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Building a Dynamic Spatial Microsimulation Model for Ireland

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ABSTRACT

Microsimulation describes economic and social events by modelling the behaviour of individual agents. These models have proved useful in evaluating the impact of policy changes at the micro-level. Spatial microsimulation models contain geographical information and allow for a regional or local approach to policy analysis. This paper builds on previous work on urban systems by employing similar modelling techniques for the analysis of rural areas. It describes the development of the SMILE (Simulation Model for the Irish Local Economy) model. SMILE is a dynamic spatial microsimulation model designed to analyse the impact of policy change and economic development on rural areas in Ireland. At its core, SMILE is a model of population. It simulates the basic components of population change, fertility, mortality and internal migration, at a small area level. This paper describes the method for projecting population change at the subcounty level. Results from the 1991 and 1996 dynamic model at county level are discussed, and a brief comparison is made with other methods. Finally, the features that distinguish microsimulation models from other population projection models are discussed.

INTRODUCTION

Irish economic growth in recent years has been accompanied by changes in the geographical and demographic landscape. The Dublin commutor belt has widened to contain nearly half of the country's population, while many rural areas have experienced population decline. The increase in employment opportunities has also reversed the traditional pattern of Irish emigration, with former emigrants returning and new immigrants arriving in Ireland. These changes have raised awareness of the need for methods of projecting population and labour force variables at subnational and subregional level. Macro- and micro-level methods can be used to project subnational population. Macro methods include cohort component applications, administrative record and housing counts, and regression techniques. Micro methods simulate demographic processes on individuals and households rather than on cohorts. This paper describes the development of a micro method for projecting small area population in Ireland.

National and regional population projections for Ireland are provided by the Central Statistics Office (CSO). The CSO uses a cohort component methodology applied to various fertility, mortality and international migration scenarios to project national population forward 30 years. Regional projections also contain assumptions about internal migration. Projections vary greatly depending on the assumptions used. For example, the national projections for total population in 2031 vary from 3.9 million to 4.7 million people depending on the combination of fertility, mortality and immigration assumptions (Central Statistics Office, 2001). Regional projections vary according to fertility, mortality and immigration assumptions, but also according to the assumptions made about internal migration and the regional distribution of international immigrants. For the Dublin region, the projections for 2031 vary from 1.4 million to 1.7 million under different fertility, mortality and migration assumptions (Central Statistics Office, 2001). County-level projections in Ireland are not available from official sources. Morganroth (2002) evaluated methods of producing county-level population projections, including cohort component, trend extrapolation, regression-based extrapolation and correlated indicators. Morganroth (2002) found that share trend extrapolation provides the best estimates based on 1991 to 1996 projections.

This paper describes the development of SMILE, an Irish dynamic spatial microsimulation model, designed to supplement macro models for population projection in Ireland by producing small area population estimates. Dynamic spatial microsimulation models create geographically referenced microdata and project them forward through time by simulating demographic processes. The paper focuses on describing the dynamic processes included in SMILE, and comparing the population projections from SMILE with other subnational projections. The following section reviews microsimulation techniques, briefly describes the SMILE static model and discusses the dynamic model in greater detail. Next we detail the results of the 1991–1996 dynamic simulation and compare the results with other population projections. Finally, we show the SMILE results for 2002 and compare them with preliminary Census of Population estimates.

SPATIAL MICROSIMULATION MODELS

Microsimulation describes economic and social events by modelling the behaviour of individual agents (Orcutt et al., 1986; Birkin and Clarke, 1995; Clarke, 1996). Microsimulation models are useful for evaluating the impact of policy change on individuals, households and firms. Creating a spatial microsimulation model by adding geographical information to micro-level data allows for a small area approach to policy analysis. These models are not solely for population projection, but dynamic spatial microsimulation models can be used to provide projections of population at the subnational level (Van Imhoff and Post, 1998; Vencatasawmy et al., 1999).

There are numerous examples of dynamic non-spatial and spatial microsimulation models. Non-spatial models include CORSIM in the US, DYNACAN in Canada, DYNAMOD in Australia, and LIFEMOD and PENSIM in the UK. CORSIM is a dynamic microsimulation model developed at Cornell University which is used to model the distribution of wealth in the US over the historical period 1960–1995, and to project its distribution into the future (Caldwell and Keister, 1996; Caldwell et al., 1998). DYNACAN is based on the CORSIM template and is used for fiscal and policy-oriented analysis of Canadian social security schemes (Caldwell and Morrison, 2000). In Australia, DYNAMOD is a dynamic model of population designed to project population characteristics over a 50-year period using a 1% population sample (King et al., 1999). LIFEMOD is a dynamic cohort microsimulation model, simulating the life histories of 2000 males and 2000 females (Falkingham and Lessof, 1992; Falkingham et al., 1995). The LIFEMOD model has been used to estimate the effects of the welfare state over the life-cycle of individuals and to estimate the degree to which income is redistributed among people over time or across the life-cycle (Falkingham and Hills, 1995a, b). It has also been used to investigate the options for financing higher education, the dynamics of lone parenthood, and the lifetime distribution of health needs and use of health services (Evandrou and Falkingham, 1995; Glennerster et al., 1995; Propper, 1995). PENSIM is a UK national dynamic microsimulation model that aims to study the influences of policy change on the income distribution of pensioners up to 2030 (Hancock et al., 1992). O'Donoghue (2001) provided an extensive survey of non-spatial microsimulation models.

Dynamic spatial microsimulation models rely heavily on the methods developed for nonspatial dynamic microsimulation models, but seek to address geographical questions. They have been developed in many countries including Australia, the Netherlands, the UK and Sweden. NATSEM (National Centre for Social and Economic Modelling) at the University of

Canberra in Australia, the group which developed DYNAMOD, is developing a spatial microsimulation model to examine issues such as poverty and ageing in a spatial context (Harding, 2002). In particular, a regional microsimulation model has been developed in conjunction with Centrelink, the agency responsible for administering social benefit payments, to project regional demographics and likely use patterns for Centrelink services (King et al., 2002). Hooimeijer (1996) described work in the Netherlands that adopted a spatial microsimulation approach to analyse the linkages between supply and demand in the housing market and labour market simultaneously, using a life-course approach to the behaviour of households. Another example from the Netherlands is RAMBLAS, a regional planning model for the Eindhoven region in the Netherlands based on the microsimulation of daily activity patterns (Veldhuisen et al., 2000). In the model, daily activity patterns are used as a basis for predicting the spatial distribution of the demand for various transport services in the urban system.

Models in Sweden and the UK are of particular relevance to SMILE. TOPSIM (Total Population Simulation Models) and SVERIGE (System for Visualising Economic and Regional Influences Governing the Environment) are relevant because, like SMILE, they are national-level comprehensive dynamic spatial microsimulation models (Holm et al., 1996; Vencatasawmy et al., 1999). These models were built at the Spatial Modelling Centre in Kiruna and are based on the CORSIM template adapted for the small area microdata available in Sweden (Holm et al., 1996; Vencatasawmy et al., 1999; Swan, 2000). SVERIGE is the first national-level spatial microsimulation model and is based on a longitudinal database of socio-economic information on every resident of Sweden between 1985 and 1995. It is aimed at studying the spatial consequences of various national, regional and local public policies. The SVERIGE database contains coordinates accurate to 100 metres for each resident in Sweden, along with various social, economic and demographic characteristics (Vencatasawmy et al., 1999). SVERIGE is designed to generate geographically detailed reports for policy-makers and regional scientists.

SMILE, although national in coverage like SVERIGE, is based on a template similar to spatial microsimulation models in the UK including SimYork and SimLeeds. SimYork is a prototype model for a dynamic spatial microsimulation model for Britain (Ballas et al., 2002, 2005). SimYork uses different techniques to SMILE but, like SMILE, its aim is national coverage. The model adopts a reweighting methodology to re-adjust the weights of a survey so that they fit census small area statistics data. It also uses data from the last three Censuses of the UK population in order to project small area socioeconomic and demographic data into 2021. It then reweights household records from the British Household Panel Survey (BHPS) so that they fit actual and simulated small area statistics tables (Ballas et al., 2002, 2005). The SimLeeds model, developed at the University of Leeds, is a spatial microsimulation model that has been used to explore the potential spatial impact of a factory closure in Leeds at ward level, and to estimate the geographical impact of other national social policies (Ballas, 2001; Ballas and Clarke, 2001a, b; Ballas et al., 2003a,b). The SMILE model presented here is based on the SimLeeds framework. However, SMILE adds a dynamic dimension to the SimLeeds framework by modelling demographic processes explicitly at the micro-level.

This paper draws on international literature for micro-level projections and describes the development of an Irish dynamic spatial microsimulation model to supplement macrolevel population projections in Ireland. The task is complicated by the data available in Ireland; like many countries, Ireland does not have a dataset such as that used by the Spatial Modelling Centre in Kiruna, Sweden to develop SVERIGE. The task of generating and updating small area population data without such a dataset is a huge challenge. The following section describes how this challenge was met in Ireland.

SMILE MODEL

SMILE is a static and dynamic population, spatial microsimulation model. It is constructed using the Census of Population Small Area Population Statistics (SAPS). It contains two processes. Firstly, the static process creates the base population at District Electoral Division (DED) level and assigns census attributes to individuals. Secondly, the dynamic process ages the population by evaluating individuals for fertility, mortality and migration.

Static Model

The static spatial microsimulation procedure constructs a micro-level population for small areas. The static process uses an approach based on Iterative Proportional Fitting (IPF) to create small area microdata. IPF is a mathematical scaling procedure that ensures that a twodimensional table of data is adjusted so that its row and column totals agree with row and column totals from alternative sources (Norman, 1999). In geography it can be used as a procedure for generating disaggregated spatial data from spatially aggregated data (Fienberg, 1970; Birkin, 1987; Wong, 1992; Clarke, 1996; Williamson et al., 1996; Ballas et al., 1999; Norman, 1999; Ballas and Clarke, 2000).

The IPF methodology can be combined with spatial microsimulation techniques for the derivation of conditional probabilities which can be used to build spatially disaggregated microdata. Let us assume that we wish to study the relationship between gender (G), age (A), employment status (ES) and industry (IND) for a given population group x in location i. From the 1996 Census of Population Small Area Population Statistics (SAPS) we can obtain tabulations of the following characteristics for the population in a specified District Electoral Division (DED): gender by marital status by employment status (SAPS table 6); gender by 5-year age groups by marital status (SAPS table 2); and industry by employment status by gender (SAPS table 7). From these tabulations we could calculate the conditional probabilities $p_{x,i}(G,MS,ES)$, $p_{x,i}(G,A,MS)$ and $p_{x,i}(IND,ES,G)$. The IPF procedure is one method of using the known conditional probabilities to estimate the probability $p_{x,i}(G,MS,A,ES,IND)$ (Fienberg, 1970; Birkin, 1987; Wong, 1992; Clarke, 1996; Williamson *et al.*, 1996; Ballas *et al.*, 1999; Norman, 1999; Ballas and Clarke, 2000).

Once the joint probability is estimated using the IPF procedure, Monte Carlo sampling can be used to assign age, gender, marital status and employment status attributes to each individual in a DED. The procedure results in a synthetic population for each DED in Ireland where the simulated individuals have age, gender, marital status, employment status and industry attributes. The static SMILE model uses a similar method to estimate further attributes using known conditional probabilities. Among these are the census variables of occupation, education and social class. Alternative methodologies include combinatorial optimisation, where survey data are reweighted to fit small area population data. In Ireland, this approach would involve reweighting household or individual microdata available from the Irish Labour Force Survey, the Household Budget Survey or the European Community Household Panel Survey to obtain spatially disaggregated microdata (Williamson *et al*., 1998; Ballas *et al*., 1999; Ballas and Clarke, 2000).

Dynamic Model

The output of the static microsimulation model provides the input for the dynamic microsimulation model. The dynamic model projects the static population forward through time by simulating the processes of mortality, fertility and internal migration.

Mortality

We assume that the probability of an individual surviving for the five-year simulation period is a function of age, gender and location. Table 1 shows a stylised version of the dynamic microsimulation procedure adopted by the SMILE model and details the method by which mortality is assessed. The first synthetic household in Table 1 has the following characteristics: male, aged 25, single, at work and living in the first District Electoral Division (DED) of Leitrim County. As shown in Table 1, the estimated probability that an individual with these characteristics will survive in the period is 0.80. The next step in the procedure is to generate a random number to see if the synthetic individual is estimated to survive. The random number in this example is 0.5 and falls within the 0.001–0.80 range needed to survive.

Table 1. A simple example of the microsimulation procedure for mortality

Steps	1st	2nd	…	Last
Age, sex and marital status, employment status and location (DED level) (given)	Age: 25 Sex: Male Marital Status: Single Employment Status: At work GeoCode: Leitrim Co., DED 001 Ballinamore	Age: 76 Sex: Female Marital Status: Married Employment Status: Other (e.g. Retired) GeoCode: Leitrim Co., DED 002 Cloverhill	…	Age: 30 Sex: Male Marital Status: Married Employment Status: At work GeoCode: Leitrim Co., DED 078 Rowan
Probability (conditional on sex, age and county location) of survival	0.80	.10	…	0.80
Random number	0.5	.9	…	0.6
Mortality outcome	Alive	Dead	…	Alive

Mortality probabilities are derived from the 1991 Report on Vital Statistics in Ireland, which details the number of deaths by age, gender and county location (Central Statistics Office, 1991). We use data from the 1991 Census to calculate the populations at risk (PAR) of dying and divide the number of deaths in each county by the respective population at risk. Because of the small numbers of deaths in some age categories, counties were clustered together to reduce the variation among locations. Counties were clustered according to the 'functional areas' classified in the National Spatial Strategy (NSS), a policy document redefining the Irish concept of regions and outlining a plan for achieving balanced regional development. Functional areas 'are areas that tend to share common characteristics and issues, where people live their working, schooling, shopping and leisure lives, and with which many can identify' (Department of the Environment, Heritage and Local Government, 2001). Each individual in the database is evaluated every year in the simulation period for survival on the basis of random sampling from the respective mortality probabilities. The mortality rates used in the paper are reported in the Appendix (Tables A1 and A2).

The assumptions used to model mortality do not account for all of the factors known to influence survival. There is evidence that mortality is associated with the quality of life of individuals (Dorling, 1997; Mitchel *et al*., 2002). Mitchel *et al*. (2000) pointed out that age, gender, social class and employment status play a very important role in producing geographical inequalities in mortality. However, in the context of the research presented here we only used age- and locationspecific mortality rates. Data availability was the primary factor governing our assumptions; however, mortality rates could be adjusted for different socio-economic groups. We also assume that the mortality rate for individuals over 85 years of age is constant because of data availability.

Fertility

In the SMILE model, fertility, like mortality, is based on location. Fertility is assumed to be a function of age, marital status and location. Births are modelled using five-year age group and marital status data available for each county from the 1991 Report on Vital Statistics. As in the mortality process, PARs are calculated from the 1991 Census of Population, and counties are grouped according to the functional areas defined by the NSS. The grouping is particularly important for the youngest and oldest cohorts of women in any simulation to mitigate problems of sample size. For example, there were only two married women under the age of 20 who gave birth in County Leitrim in 1991. Grouping counties together helps to solve problems of small numbers while preserving spatial differentiation. Table 2 shows the fertility rates used.

Table 2. Fertility (number of births per hundred of PAR) by age and grouped county location, 1991 (calculated on the basis of the basis of Irish Census data as well as Vital Statistics data reported in CSO, 1991: 222-3).

Age	15-19	20-24	25-29	30-34	35-39	40-44	45+
Meath, Kildare, Wicklow, Dublin Co. Borough	37.69	26.89	21.57	15.09	7.16	1.52	0.02
Dublin Belgard	21.21	28.44	20.43	14.31	6.05	1.46	0.03
Dublin Fingal	71.43	25.34	21.96	15.97	7.33	1.30	0.00
Dun Laoghaire	23.53	26.77	22.95	18.23	8.05	1.58	0.01
Louth, Monaghan, Cavan	40.54	25.63	21.66	14.14	6.71	1.65	0.03
Longford, Westmeath, Offaly, Roscommon	44.62	27.54	22.36	15.31	7.67	2.16	0.03
Sligo, Leitrim	50.00	25.70	25.00	17.63	8.47	2.81	0.01
Donegal	52.83	27.30	22.73	14.82	7.63	2.16	0.10
Mayo	53.33	33.72	23.77	17.09	9.55	2.82	0.03
Galway County	41.67	33.76	25.85	18.77	8.99	2.03	0.05
Galway City	23.08	30.36	16.15	14.04	6.37	0.93	0.00
Limerick, North Tipperary, Clare	56.25	25.85	23.47	16.06	7.74	1.68	0.04
Limerick City	31.82	31.92	19.30	12.80	5.56	1.52	0.00
Kerry	71.43	30.37	21.86	15.05	7.80	1.83	0.03
Cork	53.85	27.25	23.98	17.54	7.88	1.66	0.04
Cork City	37.50	21.26	18.06	13.84	5.88	1.21	0.01
Waterford, Wexford, South Tipperary	54.72	31.46	25.09	16.07	7.63	2.31	0.04
Carlow, Kilkenny, Laois	39.02	25.03	22.04	14.25	7.49	1.68	0.04
Waterford City	36.36	19.82	15.73	10.01	4.38	1.23	0.00

Every synthetic female in the database is tested for eligibility to give birth. Monte Carlo sampling against the fertility probabilities is used to determine which females give birth. If a birth is deemed to occur, the model creates a new individual. The new individual's attributes are set as follows: age is zero, sex is determined probabilistically (50% probability of each sex), marital status is single, social class and location are that of the mother, and all other attributes are left blank. In the next simulation period, the new individual is simulated along with the other individuals in the location. Data availability constrained our choices in modelling fertility, so variables such as socio-economic status and number of previous children were excluded even though they impact on fertility (Clarke, 1986; Duley *et al*., 1988; Duley, 1989).

Internal Migration

Spatial microsimulation provides an ideal basis for modelling spatial transitions such as migration. In particular, the propensity to migrate is heavily dependent on household and individual attributes, and therefore a micro-level approach may be used to model migration for different types of individuals (Rogerson and Plane, 1998). In SMILE, migration is modelled on the basis of random sampling from calculated migration probabilities derived from the 1991 and 1996 Census of Population data at county level. Probabilities of migrating from one county to another are calculated by age, gender and county location. Every individual in the database is assessed for migration using Monte Carlo sampling. The individuals that are assigned migrant status are allocated to a DED within the new county on the basis of its population size. The probability of a migrant moving to a particular DED is determined by the share of the county population currently residing in the DED. Areas with the biggest populations have the highest probability of attracting migrants. The internal migration modelling capability of SMILE could be enhanced with the incorporation of more sophisticated procedures such as spatial interaction modelling methods (Fotheringham *et al*., 2001; Nakaya, 2003; Nakaya *et al*., 2003).

Immigration is not modelled because of the lack of data. Because SMILE is a micro-level model, including international immigration would involve estimating three things: the number of immigrants and emigrants; the DED location of each immigrant and emigrant; and the individual attributes of immigrants and emigrants. Estimating the number of immigrants and emigrants could be achieved by using the net immigration scenarios produced by the CSO for their population projections. However, estimating the DED location of these individuals and their individual attributes would require more data than is currently available.

1996 RESULTS

The 1991 SMILE dynamic model uses data from the 1991 static model and ages the population forward to 1996 by simulating the demographic transitions described in the previous section. This section shows the results of the 1991 dynamic model at DED level. Results are then aggregated to county level and compared with other countylevel population projections. The results of the 1991 dynamic model are compared with the 1996 Census of Population at DED level, and the absolute percentage error for each DED is calculated. In addition to calculating the absolute percentage error, the number of over- and under-estimated DEDs are calculated along with the percentage of DEDs with deviations over 10% and the mean absolute percentage error. Figure 1 shows the absolute percentage error by DED in 1996.

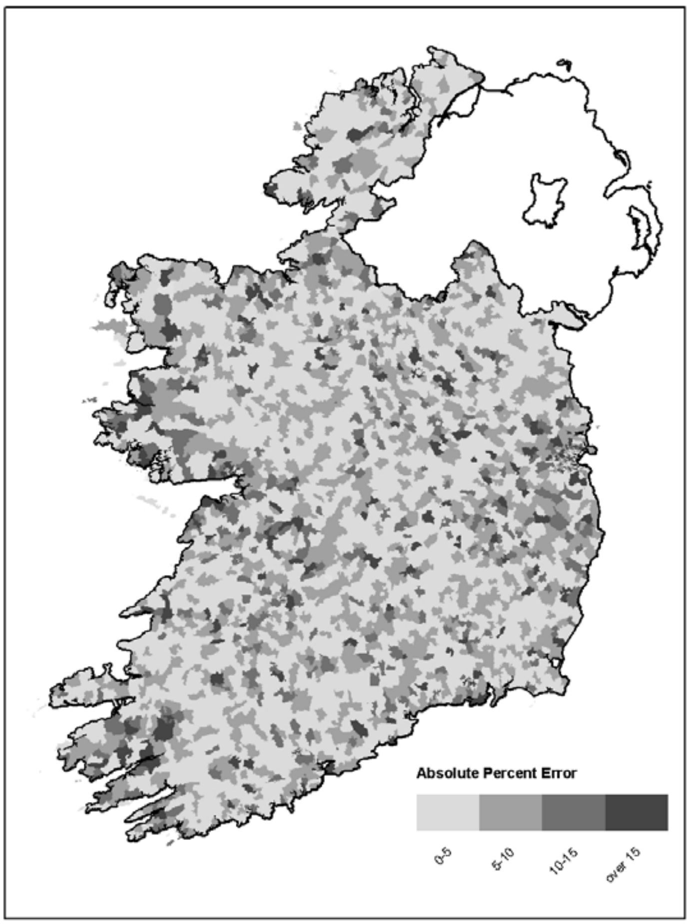

Figure 1. Absolute Percent Error by DED, 1996.
Source: SMILE model

Table 3. County level SMILE population projections and actual population, 1996. (Source: SMILE model and Irish Census of population)

County	1996 SMILE Estimate	1996 Actual Population	Error	Percent Error	Absolute Percent Error
Carlow	42,097	41,616	481	1.16%	1.16%
Dublin	1,067,556	1,058,264	9,292	0.88%	0.88%
Kildare	132,106	134,992	-2,886	-2.14%	2.14%
Kilkenny	73,999	75,336	-1,337	-1.77%	1.77%
Laoighis	51,720	52,945	-1,225	-2.31%	2.31%
Longford	29,138	30,166	-1,028	-3.41%	3.41%
Louth	91,710	92,166	-456	-0.49%	0.49%
Meath	108,418	109,732	-1,314	-1.20%	1.20%
Offaly	56,641	59,117	-2,476	-4.19%	4.19%
Westmeath	61,423	63,314	-1,891	-2.99%	2.99%
Wexford	100,603	104,371	-3,768	-3.61%	3.61%
Wicklow	101,309	102,683	-1,374	-1.34%	1.34%
Clare	90,042	94,006	-3,964	-4.22%	4.22%
Cork	411,496	420,510	-9,014	-2.14%	2.14%
Kerry	119,260	126,130	-6,870	-5.45%	5.45%
Limerick	164,173	165,042	-869	-0.53%	0.53%
Tipperary N.R.	55,784	58,021	-2,237	-3.86%	3.86%
Tipperary S.R.	72,890	75,514	-2,624	-3.47%	3.47%
Waterford	92,941	94,680	-1,739	-1.84%	1.84%
Galway	184,384	188,854	-4,470	-2.37%	2.37%
Leitrim	23,909	25,057	-1,148	-4.58%	4.58%
Mayo	105,711	111,524	-5,813	-5.21%	5.21%
Roscommon	49,724	51,975	-2,251	-4.33%	4.33%
Sligo	53,958	55,821	-1,863	-3.34%	3.34%
Cavan	51,574	52,944	-1,370	-2.59%	2.59%
Donegal	128,829	129,994	-1,165	-0.90%	0.90%
Monaghan	50,249	51,313	-1,064	-2.07%	2.07%
State	3,571,644	3,626,087	-54,443	-1.50%	1.50%

The map shows that most of the DEDs have an absolute error below 10%. Nineteen per cent of DEDs have an absolute error over 10%; many of these are located in the greater Dublin area (GDA). Fifty-seven per cent of DEDs are underestimated, and 43% are overestimated. The mean absolute percentage error for all DEDs is 6.4%.

Other projections at DED level are not available for comparison. To compare our results with other methods, we aggregate the DEDs to county level and compare them with the methods estimated by Morganroth (2002). Table 3 shows the 1996 estimated and actual population at county level along with the error, the percentage error and the absolute percentage error. The population of the state is underestimated by 1.5%. The highest error, 5.45%, is in County Kerry. Twentyfive of 27 counties are underestimated. The mean absolute percentage error at county level is 2.68%.

Morganroth (2002) finds that the most accurate population projection method for 1996 is the trend share extrapolation method applied to the 1988 M1F1 migration/fertility scenario produced by the CSO. This method results in 14 counties under-projected, zero projections with an absolute percentage error over 10%, a largest error of 2.96%, and a mean absolute error of 0.87%. The other trend share extrapolation methods, based on 1988 M2F1, 1998 M2F1, 1998 M3F1, 1995 M1F1 and 1995 M1F2 assumptions, do not perform as well. They had between 24 and 27 counties underpredicted, a largest deviation of between 3.82% and 8.59%, and a mean absolute error of between 1.33% and 6.16%. The SMILE estimates are better than the 1988 M2F1 and 1998 M3F1 scenarios.

The regression share technique performs similarly to the trend-extrapolation method, with the 1988 M1F1 scenario producing the best results. Again, SMILE outperforms the regression share technique on the 1988 M2F1 and 1988 M3F1 scenarios. The cohort component method does not perform as well as the SMILE model, the trend share extrapolation method or the regression share method.

These results show that while the share extrapolation methods can produce good results, they rely heavily on the accuracy of CSO national projections. A comparison of the trend share extrapolation methods and the regression share method reveals that the worst-performing projections use the same national CSO projections, 1988 M2F1 and 1988 M3F1. The share extrapolation method does not provide a way to determine which CSO projections will be the most accurate. The only method that does not rely on national CSO projections is the cohort component model; SMILE outperforms this model. The SMILE model estimates are not as accurate as the best estimates produced by share extrapolation. However, the SMILE model has several advantages over the share extrapolation method. Firstly, it simulates the demographic processes that influence county-level population explicitly. Secondly, it provides much more detail than the share extrapolation method because it produces microdata along with population estimates that can be aggregated to any geographical area above DED level. Finally, it does not rely on the accuracy of national CSO projections.

2002 RESULTS

This section details the SMILE model projections between 1996 and 2002. SMILE results are compared with the preliminary results of the Census of Population of Ireland, conducted in April 2002. An accounting procedure is applied to the county-level SMILE estimates to account for net immigration, a process not included in SMILE. SMILE estimates for 1996 were not adjusted for net immigration because it was not a significant factor in population change between 1991 and 1996, but in the period between 1996 and 2002 Ireland experienced net immigration of 153,067. The counties with the largest number of immigrants were Cork, Galway and Dublin along with its surrounding counties. The border counties of Monaghan and Longford received the fewest immigrants, but every county had positive net immigration. The period between 1996 and 2002 is the first census period in which average annual net immigration exceeded average annual natural increase (Central Statistics Office, 2002).

The SMILE results were adjusted to account for the change in the significance of net immigration by adding estimated national and county-level net migration figures from the CSO to the SMILE county estimates. Before adjusting the figures for net immigration, the SMILE model had 25 underestimated counties, a largest absolute error of 11.32%, five deviations above 10%, an absolute percentage error of 3.5% and a mean absolute percentage error of 6.22%. Table 4 shows the county-level SMILE estimates and the results of the 2002 preliminary Census of Population estimates after adjusting for net immigration.

For 2002, 18 counties are underestimated, the largest absolute deviation being in Tipperary N.R. at 8.22%; there are no deviations above 10%, the absolute percentage error for the state is 0.39%, and the mean absolute percentage error is 3%. Figure 2 maps the results and shows that counties surrounding Dublin tend to be overestimated, indicating that the natural rate of increase in Dublin suburbs is lower than the rates used in the SMILE model or that inter-county migration into the Dublin area is overestimated.

CONCLUSION

In this paper, we have described the SMILE model and outlined its results compared with the 1996 and 2002 Census of Population results and the results of other methods of subnational population projection. SMILE does not take population simulation as its sole purpose, but we have found that its subnational population projections are consistent with those of models only designed to project population. In addition to providing county-level population projections,

Table 4. Actual and projected population by county, 2002 (Source: SMILE model and Irish Census of population)

County	2002 SMILE Estimate + Net immigration	2002 Actual Population	Error	Percent Error	Absolute Percent Error
Carlow	47024	45,845	1,179	2.57%	2.57%
Dublin	1151252	1,122,600	28,652	2.55%	2.55%
Kildare	172549	163,995	8,554	5.22%	5.22%
Kilkenny	78983	80,421	-1,438	-1.79%	1.79%
Laoighis	57151	58,732	-1,581	-2.69%	2.69%
Longford	30025	31,127	-1,102	-3.54%	3.54%
Louth	102462	101,802	660	0.65%	0.65%
Meath	137705	133,936	3,769	2.81%	2.81%
Offaly	60411	63,702	-3,291	-5.17%	5.17%
Westmeath	69930	72,027	-2,097	-2.91%	2.91%
Wexford	114111	116,543	-2,432	-2.09%	2.09%
Wicklow	113808	114,719	-911	-0.79%	0.79%
Clare	97943	103,333	-5,390	-5.22%	5.22%
Cork	446215	448,181	-1,966	-0.44%	0.44%
Kerry	128267	132,424	-4,157	-3.14%	3.14%
Limerick	184651	175,529	9,122	5.20%	5.20%
Tipperary N.R.	56047	61,068	-5,021	-8.22%	8.22%
Tipperary S.R.	79875	79,213	662	0.84%	0.84%
Waterford	103578	101,518	2,060	2.03%	2.03%
Galway	211479	208,826	2,653	1.27%	1.27%
Leitrim	24250	25,815	-1,565	-6.06%	6.06%
Mayo	113186	117,428	-4,242	-3.61%	3.61%
Roscommon	51734	53,803	-2,069	-3.85%	3.85%
Sligo	58168	58,178	-10	-0.02%	0.02%
Cavan	53186	56,416	-3,230	-5.73%	5.73%
Donegal	137183	137,383	-200	-0.15%	0.15%
Monaghan	51462	52,772	-1,310	-2.48%	2.48%

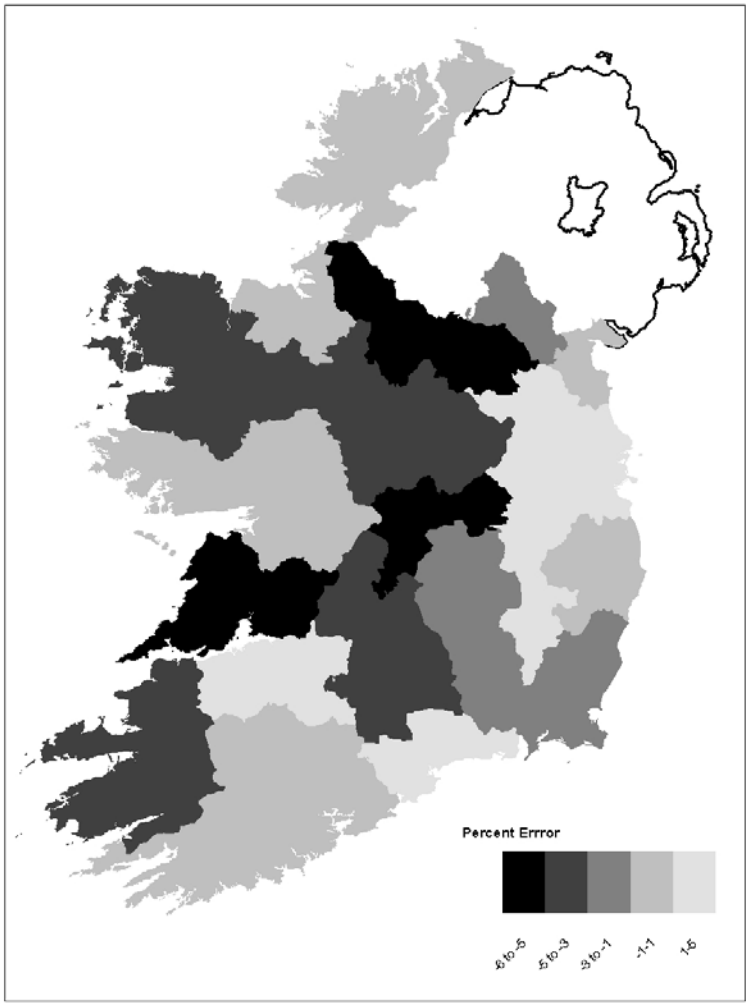

Figure 2. Estimated percent error in county population, 2002
Source: SMILE model

SMILE has the advantage of providing spatially disaggregated microdata that can be aggregated to any geographical scale, and the ability to maintain and produce consistent heterogeneity in several dimensions simultaneously. Among the innovative features of the modelling work presented here is the simulation of fertility, mortality and migration at the geographical level of District Electoral Division on the basis of census data, migration interaction data, and fertility and mortality data. Further, microsimulation models provide the enabling environment for a detailed assessment of ‘what-if’ questions related to changed conditions for specific groups (Ballas and Clarke, 2001b). Our future work aims to extend SMILE to simulate labour force characteristics dynamically along with the demographic processes already included.

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APPENDIX

Table A1. Mortality rates (number of deaths per hundred of PAR) for males by age and grouped county location, 1991(calculated on the basis of the basis of Irish Census data as well as data reported in CSO, 1991: 72)

	Males																	
Age	**0 - 4**	**5 - 9**	**10 - 14**	**15 - 19**	**20 - 24**	**25 - 29**	**30 – 34**	**35 - 39**	**40 – 44**	**45 – 49**	**50 - 54**	**55 - 59**	**60 - 64**	**65 - 69**	**70 - 74**	**75 - 79**	**80 - 84**	**85+**
Meath, Kildare, Wicklow, Dublin Co. Borough	0.21	0.01	0.02	0.06	0.09	0.10	0.14	0.15	0.20	0.44	0.65	1.21	2.37	3.62	5.50	9.19	12.77	22.50
Dublin Belgard	0.15	0.02	0.04	0.08	0.14	0.16	0.15	0.10	0.16	0.35	0.45	0.91	1.10	2.33	4.42	6.10	10.27	22.97
Dublin Fingal	0.13	0.05	0.02	0.05	0.10	0.08	0.08	0.07	0.20	0.22	0.41	1.01	1.61	2.89	3.51	6.12	10.54	20.57
Dun Laoghaire	0.34	0.00	0.00	0.05	0.11	0.08	0.09	0.08	0.19	0.25	0.49	0.75	1.71	2.92	4.91	7.51	11.42	20.19
Louth, Monaghan, Cavan	0.17	0.01	0.03	0.10	0.16	0.20	0.09	0.07	0.22	0.29	0.80	0.92	1.99	3.40	5.94	8.95	14.58	25.41
Longford, Westmeath, Offaly, Roscommon	0.07	0.01	0.03	0.11	0.16	0.11	0.04	0.17	0.06	0.53	0.57	1.12	2.27	3.34	5.63	7.70	12.83	24.13
Sligo, Leitrim	0.24	0.00	0.00	0.06	0.25	0.23	0.30	0.15	0.15	0.41	0.37	1.48	2.70	2.89	5.83	8.70	15.46	22.83
Donegal	0.29	0.00	0.03	0.00	0.12	0.16	0.10	0.13	0.10	0.33	0.67	1.08	1.64	3.10	4.24	7.57	13.97	28.25
Mayo	0.11	0.05	0.00	0.06	0.14	0.04	0.09	0.11	0.24	0.50	0.56	0.92	1.57	3.01	5.08	9.00	15.76	22.37
Galway County	0.19	0.10	0.01	0.11	0.05	0.19	0.14	0.25	0.20	0.49	0.60	0.94	1.70	2.64	4.45	8.11	12.26	25.10
Galway City	0.16	0.00	0.00	0.00	0.07	0.21	0.28	0.19	0.14	0.08	0.50	1.41	1.30	2.78	4.22	5.23	10.34	9.01
Limerick, North Tipperary, Clare	0.23	0.01	0.06	0.05	0.16	0.05	0.14	0.20	0.21	0.31	0.68	1.29	1.92	2.74	6.20	8.60	13.63	25.04
Limerick City	0.41	0.00	0.00	0.14	0.08	0.15	0.23	0.33	0.33	0.08	1.11	1.71	2.64	4.02	5.32	10.20	14.88	18.00
Kerry	0.11	0.00	0.02	0.16	0.08	0.08	0.05	0.14	0.29	0.32	0.65	1.31	2.43	3.29	5.65	9.28	12.74	23.39
Cork	0.18	0.02	0.04	0.11	0.12	0.11	0.06	0.16	0.15	0.44	0.58	1.36	2.59	3.66	5.89	8.85	14.35	24.37
Cork City	0.16	0.04	0.02	0.05	0.08	0.10	0.22	0.16	0.20	0.40	0.35	0.97	1.49	3.55	5.53	9.58	13.22	25.82
Waterford, Wexford, South Tipperary	0.27	0.03	0.05	0.09	0.15	0.15	0.10	0.20	0.23	0.32	0.43	1.01	1.77	3.30	5.88	9.57	10.91	23.54
Carlow, Kilkenny, Laois	0.18	0.05	0.02	0.11	0.13	0.11	0.15	0.14	0.30	0.33	0.38	1.35	1.66	3.56	5.11	7.67	13.03	23.33
Waterford City	0.19	0.06	0.00	0.10	0.11	0.13	0.00	0.16	0.00	0.36	0.52	1.03	1.94	4.34	5.34	6.14	17.48	21.43

Table A2. Mortality rates (number of deaths per hundred of PAR) for females by age and grouped county location, 1991 (calculated on the basis of the basis of Irish Census data as well as data reported in CSO, 1991: 72)

	Females																	
Age	**0 - 4**	**5 - 9**	**10 - 14**	**15 - 19**	**20 - 24**	**25 - 29**	**30 – 34**	**35 - 39**	**40 – 44**	**45 - 49**	**50 - 54**	**55 - 59**	**60 - 64**	**65 - 69**	**70 - 74**	**75 - 79**	**80 - 84**	**85+**
Meath, Kildare, Wicklow, Dublin Co. Borough	0.16	0.01	0.02	0.02	0.03	0.04	0.07	0.10	0.16	0.24	0.36	0.68	1.16	2.07	3.20	5.77	8.73	18.99
Dublin Belgard	0.18	0.03	0.01	0.03	0.03	0.04	0.08	0.03	0.11	0.24	0.24	0.32	0.82	1.18	1.92	3.26	6.66	12.33
Dublin Fingal	0.14	0.00	0.00	0.03	0.02	0.02	0.01	0.08	0.17	0.33	0.35	0.73	0.82	1.99	2.95	4.01	7.36	20.76
Dun Laoghaire	0.25	0.00	0.00	0.04	0.02	0.07	0.06	0.06	0.16	0.18	0.25	0.51	0.79	1.34	3.18	3.87	8.55	16.13
Louth, Monaghan, Cavan	0.10	0.05	0.04	0.05	0.02	0.06	0.02	0.08	0.13	0.19	0.23	0.83	1.07	1.45	2.97	5.95	9.51	19.26
Longford, Westmeath, Offaly, Roscommon	0.08	0.00	0.03	0.04	0.02	0.03	0.08	0.05	0.18	0.32	0.48	0.57	1.05	2.01	3.05	5.33	8.87	19.85
Sligo, Leitrim	0.14	0.03	0.05	0.00	0.00	0.09	0.11	0.08	0.08	0.21	0.24	0.31	1.38	1.99	3.08	4.25	7.09	21.49
Donegal	0.25	0.00	0.00	0.07	0.07	0.05	0.00	0.10	0.03	0.13	0.37	0.55	1.15	2.07	2.78	5.04	8.42	21.37
Mayo	0.09	0.00	0.00	0.00	0.12	0.07	0.09	0.06	0.15	0.34	0.31	0.32	0.97	1.11	2.63	4.76	8.22	20.02
Galway County	0.12	0.02	0.01	0.03	0.03	0.09	0.07	0.14	0.13	0.28	0.40	0.48	0.89	1.18	2.60	3.86	9.10	19.47
Galway City	0.00	0.00	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.23	0.48	0.37	0.83	1.03	3.30	5.85	4.99	15.14
Limerick, North Tipperary, Clare	0.16	0.01	0.02	0.03	0.09	0.04	0.08	0.07	0.07	0.16	0.36	0.58	1.21	1.74	3.03	5.45	8.04	19.07
Limerick City	0.17	0.05	0.00	0.04	0.00	0.00	0.00	0.07	0.39	0.36	0.62	0.73	1.66	2.16	4.45	7.70	11.04	17.39
Kerry	0.12	0.07	0.02	0.04	0.03	0.03	0.00	0.20	0.08	0.23	0.42	0.60	1.20	1.77	2.75	5.54	8.00	18.02
Cork	0.18	0.03	0.00	0.02	0.06	0.02	0.02	0.09	0.19	0.19	0.57	0.60	1.15	1.71	3.17	6.12	11.25	22.68
Cork City	0.14	0.02	0.02	0.05	0.03	0.02	0.11	0.03	0.06	0.21	0.30	0.42	1.23	2.06	2.90	5.58	8.78	18.19
Waterford, Wexford, South Tipperary	0.08	0.00	0.01	0.03	0.04	0.01	0.01	0.08	0.18	0.15	0.48	0.53	1.26	2.09	3.64	5.86	9.22	20.81
Carlow, Kilkenny, Laois	0.21	0.00	0.01	0.04	0.02	0.05	0.03	0.05	0.14	0.24	0.33	0.73	0.85	1.60	3.39	5.04	9.54	19.46
Waterford City	0.13	0.00	0.00	0.00	0.00	0.06	0.14	0.08	0.17	0.00	0.41	0.45	1.28	1.32	2.58	9.62	7.34	13.30

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