shamdasani, 1990). Additionally, focus groups offer the opportunity to gain both breadth and depth on a topic as a result of the participants' interactions with one another (Acocella, 2012). This interaction generates information which would otherwise not come through in an interview with a researcher, and is the value-added element of a focus group (Morrison et al., 2001).

5 Adaptation of AgriPoliS

5.1 Case Study: the Altmark

The Altmark region, located in the Northern part of Saxony-Anhalt in Eastern Germany, presents itself as an ideal case study region to adapt AgriPoliS to be a tool to analyze generational renewal because of its dualistic farm structure. During the German Democratic Republic (GDR), the large-scale farm structure resembled that of the NMS. Decades after German reunification, large scale farms remain a defining characteristic of agriculture in the region. However, the regional structure did change after the fall of the GDR and German reunification to create the dualistic farm structure seen today. The Altmark is consists of very large corporate farms, or those with over 1,000 hectares of land, similar to those in the GDR, as well as small (under 100 hectares), medium (100 up to 500 hectares), and large (500 up to 1000 hectares) family farms. Arable farms, grazing livestock - including dairy, and mixed farms are the predominant farm types in the Altmark. Using the Altmark as a case study region for simulating generational renewal means that attention is paid to what generational renewal means for both small and medium family farms, common in Western European regions, as well as the large corporate farms, common in Central and Eastern European regions.

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Table 1 shows the results of the upscaling process based on the Altmark's 2016 farm structural data. The "statistics" column is from the regional state statistics on farm structures. The second column, "adjusted" shows the removal of the non-economic farms or farms under 10 hectares which are not affected by agricultural policies, as part of implementing stakeholder feedback. The fourth column "upscaled" is the structural statistics of the farms which have been implemented into AgriPoliS through the upscaling process.

Table 1 The Altmark in AgriPoliS

	Statistics	Adjusted[a]	Upscaled[b]	Deviations in %[c]
Number of Farms	1,080	933	928	-0.54
Farm by Farm Type				
Arable crop	461	383	384	0.26
Grazing animals	364	271	268	-1.11
Granivore	43	18	18	0.00
Mixed	212	261	258	-1.15
Farms by Legal Form				
Corporate	142	142	150	5.63
Family Farms	938	791	778	-1.64
Agriculturally Used Area (UAA)	273,694	272,935	272,135	-0.29
UAA by Land Type				
Arable land	203,342	203,120	197,677	-2.68
Grassland	70,352	69,815	74,458	6.65
UAA by Farm Type				
Arable crop	94,397	94,191	95,430	1.31
Grazing animals	70,366	70,097	69,590	-0.65
Granivore	4,102	4,086	4,120	0.83
Mixed	104,829	104,561	102,995	-1.53
Farms by Land Size Group				
(from … up to … hectares)				
Under 100	555	408	409	0.24
100 – 499	368	368	369	0.27
500 – 1,000	99	99	94	-5.05
1,000 or more	58	58	56	-3.45

a) removal of non-economic farms; b) implemented into AgiPoliS.; c) from adjusted to upscaled

Statistics Source : Statistisches Landesamt Sachsen-Anhalt (2016)

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5.2 Focus Group Results

Through discussing different aspects of generational renewal with one another, the participants revealed a significant amount of information which greatly assisted the extension and calibration of AgriPoliS. The following section details the outcomes of the focus group and what these outcomes indicate with regard to resilience.

In terms of farm demographic stressors that the Altmark is facing, the ability to pay agricultural workers higher wages was a reoccurring topic. The focus group participants emphasized their belief that low wages in the agricultural sector are of particular importance when it comes to generational renewal of both family and corporate farms. They offered various examples of agriculture's reputation for low compensation and how this reputation is a significant factor which makes the sector unattractive to possible new entrants and deters potential successors from taking over. The discussion revealed that the region is struggling to adapt to market pressures.

Agriculture's reputation for low wages is not fictitious. The average increases in wages in the FADN data, a rate of 1.9%, is less than the European goal of inflation, 2%, and also significantly less than other comparably skilled jobs which experience a wage increase at an annual rate of 2.7% (WSI, 2017). The model was adjusted with these figures to improve the reality of the opportunity costs of both remaining in the sector and for a potential successor to take over.

German reunification was a shock that transformed the environments in which farms in the former GDR operated in the 1990s. The participants shared how the region is now experiencing "after-shocks" of the transformation, particularly with regard to the age distribution of farm managers. The early 1990s saw the birth of most of the farms in the region. Many of the farmers were around age 40 when they were founding the farms; this includes all forms family, partnership, and corporate. At the time, there was an uneven distribution of the age of farm managers. For the large farms with several managers, many of the managers are nearing the age to retire but also consciously trying to avoid a simultaneous turnover of management by staggering in new employees. The situation the participants discussed particularly highlights the dynamic and cyclical aspects of resilience described by Meuwissen et al. (2018). In an attempt to increase their resilience in the face of an expected upcoming shock, the farmers are now adapting their methods of employment because of pressure from the way in which the system transformed 30 years ago.

The attention paid by the focus group to the importance and effects of age distribution in a farming region emphasized the need to extend the model so that the researcher can set the

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parameters of the age of the farmers. It is not only important to be able to set the age of the farmers at initialization but also to be able to adjust the parameters of the succession age.

During the discussion on the availability of farm managers, the participants differentiated between what farm manager availability means in regard to family farms and corporate farms. Despite the fact that corporate farms have a wider pool of candidates for finding a manager's successor, they too face significant and increasing difficulties in terms of generational renewal. As farm technology and capital investment requirements increase, so does the pressure for highly skilled farm managers who have the technical farm and business knowledge to run a large-scale farm. In the Altmark, corporate farms struggle to attract qualified workers to renew the supply of managers and expect the situation to worsen in years to come.

For family farms, the renewal of managers means the availability of a willing successor within the family. The presence of potential successors is not only a question of a successor's interest to work in agriculture, but also their willingness to remain in the Altmark. The participants discussed how in other German regions they know family farmers which encounter difficulties because there are several interested potential successors. In the Altmark, however, they agreed that the greatest challenge family farms face with regard to renewing managers is the presence of a willing successor. Interestingly, all participants were in agreeance that a lack of a successor is not a problem for the region, because if a farm operation shuts at the point of generational renewal, another one will continue to farm the land.

In terms of resilience, the focus of the participants' discussion on renewing farm managers for family and corporate farms touched mainly on adaptation and transformation. For the participants, the farm system is resilient regardless of the presence of a successor, so long as other farms in the system continue to grow and farm the land. Farm managers have to adapt their skills as a result of the pressures of the farming system transforming.

The stark difference between generational renewal for family farms in different regions in Germany alone as well as the difficulty corporate farms are experiencing with renewing managers demonstrate the need to extend the model so that the researcher can define the parameters of probability that a successor exists for family and corporate farms.

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5.3 Extension: Demographics

Based on the information surrounding the parameters and probability of generational renewal, AgriPoliS now includes an additional input file named "demographics." When this file is activated, the parameters set by the researcher override the variables simulating generational renewal in the core version of the model. In the demographics file the researcher is able to define the:

- *initial age distribution of the manager of corporate and family farms,*
- *age distribution of the new manager*
- *probability that generational renewal will take place on a corporate farm and on a family farm,*
- *age at which generational renewal will take place*
- *age until which a farmer is allowed to farm if there is no successor,*
- *and a decrease in a farm's productivity if they continue to farm after generational change should have taken place if there was no successor.*

This extension further develops AgriPoliS' capacity to simulate generational renewal in European agricultural. With the "demographics" file, variables which affect generational renewal, like age and successor likelihood, can be defined by the researcher. These variables not only differ greatly depending on the region but by can also differ based on whether the farm is a corporate or family farm. With the extension, users are able to adapt the model to any European region's data, increasing the similarities between the actual region and the virtual region. The "demographics" input file enables researchers to define the variables in a particular region without making changes to the AgriPoliS' core which increases AgriPoliS' usability. Each agent's decision making process with regard to generational renewal is depicted in figure 1.

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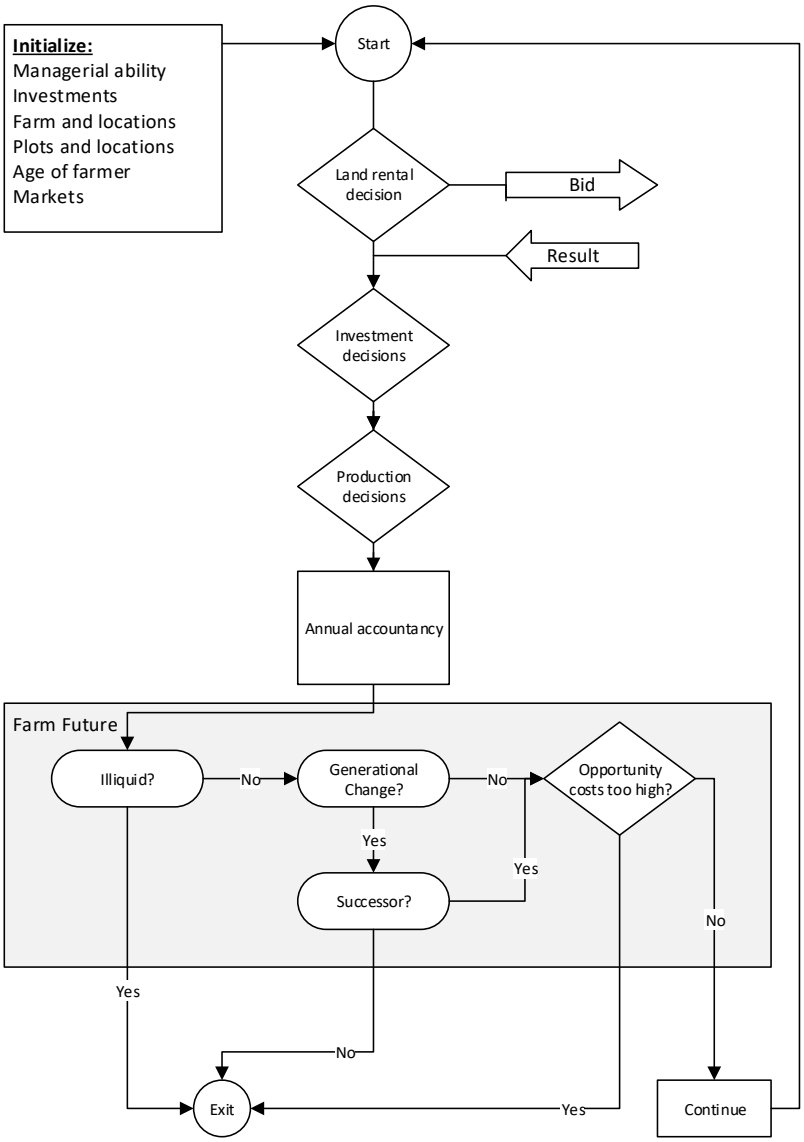

Figure 1 AgriPoliS agent decision-making flow chart
Source: Authors' own

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5.4 Scenarios

The following tables describe the different scenarios run in AgriPoliS. The "Reference" scenario serves as a baseline to which the following scenarios can be compared to. As the focus group emphasized wages in relation to labour difficulties, the "Wage" scenario tests what would happen if agricultural wages rose at the same rate as wages of comparable jobs. Finally, the "Demographics" scenario is the extended version of AgriPoliS with the "demographics" input file. It has been calibrated based on available Eurostat data at the national level and information from the focus group.

Table 2 Scenario descriptions

Scenario Title:	Description:
Reference	- Core version of model - No differentiation between corporate and family farm managers for age distribution - Normal distribution of manager ages (35 – 60) - 100% presence of successor - Generational change at 25 years of operating - Farm wages increase at 1.9% annually - Off farm wages increase at 2.7% annually
Wage	- Same as "Reference" except farm wages increase at 2.7% annually as well
Demographics	- Extended version of the model - Overridden and new parameters of the core version seen in Table 3 - Wages same as in "Reference"

Table 3 Parameters of "demographics" input file

Initialization:		
Family Farmer's age	minimum: 30 years	maximum: 70 years
Corporate Farmer's age	minimum: 30 years	maximum: 66 years
Family farmer age distribution	average: 51.5 years	standard deviation: 11.83856
Corporate farmer age distribution	average: 50.1 years	standard deviation: 11.14596
Generational Change:		
Age of generational change	67 years	
New farmer's age	minimum: 30 years	maximum: 45 years
New farmer's age distribution	average: 35 years	standard deviation: 1.5
Probability of a Successor:		
Family farms	75%	
Corporate farms	100%	
Farming without a Successor:		
Maximum age of farmer with no successor	75 years	
Productivity decrease past generational change age	1%	

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6 Results

The analysis focuses on the following aspects: the amount of farms, farm labour, changes in farm production, and effects on land markets. To minimize the random effects resulting from the initialization of AgriPoliS, each scenario is simulated 100 times. Simulations start for calendar year 2016 and goes until 2040. As the conditions under which European farms operate change frequently, long-term projections become less realistic. For this reason, we concentrate our analysis mainly on a time horizon of 10 years which means from 2016 to 2026.

6.1 Farms by number and size

Naturally, there is a decrease in the total number of farms in the Demographics scenario, as the parameters were set so that 25% of family farms would have no successor. However, between the Reference and Wage scenarios there is no change in the total number of farms, demonstrating that a rise in agricultural wages at 2.7% would not affect the number of farms in the region.

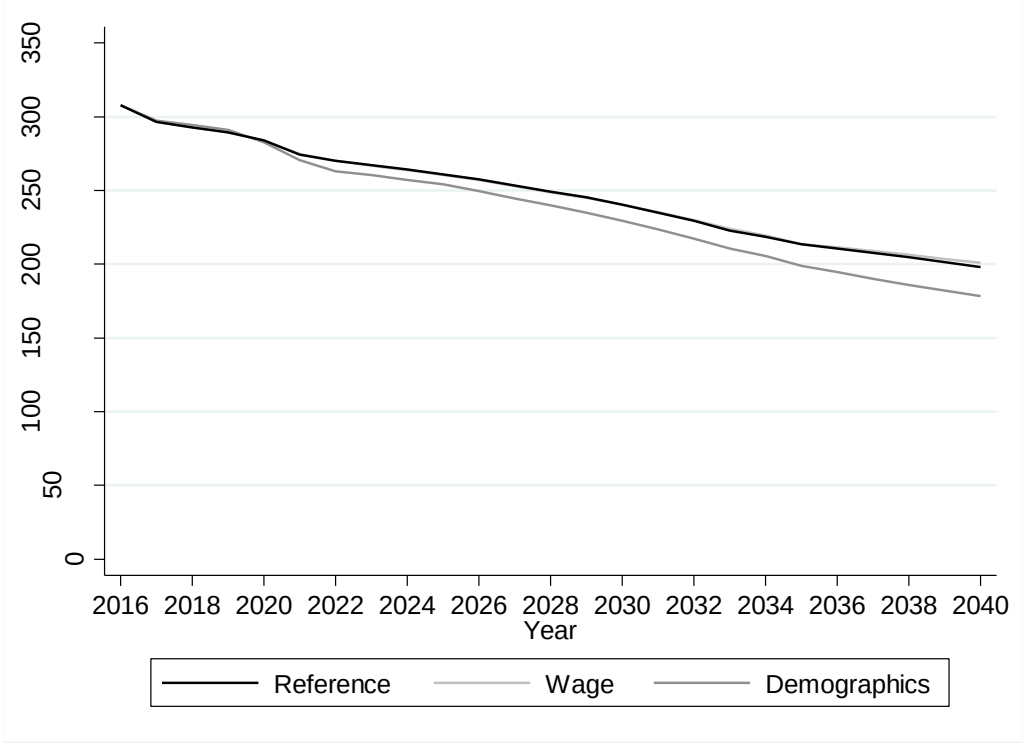

Figure 2 Number of Farms

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Table 4 shows the operational status of the region in each scenario. As already shown above with total numbers, there are slightly less farms operating in the Demographics scenario. However, there is a notable difference of percentage in reasons for closure between the Demographics and Reference scenario. There is a drop in the number of farms which closed due to opportunity costs at generational change. This indicates that even if there was a successor present in the Demographics scenario, many farms would still close due to the successor's opportunity costs.

Table 4 Status of farms in 2026 per scenario in %

	Reference	Wage	Demographics
Operating	82.3	82.1	79.5
Closed due to opportunity costs	9.5	9.8	9.8
Closed due to opportunity costs at generational change	3.5	3.5	0.6
Closed due to illiquidity	4.7	4.6	5
Closed due to lack of successor	-	-	5.1

Figure 3 shows the numbers of farms by size categories, where a small farm is under 100 hectares, a medium farm is anywhere from 100 up to 500 hectares, a large farm is 500 up to 1,000 hectares, and a very large farm is 1,000 hectares and more. Between the Reference and Wage scenarios there is no difference in the numbers of farms by size class. In comparison to the Reference scenario, in the Demographics scenario, we observe a decrease in the proportion of medium farms and a slight decrease in large farms. The decrease in the proportion of medium-sized farms is due to some of the profitable family farms, which would otherwise continue to operate, being forced to close because they do not have a successor. The slight decrease in the large farms can be accounted for in the slight increase in the very large farms, where farms in the large category have grown and moved up in size class. Interestingly, there is a slight increase in the number of small farms in the Demographics scenario which is likely due to the fact that otherwise competitive family farms in the medium size class are closing due to lack of successor. Their closures decrease the small farms' competition on the market, allowing the small farms to remain in operation in the Wage scenario.

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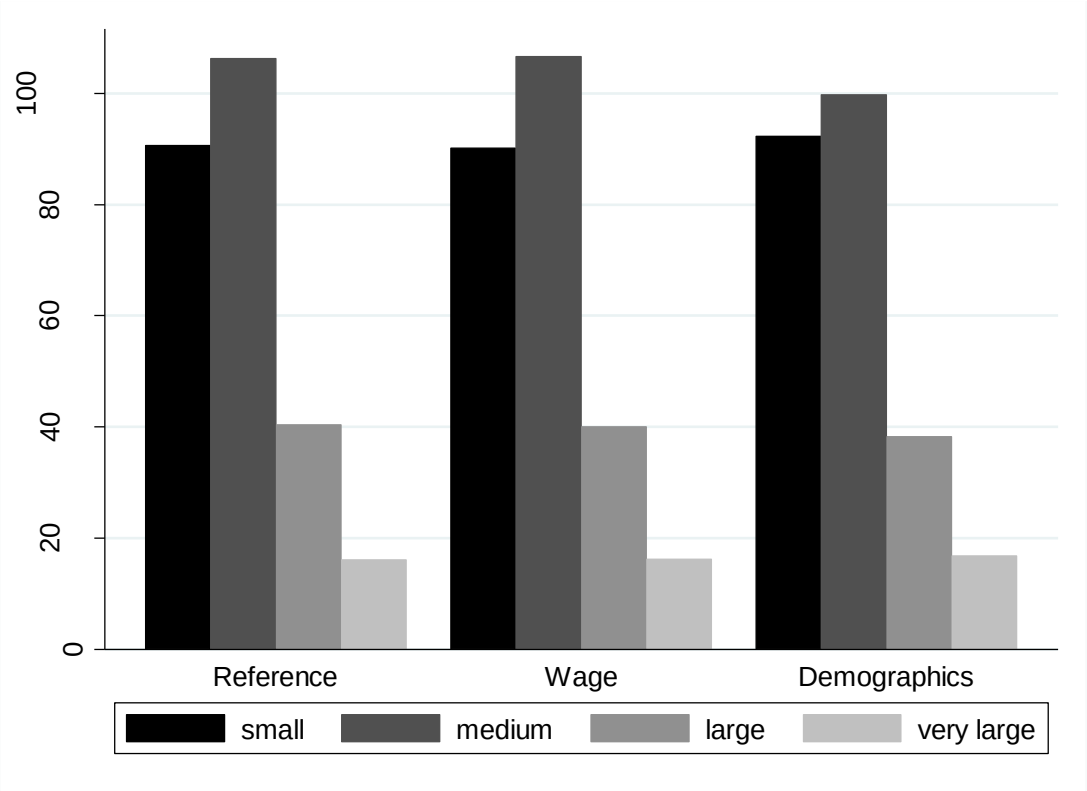

Figure 3 Number of farms per size class

6.2 Farm Labour

The figures 4 and 5show the scenarios and their effects on farm labour, which is the combined family and regional labour. In figure 4, for the first few years, there is no change in total farm labour used. However, beginning around year 2022, there is a clear departure of the Wage scenario from the Reference scenario. The more wages increase, the less labour farms are using. Despite there being fewer farms, in the Demographics scenario total farm labour remains close to the Reference scenario. This then translates to fewer workers per farm, seen in figure 5, in the Wage scenario, where the total number of farms remains the same as in the Reference scenario, and more workers per farm in the Demographics scenario, where there are fewer farms in the region but with the same labour requirements.

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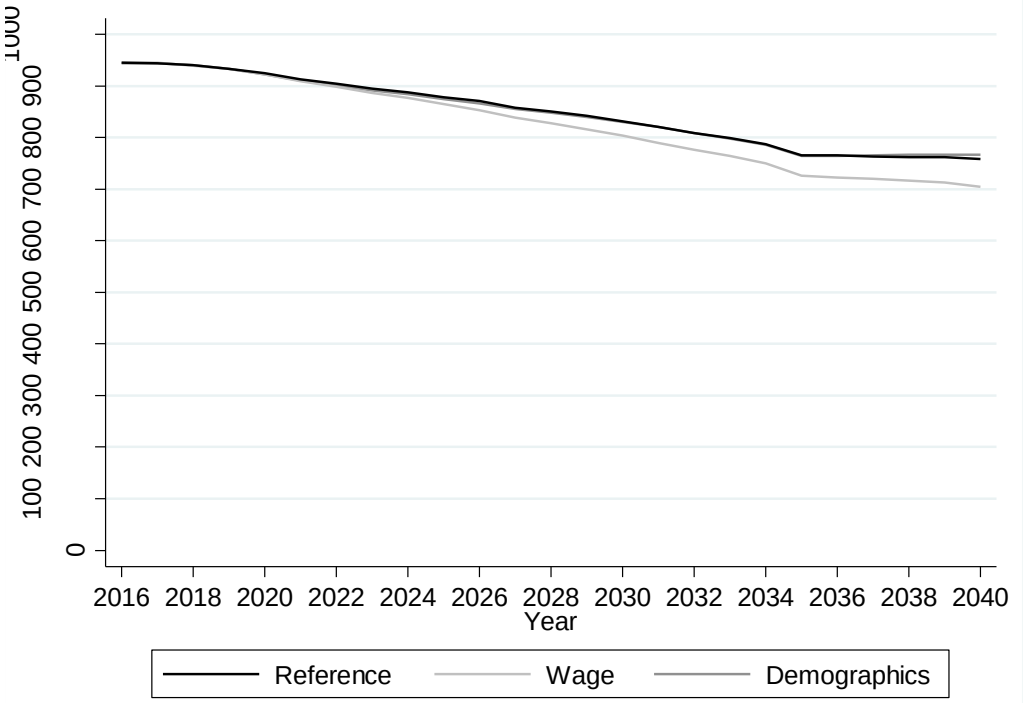

Figure 4 Total number of farm workers

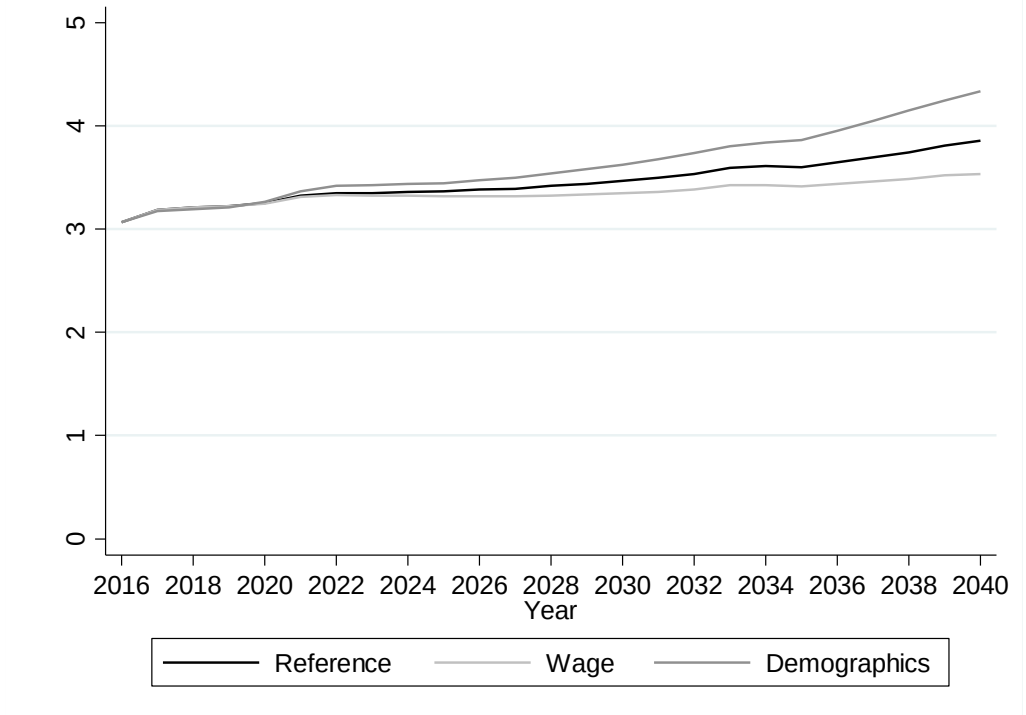

Figure 5 Number of workers per farm

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6.3 Farm Production

Figure 6 shows no differences between the Reference and Demographic scenarios but slight shifts in land use in the Wage scenario. In the Wage scenario farmers have slightly decreased their production. Upon investigating the data for the regional livestock production, the reason for the switch of land production is because in the Wage scenario, farmers are beginning to exit livestock production, which is labour-intensive. For that reason, we observe a drop in feed and increase in meadows.

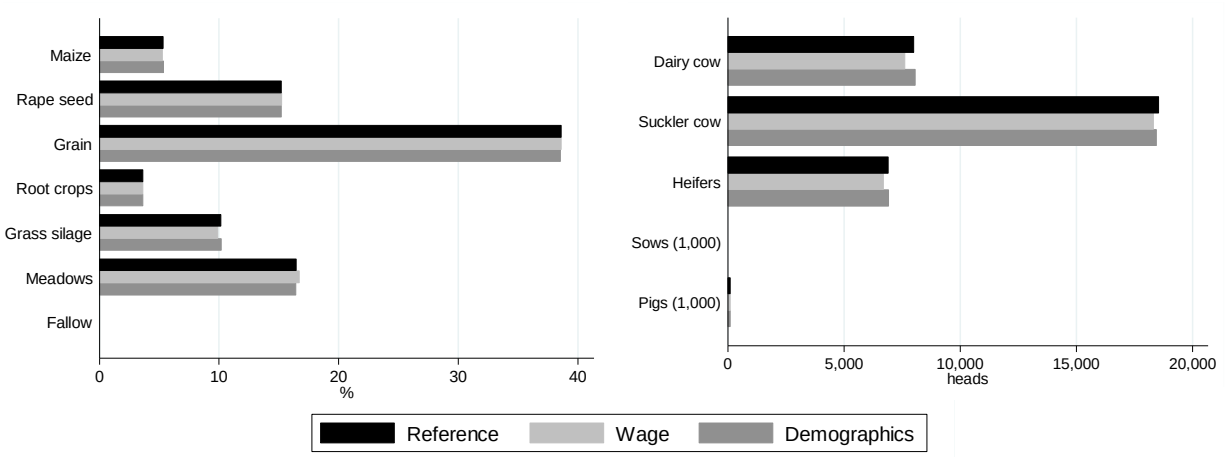

Figure 6 Land cultivation and livestock production in 2026

6.4 Land Market

The effects of farmers adapting their production are delayed hitting the land market, as seen in figure 7. As opposed to the changes in production and labour, which can be seen beginning around year 2022, effects on the land market are seen after 10 years. This is due to the long rental contracts. In the Altmark, rental contracts tend to be long-term, between 6 and 18 years. There is no observable difference between the Reference and Demographic scenario. In the Wage scenario, there is a slight downward departure away from the other scenarios in the price of arable land. For grassland, which can generate profits by labour-intensive livestock production, there is an earlier and more intense decrease in cost of land in the Wage scenario than in the other two scenarios. This can be explained by the AgriPoliS' land market operates, where bids are based on each farm's shadow price. So where farmers expect smaller returns in the Wage scenario due to the rising cost of labour, the effects are seen in their willingness to pay less on the land market.

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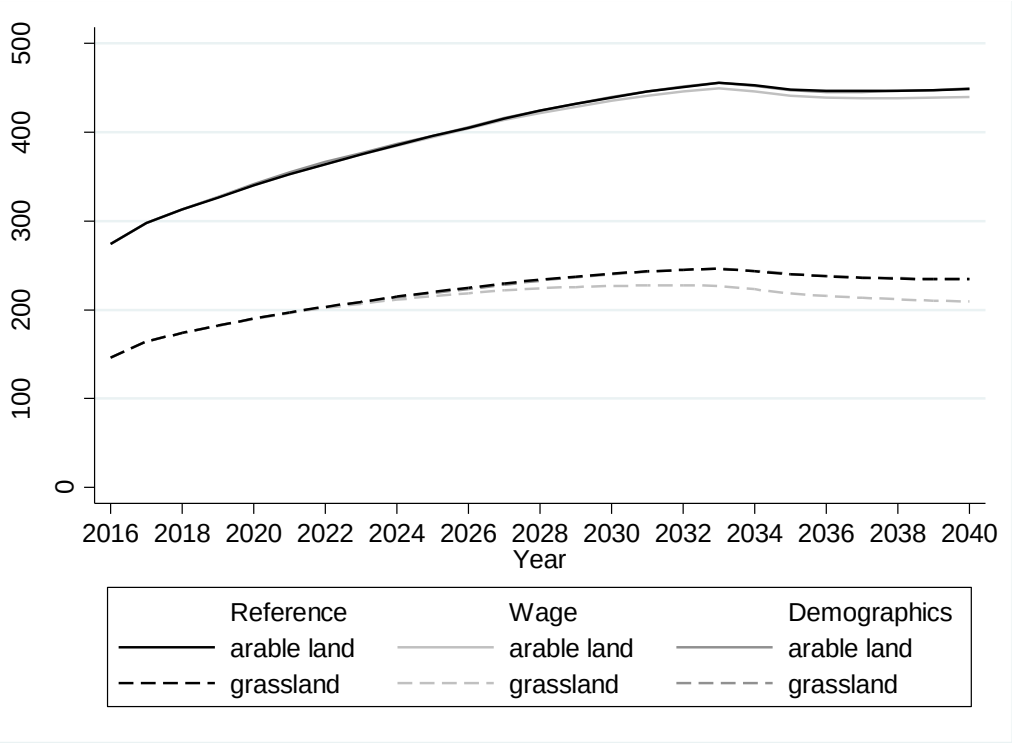

Figure 7 Rental prices for arable and grassland

7 Discussion and Conclusion

The main type of resilience capacity demonstrated in the Altmark's results is adaptability. Farms show the capacity to adapt in all three scenarios. In the Reference scenario, we observe structural change by the decreasing number and increasing size of farms. The farms which exit have either not adapted to the drivers of structural change, or chosen a "smart exit." Either way, the exit of the farms offers opportunities for the remaining farms to adapt by growing. This is also applicable to the Demographics scenario, where despite extra stress of 25% of family farms having no successor, the region maintains the same levels of production as in the Reference scenario; meaning the remaining farms adapt to the exits and the system is resilient.

In addition to the adaptations in the Reference and Demographics scenarios when farms exit, farmers in the Wage scenario must also adapt to the on-going stress of higher costs of labour. They do so by changing their production to be less labour-intensive. In this scenario we can also observe the region's robustness. For the first five years, the system is robust enough to maintain its outputs without changing production or labour use, demonstrating that it is fairly robust. An area of future research would be to simulate a more extreme wage increase, which can be expected the more extreme the labour shortage becomes. Such simulations will enable researchers to begin to capture the tipping points of the system.

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In terms of structural change, the result of farms not having a successor in the Demographics scenario does not have severe consequences on the region. Farms do grow in size, as the numbers shrink. However, the production levels remain consistent with those in the Reference scenario where there is 100% successor presence.

The results of these simulations also indicate shortcomings of the model and areas for improvement. First, there is limited room for agents to transform in the Altmark. This could be the result of one of two reasons. Either the possibilities for transformation have not been implemented into model as options for the agents. In which case more research is needed to implement regional transformational opportunities. Another reason for this could be that the scenarios we simulated did not put the farmers under enough stress which would tip them from adapting to transforming. For this reason, it would be necessary to simulate more extreme scenarios. The second shortcoming is that the model assumes an unlimited hired labour supply. The Demographics extension constrains the supply of the heads of the farm and the Wage simulation simulates the effects of a labour shortage, rising wages. However, to truly constrain the amount of hired labour, a labour market must be implemented. The pseudo-constrained labour simulation, where the cost of labour rose in the Wage scenario, demonstrated farmers' adaptability. In the case of a labour market, where hired labour is constrained, and therefore threatens to tip the system into dysfunction, there will be the potential to assess the transformability of the Altmark.

The simulations demonstrate that AgriPoliS is a tool which can be used to assess all the resilience capacities of farm regions with regard to the processes of structural change, and particularly to generational renewal. With AgriPoliS' extension, researchers are able to match characteristics of farm demographics which drive generational renewal. In the Altmark, the main difference between the Demographics and Reference scenarios was the decrease in the number of farms and increase in workers per farm. However, the effects will be interesting to observe in other farming regions with a more extreme distribution of farmers ages and successor likelihood. Researchers can calibrate AgriPoliS to new farming regions and begin to analyze effects of potential or existing generational renewal policies and measures.

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