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Housing supply and the interaction of regional population and employment

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Abstract in English

Housing markets may significantly affect the relationship between regional population and employment, if housing supply is not fully accommodative to demand. We analyse the relationships between housing supply, regional population and employment empirically in a three-equation dynamic model. Annual regional panel data are used for the Netherlands, where a strong tradition of spatial planning exists. We find that net internal migration is strongly determined by housing supply, whereas employment growth has no statistically significant impact. Growth of the housing stock is only moderately affected by population and employment, possibly as a result of restrictive spatial policies. Employment adjusts substantially towards a long-run relationship with the regional population. The analysis further indicates that labour markets drive this long-run adjustment more than local consumer demand. Hence, people follow houses rather than jobs, and jobs follow people in the long run.

Keywords: housing supply, population-employment interaction, regional panel data

Classification-JEL: R11, R23, J23

Abstract in Dutch

De huizenmarkt kan een belangrijk effect hebben op de relatie tussen regionale bevolking en werkgelegenheid, als het aanbod van woningen de vraag niet accommodeert. Wij bestuderen de relaties tussen woningaanbod, regionale bevolking en werkgelegenheid empirisch in een dynamisch simultaan model. Er wordt in deze studie gebruik gemaakt van regionale panel data voor Nederland, waar een lange traditie van ruimtelijke ordening bestaat. We vinden dat netto binnenlandse migratie sterk bepaald wordt door woningaanbod, terwijl het effect van werkgelegenheidsgroei niet statistisch significant is. Groei van de woningvoorraad is maar in beperkte mate gevoelig voor bevolking en werkgelegenheid, mogelijkerwijs als gevolg van een strikt ruimtelijke ordeningsbeleid. Werkgelegenheid past zich sterk aan naar een lange termijn relatie met de regionale bevolking. Onze analyse geeft verder aan de rol van arbeidsmarkten hierin groter is dan de rol van de lokale vraag naar consumptiegoederen. Dus, mensen volgen eerder huizen dan banen, en banen volgen mensen op de lange termijn.

Steekwoorden: woningaanbod, interactie bevolking en werkgelegenheid, regionale panel data

Een uitgebreide Nederlandse samenvatting is beschikbaar via www.cpb.nl.

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Summary

Much of the population-employment interaction literature ignores housing supply, either implicitly or explicitly assuming that it will fully accommodate any changes in the regional population. In this paper, we analyse the relationships between housing supply, regional population and employment empirically for the Netherlands, where a strong tradition of spatial planning exists. We estimate a three-equation simultaneous model, which distinguishes short-run and equilibrium adjustment effects. All national developments and time-invariant regional heterogeneity are controlled for.

We find that growth of the housing stock is only moderately affected by population and employment, so the assumption of accommodative housing supply appears to be inappropriate in the Dutch context. On the contrary, net internal migration is strongly determined by housing supply, whereas employment growth has no statistically significant impact on this variable. Employment appears quite insensitive to demand side variables, while it adjusts substantially towards a long-run relationship with the regional population. A sector-specific analysis suggests that the adjustment of employment restores equilibrium on regional labour markets, and is not predominantly driven by the demand for nontradable consumption goods. Hence, housing supply is a key long-run determinant of the spatial distribution of both people and jobs.

From an economic perspective, these findings make sense. One would expect the regional demand for labour to be elastic with respect to wages, in particular in a small and open economy such as the Netherlands. On the other hand, the regional supply of labour may be quite inelastic. Migration must be an important component of the long-run regional adjustment of labour supply, but labour is known to be rather immobile, in particular in most European countries. This immobility is enhanced by rigid housing supply. Even if migration patterns would be highly sensitive to real wages, then labour supply would still be inelastic if housing supply were inelastic. Hence, employment would relatively easily adjust to the regional distribution of people, but the reverse is less likely to occur.

The evidence that, in the long run, employment is mainly determined by labour supply, suggests that demand side policies, such as land subsidies for firms or investment in regional infrastructure, may not be so helpful in attracting jobs. Furthermore, a plausible reading of our findings is that people move to regions where houses are built, but houses are not necessarily built in regions were people would want to live. The costs in terms of welfare associated with a mismatch between regional demand and supply for housing are likely to be substantial, and may spill over to the labour market.

1 Introduction*

Housing supply may significantly affect the spatial distribution of people and jobs, as has been recently argued by Glaeser et al. (2006). Hence, its role in the interaction of regional population and employment deserves a more detailed empirical investigation. After the landmark papers by Steinnes (1977), Carlino and Mills (1987) and Boarnet (1994), a variety of studies have estimated simultaneous models of regional population and employment. The central issue in this literature has become known as the question whether “people follow jobs” or “jobs follow people”.[1] Muth (1969) already pointed to the vital role of housing in this interplay, relating the movement from central city residents to suburbs in the US to the income-induced rise in demand for low-density housing. Greenwood (1980) and Greenwood and Stock (1990), who incorporate a housing equation in their analyses of population-employment interaction, provide support for the significant role of housing supply. However, this role has been ignored in the larger part of the subsequent empirical literature.

Ties between housing supply, regional population and employment are likely to be exceptionally strong. The interdependency is apparent from casual inspection, as the number of houses, people and jobs correlate strongly over cities, regions and states. The following argument highlights the potential role of housing supply in this interplay. Given a fixed number of houses, population growth can only be accommodated by an increase in household size or by a decrease in vacancy rates. Since the long-run accommodative capacity of these channels is limited, population growth is likely to be hampered if the housing stock does not adjust to demand. Hence, the extent to which a labour demand shock translates into regional employment growth depends, at least partially, on housing supply (cf. DiPasquale and Wheaton, 1996, Glaeser et al., 2006).

In an analysis of population-employment interaction, it is justified to ignore housing only if supply is fully elastic. In this special case, changes in the housing stock accommodate shifts in demand, so population growth is unaffected by housing market conditions. However, fully elastic supply is not a realistic assumption. For example, it is well established in the urban economics literature that small increases in house prices will not cause large supply responses in cities, because the increase in the housing stock will be accompanied by a rise in land prices (cf. Fujita, 1989, DiPasquale and Wheaton, 1994). The short-run elasticity is further reduced by the delay in supply due to the construction process.

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[1] Note that this terminology is slightly misleading, because the issue under consideration is whether regional employment growth drives population growth, or the other way around. This literature does generally not consider micro data on people and jobs. It may be the case that many people move between regions for a job, although (aggregate) regional population growth drives employment growth. Nevertheless, we will stick to the terminology, as it is so widely used.

Another potential cause of inelastic supply is the presence of restrictive policies, such as spatial planning. In the past decade, a number of studies have emphasized the importance of restrictive spatial policies in US local housing markets (cf. Abraham and Hendershot, 1996, Malpezzi, 1999, Mayer and Summerville, 2000, and Glaeser et al., 2005). Other work suggests that such policies have an even larger impact in some European countries (cf. Malpezzi and MacLennan, 2001). Rather than accommodate, housing supply may shape the regional distribution of population and employment in the presence of restrictive policies. For instance, Glaeser et al. (2006) show that productivity shocks translate more into increased wages and house prices, and less into population and employment growth, when metropolitan areas are subject to restrictive policies.

This paper investigates the interaction of regional housing, population and employment in the Netherlands. A strong tradition of spatial planning exists in this country, probably originating from the fact that a significant part of its surface has been reclaimed from the sea. Because of the cooperation between inhabitants required by this process, (local) governments have participated in land use decisions for centuries. Nowadays, externalities in land use provide a more important rationale for spatial planning, as the population density is high, particularly in the west of the country. Open space is preserved through the imposition of land use plans, which specify at a detailed level on which locations housing construction is allowed for. Not only are local authorities involved, but also the national government plays a major role in deciding which areas should be protected from development. The impact of these government interventions on housing supply are likely to be substantial.[2]

We estimate a system of equations that identifies whether housing supply determines or accommodates regional population and employment growth. Our econometric approach essentially follows Carlino and Mills (1987), although we extend their framework in a number of ways. First of all, we introduce an equation for growth of the housing stock, as in Greenwood (1980) and Greenwood and Stock (1990). Second, as the regions in our data are not closed in terms of commuting, spatial interaction is accounted for following Boarnet (1994). Because internal migration is the main channel through which the population adjusts to regional labour and housing market conditions, we model the net internal migration rate rather than population growth (cf. Greenwood and Hunt, 1984).

[2] For instance, strong government intervention in housing supply is suggested by the development of prices and construction. In recent decades, prices have risen substantially, but housing construction has decreased. Furthermore, we have performed an analysis of housing demand survey data, and we were not able to identify a significant positive correlation between regional house prices and subsequent supply. An additional indication that it is land use policies and not only land prices that explain this outcome, is that a large part of the land is not inhabited, even in densely populated areas. At the national level, 56 percent of the land is used for agriculture. In the region of Amsterdam, for example, this is still 45 percent, although house prices in Amsterdam are significantly higher than the national average. Note that, as we observe regional house price differentials only for a limited number of years, the analysis of house prices is not pursued in our present paper.

We analyse yearly observations over a fairly long period of time, rather than one or two large cross-sections, which is common in the population-employment interaction literature. Hence, our dynamic specification is richer than the lagged adjustment model that is generally used in this literature, distinguishing between short-run and equilibrium adjustment effects. Moreover, the use of panel data allows for the inclusion of region and period fixed effects, so time-invariant regional heterogeneity and national developments are fully controlled for. This significantly enhances the robustness of our findings to omitted variables.

It is common in the population-employment interaction literature to study industrial breakdowns of regional employment growth (cf. Steinnes, 1977, Carlino and Mills, 1987, Thurston and Yezer, 1994). We analyse such a breakdown as well, to shed light on the issue whether this interaction is driven by markets for labour or local consumption goods. Our evidence indicates that labour markets are the dominant force, which is a maintained hypothesis in other parts of the study.

Although the main contribution of this paper is empirical, we find it useful for the interpretation of our findings to set out a theoretical framework. Hence, the next section relates the interaction of regional housing, population and employment to supply and demand elasticities in relevant markets. The data are introduced in Section 3, including a number of stylized facts. Section 4 discusses the econometric specification of our model, and empirical results are presented in Section 5. The sector-specific analysis is performed in Section 6. Conclusions are drawn and put into a wider perspective in the final section.

2 Theoretical framework

The question whether jobs follow people or reversely may be reframed as the question whether regional growth is labour demand or supply induced (cf. Muth, 1969, 1990, and DiPasquale and Wheaton, 1996). Suppose that demand in a region shifts upward due to, for instance, changes in technology or tastes. Increased demand will generally cause wages to rise and attract workers to the region. In that case, people follow jobs. Alternatively, it may be that the regional population increases for exogenous reasons such as natural population increase, and the labour supply curve shifts upward. The resulting fall in wages will generally attract firms, so that in this case, jobs follow people.[3]

One key parameter in this framework is the wage elasticity of regional labour demand. If demand is highly elastic, the increase in regional population will be followed by an almost similar increase in employment, and wages will hardly fall. The demand curve will merely slide along itself (Muth, 1990). Jobs therefore follow people in this case. On the other hand, inelastic labour demand implies that a population increase will hardly lead to any new jobs, and a large fall in wages.

Amongst other things, the wage elasticity of labour demand depends on openness of the region in terms of trade, and mobility of capital. The argument is illustrated by Muth (1990), in a simple version of the Borts and Stein (1964) model. Consider a small open region that is diversified in the production of an export and a local (nontradable) consumption good. Both goods are produced with a constant returns technology, using labour and capital. If the region is small and open in terms of trade, the price of the export good is fixed on national or world markets. If we further assume perfect capital mobility, returns to capital are fixed as well. This implies that wages in the export sector are fixed. If labour markets are in equilibrium, wages in the local sector must equal wages in the export sector. Hence, the wage elasticity of regional labour demand is infinite. The demand curve slopes downward in this model only if the region is fully specialized in the production of local consumption goods, something which is rarely observed in reality.[4]

[3] Jobs may follow people also for other than labour market reasons, such as the demand for local consumption goods induced by a population increase. In most post-industrial economies, a large share of labour supply is employed in the production of nontradable consumer goods like local government, health care or retail. Therefore, producers of these goods have an incentive to locate near people (and people have an incentive to locate near these producers). We verify the roles of markets for labour and local consumption goods in Section 6.

[4] See also Hanson and Slaughter (2002). This study finds that state-level production in the US responds to labour supply shocks by adjusting output in the traded sector. The authors also present evidence for productivity-adjusted factor price equalization between US states. Factor price equalization is relevant in the context of regional population – employment interaction, because it implies that shifts in labour supply are accommodated through rybczynski effects. This means that production will shift towards labour intensive industries after a positive labour supply shock, so jobs follow people without any fall in wages.

The wage elasticity of regional labour demand is probably larger than minus infinity, as this stylized model predicts. On one hand, the assumptions on the technology rule out economies of agglomeration, which some believe to be a major determinant of the spatial distribution of people and jobs (cf. Fujita et al., 1999). On the other hand, the absence of barriers to trade and capital mobility seems a more realistic assumption for regions than for countries.[5] Consequently, the wage elasticity of regional labour demand should exceed wage elasticities of national labour demand, such as reported by Hamermesh (1993).[6] Bartik (1991) reviews the US literature on local employment growth, which indicates wage elasticities in the range from -0.2 to -1.0.[7] In countries which are smaller and more open in terms of trade, such as the Netherlands, regional labour demand elasticities may exceed estimates for the US.

Another key parameter is the real wage elasticity of interregional migration. If migration is inelastic, a rise in labour demand can be accommodated only through a fall in unemployment or inactivity. In the long run, the accommodative capacity of these channels is limited, so a continued rise in labour demand will lead to a large rise in wages and a small increase in employment. If on the other hand migrants are sensitive to real wages, a rise in labour demand leads to a large increase in employment and a small rise in wages. People will therefore follow jobs in this case. The empirical literature suggests that internal migration is less sensitive to wages in European countries than in the US (cf. Eichengreen, 1993, Decressin and Fatas, 1995, OECD, 2005).[8] For the UK, estimates by Pissarides and McMaster (1990) imply a rather slow adjustment to regional labour market equilibrium through migration.[9] Evidence in Jackman and Savouri (1992) even suggests the absence of a significantly positive wage elasticity.

What matters to potential migrants is real regional wage differentials, which may differ significantly from nominal wage differentials because of regional cost-of-living differentials. Variation in housing costs is generally the dominant component in these regional cost-of-living differentials. One potential source of house price differentials is the positive relationship between land prices and population density (Fujita, 1989, DiPasquale and Wheaton, 1994). Housing is more expensive in attractive cities or regions, simply because inhabitable land is scarce. As a wage increase, induced by labour demand, makes a region more attractive, it

[5] The diminishing effect of country borders on trade is well established in the literature (cf. Anderson and Van Wincoop, 2003). With respect to capital mobility, we note that capital stocks in most countries have risen significantly. Although relocation of capital may be costly, and therefore hamper capital mobility, this does not hold for new capital goods.

[6] Alternatively, one could argue that locations are closer substitutes if they are in the same country, so that demand is more sensitive to wage differentials.

[7] According to Bartik (1991), these coefficients are likely to underestimate the true wage-elasticity because of measurement error and simultaneity problems.

[8] Decressin and Fatas (1995) argue that participation is more sensitive to labour market conditions in Europe than in the US. However, unlike Blanchard and Katz (1992), the authors do not distinguish between supply and demand induced shocks. Hence, it may be the case that the observed relationship between employment shocks and participation is largely the result of supply shocks.

[9] Note that these are estimates of the (real) wage elasticities of migration, and not of regional labour supply. Since migration is small relative to the labour force, elastic migration may still imply slow adjustment of the labour force.

pushes up house prices and the regional cost-of-living. Hence, real wages increase by less than nominal wages, people are hampered in following jobs and the rise in employment is reduced.

The third key parameter in our framework, therefore, is the price elasticity of housing supply. Housing supply appears to be elastic in the US, but estimates of this parameter vary wildly between different studies (DiPasquale, 1999). For most studies, an infinite price elasticity can be rejected. This finding is important in the context of regional population-employment interaction, because it means that the assumption of accommodative housing supply is not valid. A recent literature relates rigidities in housing supply to restrictive spatial policies (cf. Abraham and Hendershot, 1996, Malpezzi, 1999, Mayer and Summerville, 2000, and Glaeser et al., 2005). Malpezzi and MacLennan (2001) find that the supply elasticity is substantially lower in the United Kingdom than in the US, which may be the result of more restrictive planning in this country. Hence, we may expect that housing supply in the Netherlands, where planning puts strong restrictions on construction too, is rather inelastic.

Summing up, we may expect labour demand to be relatively wage elastic, and migration and housing supply to be quite inelastic in the Netherlands.[10] Hence, from the arguments outlined in this section, it may be predicted that at the level of regional aggregates, jobs follow people rather than the other way around.

[10] In the Netherlands, the adjustment of wages to regional labour market conditions is hampered by bargaining at the national level. Such rigidities are likely to reduce the responsiveness of labour demand as well as migration to these local conditions. However, we would expect both labour demand and internal migration to be more responsive to regional unemployment differentials in this case.

3 Data exploration

In this section, we explore yearly data on the regional housing stock, population and employment from 1973 to 2002 in the Netherlands. The regional unit is the so-called COROP region (40), which coincides with the European NUTS3 level. These regions are partly designed to minimize cross-border commuting.[11]

The demographic information employed in this study consists of regional population and migration, disaggregated to age and gender. Natural population increase is derived by subtracting internal and foreign migration from regional population growth. The regional housing stock is the number of housing units per region, so we do not control for differences in quality. Regional employment is measured as the number of person-years of employees. We also use regional value added, for which an industrial breakdown is available, like for employment. At the national level, gender and age-specific labour participation rates and age-specific headship rates are available.[12]

3.1 Endogenous variables

We explore growth rates of housing, population, net internal migration and employment in a series of maps, shown in Appendix 1. The growth rate of the regional housing stock from 1973 to 2002 is shown in Figure A.1. The next figure shows growth of the regional population between 15 and 65 years old, which may be interpreted as the potential labour force. Since we expect labour markets to be the dominant channel of population-employment interaction, this variable is preferred over the total population. Figure A.3 shows net internal migration, scaled to the regional population in 1973, for the same age group. Finally, regional growth rates of employment of employees in person-years are shown in Figure A.4.

The figures point to substantial interregional differences. Regional growth of the housing stock varies between about thirty and hundred percent over three decades. Population and employment have not grown at all in some regions, but increased by some fifty and seventy percent respectively in others. In the region of Flevoland, which is left out of our analysis, population increased by almost a factor fifteen. This region was gained from the sea between 1940 and 1968, so population in the base year was small.

[11] The average share of workers that work outside their region of residence is about 20 percent. In 2002, the average population size was about 400 000 people, ranging from 53 000 to 1 356 000.

[12] Demographic information stems from municipal administrations, and has been collected and aggregated to the COROP level by Statistics Netherlands (CBS). Data on the regional housing stock were kindly provided by ABF Research. Employment and value added were derived from regional accounts from Statistics Netherlands. We thank Carel Harmsen of Statistics Netherlands for providing information on historic age-specific headship rates.

Urban sprawl or suburbanization seems to account at least partially for the developments shown in these maps. The population in the regions that contain the largest cities of the Netherlands, Amsterdam, Rotterdam and The Hague, has grown at a slower rate than nationally, which is the result of two developments. As shown in Figure A.3, net migration in these regions is negative, and in addition, the rate of natural population increase has been lower than the national average. Regions on a commutable distance, such as the regions to the north of Amsterdam, Flevoland, and in particular the regions in the centre of the country, seem to have benefited from this development.

Table 3.1 Correlation matrix of growth rates over the period 1973 - 2002

	Housing	Population	Migration	Employment
Housing	1			
Population	0.772	1		
Migration	0.756	0.767	1	
Employment	0.772	0.724	0.699	1

Notes: This table shows unweighted bivariate correlations, leaving the region of Flevoland out of the sample.

The Figures A.1-A.4 suggest a strong correlation between housing, population and employment, which is confirmed in Table 3.1. This table reports correlations between growth rates of these variables over the period 1973 – 2002.[13] If urban sprawl has indeed been a major force behind shifts in the regional distribution of people, then the correlation between population and employment growth would mean that jobs have followed this movement. Another indication for this direction of causality is that the industrial breakdown is the most favourable in the large cities, so shift-share analyses would predict employment growth to be largest here. However, employment growth is clearly larger in neighbouring regions.

At first sight, the strong correlation between population and housing growth rates may be interpreted as evidence of accommodative housing supply. However, the causation may be the other way around because of restrictive spatial policies. One straightforward way to see this is by focussing on Amsterdam and its surroundings. Consider for example the region of Flevoland, which was planned by the national government as a growth region. In the absence of restrictions on housing supply, many people have moved from Amsterdam to this almost vacant region. However, considerably less people have moved to the south and south-west of

[13] Table A.1 in Appendix 1 shows correlations between housing, population and employment for yearly data, rather than for developments over the entire period of observation. Some relationships appear to be weaker, especially when region and period fixed effects are included. Remarkably, these fixed effects account for about three quarters of the variation in yearly regional housing and population growth already. They explain significantly less of the variation in employment growth and, in particular, migration. Growth of housing and population and migration still correlate significantly to each other, but they do not seem to correlate strongly to employment growth anymore, once fixed effects are included.

Amsterdam, where housing supply has been constrained by rather restrictive spatial policies.[14] The econometric analysis in Section 5 aims to identify these causal relationships in a more formal manner.

3.2 Exogenous variables

To construct exogenous variables that affect growth of the housing stock, we follow a standard approach based on age-specific headship rates and regional demographic information (cf. DiPasquale and Wheaton, 1996). Let h_t^k denote the share of people in age group *k* and period *t* that are household head. *Expected housing demand* is obtained by multiplying these headship rates by the regional age-specific population size and summing over age groups. We scale this variable to the regional population $POP_{r,t}$ to obtain $EHD_{r,t} = \sum_k h_t^k POP_{r,t}^k \Big/ POP_{r,t}$.[15]

Changes in the regional population, which drive changes in expected housing demand, will be endogenous in our model. We may decompose population growth into migration and natural population increase, $NPI_{r,t}^k$.[16] Exogeneity of this latter variable seems plausible, as it is the result of birth, death and ageing, which are unlikely to be affected by conditions on local housing or labour markets.[17] Hence, we use natural population increase to compute an exogenous growth rate for the expected demand for housing as $\Delta ehd_{r,t} = \sum_k h_{t-1}^k NPI_{r,t}^k \Big/ \sum_k h_{t-1}^k POP_{r,t-1}^k - NPI_{r,t} / POP_{r,t-1}$.[18]

In a similar way, we compute the regional *expected labour supply* based on the demographic composition, using national age and gender-specific participation rates. Let $p_t^{k,g}$ denote the participation rate in age group *k* and gender *g*, and $ELS_{r,t}$ the expected labour supply. We define $ELS_{r,t} = \sum_{k,g} p_t^{k,g} POP_{r,t}^{k,g} \Big/ POP_{r,t}$, scaling again to the regional population. As changes in this variable may be also endogenous, we compute $\Delta els_{r,t} = \sum_{k,g} p_{t-1}^{k,g} NPI_{r,t}^{k,g} \Big/ \sum_{k,g} p_{t-1}^{k,g} POP_{r,t-1}^{k,g} - NPI_{r,t} / POP_{r,t-1}$.

Demand-driven changes in employment are identified by two variables. The expected growth rate of employment based on the composition of employment with respect to industries is known in the literature as the *share*, denoted $SHA_{r,t}$ (cf. Bartik, 1991). We construct *productivity* $PRO_{r,t}$ as the ratio of value added to employment. This variable proxies labour

[14] Flevoland could be more attractive *ceteris paribus* than these other regions, but this is unlikely to be the case. For example, the distance from Flevoland to Amsterdam is large, relative to other areas close to Amsterdam.

[15] Correlation between expected housing demand and any population variables in the housing equation will be minimized by this scaling procedure, and interpretation is facilitated.

[16] The natural population increase in age group *k* obtains by subtraction of net internal and foreign migration from the change in population.

[17] One may argue that this variable is endogenous because the size and composition of the current population is the result of past migration decisions. However, net migration is small relative to the size of the average regional population, so this is unlikely to be relevant empirically.

[18] Note that this variable follows from the growth rate of $EHD_{r,t}$ by replacing $\Delta POP_{r,t}^k$ by $NPI_{r,t}^k$.

productivity, although it reflects the average regional human capital and returns to other factors as well. Regional productivity may be higher due to, for instance, the presence of agglomeration economies. This will attract firms to the extent that productivity differentials are not capitalised in wages or rents.

4 Model specification and identification

In this section, a dynamic specification is derived from a fairly general simultaneous model of regional housing, population and employment. We decompose the interaction of these three main variables of interest into short and long-run effects, extending most of the current literature on population-employment interaction. Long-run effects are interpreted as the result of density effects and adjustments on labour and housing markets. The exogenous variables are then substituted into the model, and we discuss some identification issues. As prices are not observed, this model is necessarily of a reduced-form type, but the use of instrumental variables allows us to identify causal relationships nevertheless.

4.1 Derivation of a simultaneous error correction model

Our starting point is a relationship between the regional housing stock, population and employment, time lags of these variables and exogenous variables. We make one exclusion restriction at the outset, which is that housing supply does not directly affect employment, but only through the population it attracts.[19] Consider the following set of equations:

$$HOU_{r,t} = f\left(A_1(L)HOU_{r,t}, A_2(L)POP_{r,t}, A_3(L)\overline{EMP}_{r,t}, X_{r,t}, u_{r,t}\right),$$

$$POP_{r,t} = g\left(A_4(L)HOU_{r,t}, A_5(L)POP_{r,t}, A_6(L)\overline{EMP}_{r,t}, Y_{r,t}, v_{r,t}\right), \quad (4.1)$$

$$EMP_{r,t} = h\left(A_7(L)\overline{POP}_{r,t}, A_8(L)EMP_{r,t}, Z_{r,t}, w_{r,t}\right),$$

where $HOU_{r,t}$, $POP_{r,t}$ and $EMP_{r,t}$ are the levels of housing, population and employment in region *r* during period *t*. The lag polynomials $A_k(L)$ allow for a dynamic adjustment process. Exogenous control variables are represented by $X_{r,t}$, $Y_{r,t}$, and $Z_{r,t}$. Furthermore, $u_{r,t}, v_{r,t}$ and $w_{r,t}$ are independently distributed disturbances, and the functions *f*, *g* and *h* can take arbitrary forms.

Generally speaking, jobs in one region may be filled by people living in other regions, and vice versa. Commuting is therefore accounted for by adopting a method that was introduced by Boarnet (1994). In the employment equation, population is multiplied by a spatial weight matrix W^1, obtaining $\overline{POP}_{r,t}$.[20] This variable may be interpreted as the expected potential labour

[19] This ignores the building industry, which is small relative to total employment and also quite footloose. In our sensitivity analysis, we verify this assumption empirically.

[20] Construction of the weight matrices is described in the appendix. Note that in the absence of commuting between regions, $\overline{POP}_{r,t} = POP_{r,t}$ and $\overline{EMP}_{r,t} = EMP_{r,t}$.

supply in region *r*, given commuting patterns and the regional distribution of population. In the housing and population equations, employment is multiplied by the weight matrix W^2, obtaining $\overline{EMP}_{r,t}$. It may be interpreted as the expected working labour force in region *r*, given commuting patterns and the regional distribution of employment. Both weight matrices have been estimated on observed interregional commuting flows, see Appendix 2.

We specify (4.1) as a log-linear model.[21] To keep the exposition of the model tractable, we include only one-year lags here, although we include more lags in the empirical analysis.[22] Applying the convention that variables are written in capitals and their logarithms are written in lower-case letters, the model is then as follows:

$$hou_{r,t} = \alpha_1 hou_{r,t-1} + \alpha_2 pop_{r,t} + \alpha_3 pop_{r,t-1} + \alpha_4 \overline{emp}_{r,t} + \alpha_5 \overline{emp}_{r,t-1} + \mu x_{r,t} + u_{r,t} \; ,$$

$$pop_{r,t} = \beta_1 hou_{r,t} + \beta_2 hou_{r,t-1} + \beta_3 pop_{r,t-1} + \beta_4 \overline{emp}_{r,t} + \beta_5 \overline{emp}_{r,t-1} + \nu y_{r,t} + v_{r,t} \; , \qquad (4.2)$$

$$emp_{r,t} = \delta_1 \overline{pop}_{r,t} + \delta_2 \overline{pop}_{r,t-1} + \delta_3 emp_{r,t-1} + \varpi z_{r,t} + w_{r,t} \; .$$

In order to distinguish short and long-run effects, we substitute $hou_{r,t} = \Delta hou_{r,t} + hou_{r,t-1}$, $pop_{r,t} = \Delta pop_{r,t} + pop_{r,t-1}$ and $emp_{r,t} = \Delta emp_{r,t} + emp_{r,t-1}$ into (4.2).[23] Furthermore, we decompose the exogenous variables $x_{r,t}$, $y_{r,t}$ and $z_{r,t}$ into variables in changes - $\Delta x^1_{r,t}$, $\Delta y^1_{r,t}$ and $\Delta z^1_{r,t}$ - and variables in (lagged) levels - $x^2_{r,t-1}$, $y^2_{r,t-1}$ and $z^2_{r,t-1}$ - , as well as region and

[21] Both linear (e.g. Carlino and Mills, 1987, Boarnet, 1994) and log-linear (e.g. Luce, 1994) specifications have been employed in the literature. Given time series data, it is preferable to specify a log-linear model. Housing, population and employment growth are multiplicative rather than additive processes, in the sense that changes are proportional to lagged levels. This is obvious for population growth, because new members of the population are born from existing members. This implies the need to model growth rates, which are obtained by first-differencing the logarithms of housing, population and employment.

[22] Note that the specification with one-year lags encompasses the lagged adjustment model, which is standard in the population-employment interaction literature. This specification, introduced by Steinnes and Fisher (1974) entails that changes in local population and employment are interpreted as partial adjustments towards a long-run equilibrium, ignoring short-term dynamics. It may be interpreted as a two-equation version of the partial adjustment model that is sometimes used in macroeconometrics (cf. Harvey, 1990).

[23] This step is necessary and sufficient if housing, population and employment are nonstationary, but co-integrated variables, because first differences and long-run relationships are then stationary. However, stationarity seems a plausible assumption as the regions in our data are small, so that space constraints matter. In particular in an urban context, local housing, population and employment are unlikely to be random walks. Moreover, it seems implausible that housing, population and employment are nonstationary, once we have controlled for national developments and time-invariant regional heterogeneity. Nevertheless, formal testing is complicated because of spatial correlation.

period-specific constants (fixed effects) a_r, b_t, c_r, d_t, e_r, and f_t.[24] Rearranging terms, this yields the following specification:

$$\begin{aligned}\Delta hou_{r,t} &= a_r + b_t + \alpha_2 \Delta pop_{r,t} + \alpha_4 \Delta \overline{emp}_{r,t} - (1-\alpha_1) hou_{r,t-1} + (\alpha_2 + \alpha_3) pop_{r,t-1} \\ &\quad + (\alpha_4 + \alpha_5) \overline{emp}_{r,t-1} + \mu_1 \Delta x^1_{r,t} + \mu_2 x^2_{r,t-1} + u_{r,t}\end{aligned},$$

$$\begin{aligned}\Delta pop_{r,t} &= c_r + d_t + \beta_1 \Delta hou_{r,t} + \beta_4 \Delta \overline{emp}_{r,t} - (1-\beta_3) pop_{r,t-1} + (\beta_1 + \beta_2) hou_{r,t-1} \\ &\quad + (\beta_4 + \beta_5) \overline{emp}_{r,t-1} + v_1 \Delta y^1_{r,t} + v_2 y^2_{r,t-1} + v_{r,t}\end{aligned}, \qquad (4.3)$$

$$\begin{aligned}\Delta emp_{r,t} &= e_r + f_t + \delta_1 \Delta \overline{pop}_{r,t} - (1-\delta_3) emp_{r,t-1} + (\delta_1 + \delta_2) \overline{pop}_{r,t-1} \\ &\quad + o_1 \Delta z^1_{r,t} + o_2 z^2_{r,t-1} + w_{r,t}\end{aligned}$$

The effects of variables in changes can be interpreted as instantaneous responses or short-run effects, whereas variables in lagged levels measure long-run adjustments (cf. Harvey, 1990). The region and time dummies control for all time and region-invariant heterogeneity. Hence, the interaction of housing, population and employment is identified on regional variation in development over time.[25]

4.2 Decomposition into long-run relationships and density effects

As long as coefficients of the lagged dependent variables (α_1, β_3 and δ_3) are smaller than unity in absolute value, (4.3) implies that housing, population and employment tend to adjust towards some long-run equilibrium.[26] In this section, we elaborate on the interpretation of this long-run behaviour in terms of housing, labour and land markets. To this aim, we rewrite (4.3) as follows:

[24] We write superscripts *1* and *2* because exogenous variables may appear in changes or lagged levels only, as well as in both forms. For example, in the empirical application we will include the lagged level of productivity, but not the lagged level of the share.

[25] Housing, population and employment growth in model (3) respond to any variable $z_{r,t}$ only to the extent that this variable deviates from a combination of means over time and regions $z_{r,t}$*, where $z_{r,t}{}^* = \frac{1}{N}\sum_r z_{r,t} + \frac{1}{T}\sum_t z_{r,t} - \frac{1}{NT}\sum_r \sum_t z_{r,t}$. In particular, there is no response to variables that are constant over time or over regions.

[26] To be more precise, it should be the case that the dominant eigenvalue of the reduced form of (3) does not exceed unity in absolute value. Even if coefficients of lagged dependent variables are smaller than unity, this may not be the case because of simultaneity effects and because of interregional spillovers through the weight matrices. However, when simultaneity effects are small and regions are relatively closed in terms of commuting, this condition gives a reasonable indication.

$$
\begin{aligned}
\Delta hou_{r,t} &= a_r + b_t + \alpha_2 \Delta pop_{r,t} + \alpha_4 \Delta \overline{emp}_{r,t} + (\alpha_4 + \alpha_5)\overline{emp}_{r,t-1} \\
&\quad - \left(1 - \sum\nolimits_{k=1}^{3} \alpha_k\right) hou_{r,t-1} - (\alpha_2 + \alpha_3)(hou_{r,t-1} - pop_{r,t-1}) \ , \\
&\quad + \mu_1 \Delta x^1_{r,t} + \mu_2 x^2_{r,t-1} + u_{r,t}
\end{aligned}
$$

$$
\begin{aligned}
\Delta pop_{r,t} &= c_r + d_t + \beta_1 \Delta hou_{r,t} + \beta_4 \Delta \overline{emp}_{r,t} - \left(1 - \sum\nolimits_{k=1}^{5} \beta_k\right) pop_{r,t-1} \\
&\quad - (\beta_1 + \beta_2)(pop_{r,t-1} - hou_{r,t-1}) - (\beta_4 + \beta_5)(pop_{r,t-1} - \overline{emp}_{r,t-1}), \\
&\quad + \nu_1 \Delta y^1_{r,t} + \nu_2 y^2_{r,t-1} + v_{r,t}
\end{aligned}
\tag{4.4}
$$

$$
\begin{aligned}
\Delta emp_{r,t} &= e_r + f_t + \delta_1 \Delta \overline{pop}_{r,t} - \left(1 - \sum\nolimits_{k=1}^{3} \delta_k\right) emp_{r,t-1} \\
&\quad - (\delta_1 + \delta_2)(emp_{r,t-1} - \overline{pop}_{r,t-1}) + o_1 \Delta z^1_{r,t} + o_2 z^2_{r,t-1} + w_{r,t}
\end{aligned}
.
$$

Consider first the employment equation of this model. The long-run effects of population and employment are embodied in the variables $emp_{r,t-1}$ and $\left(emp_{r,t-1} - \overline{pop}_{r,t-1}\right)$. If it holds that $1 - \sum\nolimits_{k=1}^{3} \delta_k > 0$, then employment growth is reduced in regions where its level exceeds a value determined by an equilibrium condition. In the presence of region and period fixed effects, this condition may be written as $EMP_{r,t-1} = K_r K_t$. Note that the constants K_r and K_t may take up any value, so they account for the geographical size of a region amongst other things. Hence, the variable $emp_{r,t-1}$ may be interpreted as a measure for the long-run effect of employment density. If a higher density of employment implies higher land prices, it will hamper employment growth. However, the existence of strong agglomeration economies may imply a positive effect.

Employment growth is reduced in regions where its level exceeds a long-run relationship with the population, if it holds that $\delta_1 + \delta_2 > 0$. The equilibrium condition may be written as $EMP_{r,t-1} / \overline{POP}_{r,t-1} = K_r K_t$. Again, the constants K_r and K_t may take up any value, so they control, for instance, for national trends in labour participation and for long-run differences between urban and rural regions. Its seems reasonable to interpret this employment-population ratio as an indicator for equilibrium on regional labour markets.[27] Hence, the variable $\left(emp_{r,t-1} - \overline{pop}_{r,t-1}\right)$ measures to what extent employment growth adjusts to restore a regional labour market equilibrium.[28]

[27] Note that this interpretation is enhanced by the use of potential labour force instead of population, which we will do in our empirical analysis. This concept of regional labour market equilibrium is reminiscent to other formulations in the regional economics literature, see for example the *relative probability of employment* variable in Treyz et al. (1993).

[28] We will verify empirically that the effect of population on employment growth works mainly through labour market interaction, and not the demand for local consumption goods. Otherwise, the long-run effect should be interpreted as a measure for equilibrium on local consumption goods markets.

In the housing equation of (4.4), long-run effects of housing, population and employment are embodied in the variables $hou_{r,t-1}$, $\overline{emp}_{r,t-1}$ and $\left(hou_{r,t-1} - pop_{r,t-1}\right)$. As long as $1 - \sum_{k=1}^{3} \alpha_k > 0$, housing growth is hampered in regions where its level exceeds some equilibrium value. As land is more expensive in densely built-up areas, we would expect to find this effect. If $\alpha_4 + \alpha_5 > 0$, housing growth is reduced if employment is smaller than some equilibrium value. This long-run effect of employment (density) may occur if planners or developers take account of long-run employment opportunities when deciding about the construction of new houses.

Housing is also reduced in regions where its level exceeds a long-run relationship with the population, if it holds that $\alpha_2 + \alpha_3 > 0$. We write the equilibrium condition as $HOU_{r,t-1} / POP_{r,t-1} = K_r K_t$. The region and period dummies control for national trends such as a decrease in the average household size, as well as for the fact that households tend to be larger on average in rural areas. It seems reasonable to interpret this ratio of housing to population, or *headship rate,* as an indicator for equilibrium on regional housing markets. Hence, the variable $\left(hou_{r,t-1} - pop_{r,t-1}\right)$ measures to what extent housing growth adjusts to restore a regional housing market equilibrium.

Turning to the population equation in (4.4), long-run effects are embodied in the variables $pop_{r,t-1}$, $\left(pop_{r,t-1} - hou_{r,t-1}\right)$ and $\left(pop_{r,t-1} - \overline{emp}_{r,t-1}\right)$. The variable $pop_{r,t-1}$ may be interpreted as a measure for the effect of population density on growth. Note that the two other long-run variables are variants of the housing and labour market indicators that we have already discussed. Hence, $\left(pop_{r,t-1} - hou_{r,t-1}\right)$ measures to what extent population adjusts to restore equilibrium on regional housing markets, and $\left(pop_{r,t-1} - \overline{emp}_{r,t-1}\right)$ measures to what extent it adjusts to restore equilibrium on regional labour markets.

We finally remark that no restrictions are imposed by rewriting (4.3) into (4.4), and this step serves only to facilitate the economic interpretation of the model. Interpretation of the long-run behaviour of this model in terms of density effects and adjustments on regional labour and housing markets is conditional on a unit long-run elasticity assumption. This assumption is made implicitly by regarding the employment-population *ratio* and the headship *rate* as reasonable labour and housing market equilibrium indicators.

4.3 Substitution of exogenous variables and identification

Regional population growth is the result of natural population increase, foreign migration and internal migration. Of these components, we expect internal migration to be the most sensitive to conditions on regional labour and housing markets. Hence, we transform the population equation in (4.4) into an equation for the net internal migration rate $NIM_{r,t} / POP_{r,t-1}$. This can be done by including the rate of natural population increase and the net foreign migration rate in the set explanatory variables, and restricting their coefficients to unity.[29] The other explanatory variables discussed in the previous section may be included in a straightforward manner to obtain:

$$\begin{aligned}\Delta hou_{r,t} &= a_r + b_t + \alpha_2 \Delta pop_{r,t} + \alpha_4 \Delta \overline{emp}_{r,t} + (\alpha_4 + \alpha_5)\overline{emp}_{r,t-1} \\ &\quad - \left(1 - \sum_{k=1}^{3} \alpha_k\right) hou_{r,t-1} - (\alpha_2 + \alpha_3)(hou_{r,t-1} - pop_{r,t-1}) \ , \\ &\quad + \mu_1 \Delta ehd_{r,t} + \mu_2 ehd_{r,t-1} + u_{r,t}\end{aligned}$$

$$\begin{aligned}NIM_{r,t}/POP_{r,t-1} &= c_r + d_t + \beta_1 \Delta hou_{r,t} + \beta_4 \Delta \overline{emp}_{r,t} - \left(1 - \sum_{k=1}^{5} \beta_k\right) pop_{r,t-1} \\ &\quad - (\beta_1 + \beta_2)(pop_{r,t-1} - hou_{r,t-1}) - (\beta_4 + \beta_5)(pop_{r,t-1} - \overline{emp}_{r,t-1}) + v_{r,t}\end{aligned}, \qquad (4.5)$$

$$\begin{aligned}\Delta emp_{r,t} &= e_r + f_t + \delta_1 \Delta \overline{pop}_{r,t} - \left(1 - \sum_{k=1}^{3} \delta_k\right) emp_{r,t-1} \\ &\quad - (\delta_1 + \delta_2)(emp_{r,t-1} - \overline{pop}_{r,t-1}) + o_1 \Delta \overline{els}_{r,t} + o_2 \overline{els}_{r,t-1} \ . \\ &\quad + o_3 SHA_{r,t} + o_4 pro_{r,t-1} + w_{r,t}\end{aligned}$$

The exogenous demographic variables in the housing and employment equation enter both in levels and differences, identifying short and long-run effects. The demand side variable $PRO_{r,t}$ in the employment equation enters only in lagged levels in order to avoid endogeneity problems.

In the specification of (4.5), a number of exclusion restrictions are explicit. Expected housing demand is excluded from the migration equation, because it is assumed to play no role once we have controlled for growth of the housing stock. As we have discussed earlier, growth of the housing stock is excluded from the employment equation. Labour demand variables are excluded from the housing and migration equations, as we condition on employment growth. Natural population increase is excluded from all three equations. This exogenous variable may be excluded from the housing and employment equations, as these include population growth already. Its exclusion from the migration equation follows from the assumption that it enters the population growth equation in (4.4) with a unit elasticity. Not only does natural population increase serve as a strong instrument itself, but it is also used in constructing the exogenous growth rates of $EHD_{r,t}$ and $ELS_{r,t}$. Hence, this variable plays an important role in the identification of our model.

[29] Population growth is approximately equal to the sum of the net internal migration rate, the net foreign migration rate and the rate of natural population increase, so the latter two variables cancel out in the population equation. The approximation is $\Delta pop_{i,t} \approx \Delta POP_{i,t}/POP_{i,t-1}$.

5 Empirical analysis

We estimate (4.5) with ordinary least squares (OLS) and two-stage least squares (2SLS). Note that this model is overidentified in each equation. For the 2SLS estimators, we use subsets of all available instruments for which overidentifying restrictions tests do not reject our exclusion restrictions. Hence, the identification of our model is not only intuitive, but rests on formal statistical testing as well.

In the exposition of our model, we have used only one-year time lags for simplicity. In the empirical analysis, we have experimented with several lags, but the inclusion of two-year lags appeared relevant only for the housing equation. Hence, we present results for a version of the housing equation in (4.5) that is extended with one-year lags of housing, population and employment growth. The other two equations are specified as in (4.5). See the sensitivity analysis in Appendix 3 for details on other dynamic specifications.

Table 5.1 Growth of the housing stock $\Delta hou_{r,t}$

	OLS	2SLS
Lagged housing growth $\Delta hou_{r,t-1}$	0.594 (0.036)	0.620 (0.034)
Population growth $\Delta pop_{r,t}$	0.136 (0.033)	0.055 (0.030)
Lagged population growth $\Delta pop_{r,t-1}$	0.006 (0.012)	0.050 (0.028)
Growth expected housing demand $\Delta ehd_{r,t}$	0.108 (0.053)	0.030 (0.052)
Lagged expected housing demand $ehd_{r,t-1}$	0.009 (0.008)	0.005 (0.009)
Employment growth $\Delta \overline{emp}_{r,t}$	0.014 (0.006)	0.081 (0.028)
Lagged employment growth $\Delta \overline{emp}_{r,t-1}$	0.019 (0.006)	0.023 (0.028)
Lagged employment level $\overline{emp}_{r,t-1}$	0.009 (0.004)	0.021 (0.007)
Lagged housing stock $hou_{r,t-1}$	– 0.020 (0.004)	– 0.030 (0.007)
Housing market equilibrium $(hou_{r,t-1} - pop_{r,t-1})$	– 0.010 (0.005)	0.002 (0.006)
Region dummies a_r (39)	included	included
Year dummies b_t (28)	included	included
R^2 (weighted)	0.902	0.884

Notes: Estimates of the housing equation in model (4.5). Observations are weighted to the regional housing stock averaged over time. The outlier region of Flevoland is left out of our sample. The equation further includes a number of dummies that control for administrative shifts in regional borders, which are not reported in the table. Standard errors, reported in brackets, are robust to heteroskedasticity and autocorrelation over time. Population and employment growth, as well as their lags, are instrumented with natural population increase, the change in expected labour supply, productivity and the share, as well as their lags. These instrument are highly significant in the first stage regression (F = 224, t = 0.00 for population growth, F = 193, t = 0.00 for lagged population growth, F = 7.43, t = 0.00 for employment growth, F = 5.07, t = 0.00 for lagged employment growth). An overidentifying restrictions test does not reject our exclusion restrictions ($\chi^2(4)$ = 5.35, p = 0.25). A Hausman test rejects exogeneity of all variables except lagged employment growth (t = 4.42, p = 0.00 for population growth, t = -3.09, p = 0.00 for lagged population growth, t = -2.15, p = 0.04 for employment growth, t = -0.30, p = 0.77 for lagged employment growth).

Table 5.1 presents estimates for the housing equation. In the 2SLS estimates we instrument population and employment growth, as well as their one year lags. Natural population increase $npi_{r,t}$, growth of expected labour supply $\Delta \overline{els}_{r,t}$, the share $\overline{SHA}_{r,t}$, productivity $\overline{pro}_{r,t-1}$ and their one-year lags are used as instruments.[30] Note that the instruments for employment growth are weighted, using W^1. A Hausman test rejects exogeneity of population and employment growth, so the 2SLS estimates are preferred over the OLS estimates.

Lagged growth of the housing stock $\Delta hou_{r,t-1}$ appears to be a strong predictor of present growth, even when we condition for a host of other variables. This may be because construction projects usually take several years, so that there is substantial autocorrelation in the housing series.[31]

Housing growth is accommodative to population growth, but the coefficients on $\Delta pop_{r,t}$ and $\Delta pop_{r,t-1}$ are of both moderate size. The exogenous demographic variables $\Delta ehd_{r,t}$ and $ehd_{r,t-1}$ appear with the expected sign, but they turn out to be statistically insignificant. Employment affects growth of the housing stock as well, both in the short and in the long-run, suggesting that developers and planners take account of employment prospects when they decide on new construction projects. However, the coefficients on $\Delta \overline{emp}_{r,t}$, $\Delta \overline{emp}_{r,t-1}$ and $\overline{emp}_{r,t-1}$ are of a quite modest size too.

In the long-run, housing growth adjusts not only to employment opportunities, but also to $hou_{r,t-1}$, which we interpret as the density of housing. Land prices are likely to increase with housing density. Moreover, spatial planning controls may bite more fiercely in densely built areas, to protect remaining open space. Both mechanisms may explain the negative effect of this variable. However, we do not find evidence of adjustments to clear regional housing markets, as the coefficient on $(hou_{r,t-1} - pop_{r,t-1})$ is statistically insignificant.

Estimates of the net migration equation of (4.5) are presented in Table 4.2. Note that the net migration rate refers to the age group 15 – 65, just like the other population variables. Housing and employment growth are instrumented with growth of the expected housing demand $\Delta ehd_{r,t}$, natural population increase $npi_{r,t}$, the share $\overline{SHA}_{r,t}$, and productivity $\overline{pro}_{r,t-1}$. A Hausman test rejects exogeneity of housing growth, so that the 2SLS estimates are preferred over the OLS estimates.

[30] The variable $npi_{r,t}$ is computed as $NPI_{r,t} / POP_{r,t-1}$.

[31] Note that as a result, all other coefficients have to be multiplied by 1 / (1 - 0.620) to infer long-run effects of the associated variables.

Table 5.2 Net internal migration $NIM_{r,t}/POP_{r,t-1}$		
	OLS	2SLS
Housing growth $\Delta hou_{r,t}$	0.654 (0.057)	1.543 (0.236)
Employment growth $\Delta \overline{emp}_{r,t}$	0.009 (0.008)	0.034 (0.101)
Lagged level of population $pop_{r,t-1}$	– 0.009 (0.009)	0.039 (0.011)
Housing market equilibrium $(pop_{r,t-1} - hou_{r,t-1})$	– 0.023 (0.012)	– 0.078 (0.021)
Labour market equilibrium $(pop_{r,t-1} - \overline{emp}_{r,t-1})$	0.003 (0.008)	0.010 (0.019)
Region dummies c_r (39)	included	included
Year dummies d_t (29)	included	included
R^2 (weighted)	0.685	0.582

Notes: Estimates of the net migration equation in model (4.5). Observations are weighted to the regional population averaged over time. The outlier region of Flevoland is left out of our sample. The equation further includes a number of dummies that control for administrative shifts in regional borders, which are not reported in the table. Standard errors, reported in brackets, are robust to heteroskedasticity and autocorrelation over time. Instruments in the 2SLS estimates are the change in expected housing demand, the change in expected labour supply, the share and value added per capita. This set of instruments is jointly significant in both first stage regressions (F = 3.60, p = 0.01 for housing growth and F = 3.58, p = 0.01 for employment growth). Validity of the exclusion restrictions is tested with an overidentifying restrictions test, which does not reject our assumptions ($\chi^2(2)$ = 2.49, p = 0.29). A Hausman test rejects exogeneity of housing growth (t = -5.93, p = 0.00), but it does not reject exogeneity of employment growth (t = -0.29, p = 0.77).

Housing supply $\Delta hou_{r,t}$ is identified as a key determinant of migration. A one percent increase in housing supply induces an increase in the regional population through internal migration of more than one percent.[32] Employment growth $\Delta \overline{emp}_{r,t}$ does not statistically significantly affect migration. We remark though, that the confidence interval associated with this estimate is quite large, so that a small positive effect cannot be rejected.

The lagged level of population $pop_{r,t-1}$ affects migration positively, which suggests that population density attracts people, once we have conditioned on housing market variables.[33] However, we also find that migration adjusts to restore housing market equilibrium through the variable $(pop_{r,t-1} - hou_{r,t-1})$. Hence, the total effect of the lagged level of population on migration is negative. As more houses are built in areas where construction is less dense, people move to less densely populated regions on average. Finally, the coefficient on $(pop_{r,t-1} - \overline{emp}_{r,t-1})$ indicates that equilibrium on regional labour markets is not restored through migration.

[32] Note that the 2SLS estimate is higher than the OLS estimate, because simultaneity would bias the OLS estimate rather upwardly. Apparently, some variables are omitted from the equation, which correlate negatively to housing supply and positively to migration. For instance, it may be that spatial policies are more restrictive near large cities (so housing supply is smaller), which offer attractive amenities (so net migration is larger).

[33] This may be understood from social interaction externalities, for example. Or, alternatively, it may be that the level of amenities is higher on average in densely populated regions.

Table 5.3 **Employment growth** $\Delta emp_{r,t}$	OLS	2SLS
Population growth $\Delta emp_{r,t}$	– 0.209 (0.196)	– 0.282 (0.317)
Growth expected labour supply $\Delta \overline{els}_{r,t}$	1.133 (0.859)	1.129 (0.864)
Lagged expected labour supply $\overline{els}_{r,t-1}$	0.023 (0.155)	0.052 (0.192)
Share $sha_{r,t}$	0.474 (0.315)	0.476 (0.317)
Productivity per capita $pro_{r,t-1}$	0.010 (0.009)	0.011 (0.009)
Lagged level of employment $emp_{r,t-1}$	0.043 (0.031)	0.041 (0.033)
Labour market equilibrium $\left(emp_{r,t-1} - \overline{pop}_{r,t-1}\right)$	– 0.185 (0.043)	– 0.184 (0.044)
Region dummies e_r (39)	included	included
Year dummies f_t (29)	included	included
R^2 (weighted)	0.499	0.499

Notes: Estimates of the employment equation in model (4.5). Employment refers to the volume of man-years worked by employees. Observations are weighted to regional employment averaged over time. The outlier region of Flevoland is left out of our sample. The equation further includes a number of dummies that control for administrative shifts in regional borders, which are not reported in the table. Standard errors, reported in brackets, are robust to heteroskedasticity and autocorrelation over time. Instruments in the 2SLS estimates are growth of the housing stock and natural population increase. This set of instruments is jointly significant (F = 54.2, p = 0.00), as are both instruments individually. Validity of the exclusion restrictions is tested with an overidentifying restrictions test, which does not reject our assumptions ($\chi^2(1)$ = 2.49, p = 0.11). A Hausman does not reject exogeneity of population growth (t = 0.29, p = 0.77).

Table 5.3 presents estimation results for the employment equation of (4.5). Population growth is instrumented with natural population increase $npi_{r,t}$ and housing growth $\Delta hou_{r,t}$. Notably, overidentifying restrictions tests do not reject our exclusion restrictions, so our assumption that housing supply may be excluded from the employment equation is consistent with the data. A Hausman test does not reject exogeneity of employment growth, so we prefer the OLS estimates over the 2SLS estimates.

The effect of population on employment is negative in the short run, but statistically insignificant. Note that the estimated effect of $\Delta \overline{pop}_{r,t}$ is associated with quite a high standard error. Both the demographic variables $\Delta \overline{els}_{r,t}$ and $\overline{els}_{r,t-1}$ and the demand-side variables $sha_{r,t}$ and $pro_{r,t-1}$ appear to affect employment growth positively, but they are all statistically insignificant.

The only variable in the employment equation that does have a large and statistically significant effect is the deviation from equilibrium on regional labour markets $\left(emp_{r,t-1} - \overline{pop}_{r,t-1}\right)$. We find that any deviation of the employment-population ratio from a regional equilibrium value is reduced by about 20 percent yearly through employment growth, and it is almost halved in three years. Regional employment and population are brought back almost fully to equilibrium levels within a decade. Finally, employment density does not appear to affect employment growth in a statistically significant manner, although the total effect of lagged employment on growth is strongly negative.

Summing up the evidence, we come to the following picture of the interaction of housing, population and employment. Employment adjusts to the regional population in the long run, so jobs follow people. We do not find much evidence that migration adjusts to employment, either in the short or in the long run, so people follow jobs at most to a limited extent. Housing supply is a major determinant of net internal migration, while being quite unresponsive to demand factors. This is consistent with the notion that spatial policies put strong restrictions on housing supply, and therefore on the regional distribution of people. For example, our findings suggest that more people would have lived in densely populated areas under more accommodative housing supply schedules. Nevertheless, we do find a moderate effect of employment on growth of the housing stock, and hence indirectly on the regional population. But the indirect long-run effect of housing supply on the regional distribution of jobs turns out to be much larger.

A sensitivity analysis indicates that the evidence is robust to a fairly broad range of specifications, see Appendix 3. In particular, coefficients are found to be remarkably homogeneous over central and peripheral regions. Therefore, although urban processes may have played an important role in shaping the data, our results may be interpreted in a regional context as well.

6 Labour supply or local consumer demand?

One of our main findings with respect to population-employment interaction is that jobs follow people in the long run. It is not a priori clear however, whether this adjustment is triggered by labour supply or consumer demand. This section sets out to throw some light on the issue by disaggregating employment into two broad industrial sectors. We distinguish production for *local consumption*, such as groceries or health care, and production for *export* to other regions or countries, like agriculture or insurance.[34] These sectors may also be interpreted as producing nontradables and traded goods respectively. If it is consumer demand that causes employment to adjust, then only the former sector should respond to population changes. On the other hand, if employment in the export sector adjusts to population in the same way, it is more likely that labour supply has been the main reason for equilibrium adjustment.

Using the employment equation of (4.5) as a starting point, we derive a simultaneous model for employment growth in two sectors. Firstly, we replace employment by sector-specific employment, and we allow all coefficients and fixed effects to vary over the two sectors. The regional labour market equilibrium interpretation of the long-run effects no longer holds when we disaggregate employment. Hence, we do not distinguish between density and equilibrium adjustment effects in this specification. Secondly, we include employment growth and its lagged level in the other sector. Employment growth in one sector may attract employment growth in the other through linkages, but it may reduce it because of competition for scarce labour. Using the superscripts *EX* and *LO* for the export and local sectors respectively, we obtain the following specifications:

$$\begin{aligned}\Delta emp_{r,t}^{EX} &= e_r^{EX} + f_t^{EX} + \delta_1^{EX}\Delta\overline{pop}_{r,t} - \left(1-\delta_3^{EX}\right)emp_{r,t-1}^{EX} + \left(\delta_1^{EX}+\delta_2^{EX}\right)\overline{pop}_{r,t-1} \\ &\quad + o_1^{EX}\Delta\overline{els}_{r,t} + o_2^{EX}\overline{els}_{r,t-1} + o_3^{EX}SHA_{r,t}^{EX} + o_4^{EX}pro_{r,t-1}^{EX} \\ &\quad + o_5^{EX}\Delta emp_{r,t}^{LO} + o_6^{EX}emp_{r,t-1}^{LO} + w_{r,t}^{EX}\end{aligned},$$

$$\begin{aligned}\Delta emp_{r,t}^{LO} &= e_r^{LO} + f_t^{LO} + \delta_1^{LO}\Delta\overline{pop}_{r,t} - \left(1-\delta_3^{LO}\right)emp_{r,t-1}^{LO} + \left(\delta_1^{LO}+\delta_2^{LO}\right)\overline{pop}_{r,t-1} \\ &\quad + o_1^{LO}\Delta\overline{els}_{r,t} + o_2^{LO}\overline{els}_{r,t-1} + o_3^{LO}SHA_{r,t}^{LO} + o_4^{LO}pro_{r,t-1}^{LO} \\ &\quad + o_5^{LO}\Delta emp_{r,t}^{EX} + o_6^{LO}emp_{r,t-1}^{EX} + w_{r,t}^{LO}\end{aligned}. \qquad (6.1)$$

[34] Our local consumer supply sector consists of “merchandise, catering and repair”, “real estate, other services in the third sector and health care” and “government”. Our export sector consists of “agriculture and fishery”, “manufacturing”, “construction”, “transport and communications” and “banks and insurance”. Because of the limited number of industries distinguished, our subdivision is necessarily rough..

These equations are estimated with 2SLS, using the sector-specific share variables as instruments for employment growth in the other sector. For both sectors, Hausman tests reject exogeneity of this variable. Results are presented in Table 6.1.

Table 6.1 Employment growth $\Delta emp^{S}_{r,t}$ in export and local sector

	Export	Local
Population growth $\Delta \overline{pop}_{r,t}$	– 0.062 (0.383)	– 0.357 (0.236)
Growth expected labour supply $\Delta \overline{els}_{r,t}$	1.532 (1.545)	1.281 (1.278)
Lagged expected labour supply $\overline{els}_{r,t-1}$	– 0.637 (0.274)	– 0.053 (0.298)
Share $SHA^{S}_{r,t}$ (sector-specific)	0.747 (0.264)	0.986 (0.312)
Productivity per capita $pro^{S}_{r,t-1}$ (sector-specific)	0.015 (0.011)	0.027 (0.027)
Employment growth in other sector $\Delta emp^{-S}_{r,t}$	– 0.459 (0.379)	– 0.166 (0.179)
Lagged employment in other sector $emp^{-S}_{r,t-1}$	– 0.074 (0.080)	– 0.024 (0.028)
Lagged sector-specific employment $emp^{S}_{r,t-1}$	– 0.118 (0.023)	– 0.178 (0.053)
Lagged population $\overline{pop}_{r,t-1}$	0.292 (0.080)	0.174 (0.091)
Region dummies e^{S}_{r} (39)	included	included
Year dummies f^{S}_{t} (29)	included	included
R^2 (weighted)	0.346	0.256

Notes: Estimates of the sector-specific employment equations in model (6.1). Observations are weighted to regional employment averaged over time. The outlier region of Flevoland is left out of our sample. The equations further include a number of dummies that control for administrative shifts in regional borders, which are not reported in the table. Standard errors, reported in brackets, are robust to heteroskedasticity and autocorrelation over time. Both equations are estimated with 2SLS, where employment in the other sector is instrumented by its share.

In both sectors, population growth $\Delta \overline{pop}_{r,t}$ has no statistically significant short-run effect, and in particular, the effects are not statistically distinct between sectors. The expected labour supply effects $\Delta \overline{els}_{r,t}$ and $\overline{els}_{r,t-1}$ are statistically insignificant in both sectors.[35] The labour demand variables $SHA^{S}_{r,t}$ and $pro^{S}_{r,t-1}$ are not statistically distinct for the two sectors, but interestingly, the shares predict employment growth much better in these sector-specific models than in the aggregate employment equation. Employment growth in the other sector $emp^{-S}_{r,t}$ appears to affect sector-specific employment growth negatively, both in the short and in the long run. However, these effects are not statistically significant either.

Lagged sector-specific employment $emp^{S}_{r,t-1}$ affects growth downwardly, and the lagged population $\overline{pop}_{r,t-1}$ has a significant positive effect in both sectors. Interpretation of these effects is not so straightforward, as we cannot decompose these findings into density effects and adjustments on regional labour markets. However, it is clear that lagged population does not affect employment growth less in the export sector than in the local consumption sector. On the contrary, the point estimate appears to be higher. Furthermore, we remark that the effect of $emp^{S}_{r,t-1}$ is smaller in the export than in the local consumption sector. Together with the findings for lagged population, this suggests that there is a positive effect of employment

[35] The only exception is a significantly negative long-run effect of expected labour supply in the export sector, which is difficult to reconcile with economic theory.

density on growth in the export sector. To the extent that this variable reflects economies of agglomeration, it is not surprising that it plays a larger role in the export sector than in the local consumption sector.

So is it labour supply or local consumer demand that drives employment growth? Based on the estimates in Table 6.1, we have several reasons to believe that the labour supply effect dominates. In the first place, lagged population affects employment growth in the export sector at least as strongly as in the local sector. We would not expect to find this if local consumer demand was the major motivation for jobs to follow people. In the second place, employment growth in another sector affects sector-specific employment growth negatively, suggesting that labour supply constrains employment growth. The notion that employment growth is restricted by labour supply is also consistent with the finding that sector-specific shares predict sector-specific employment growth well, but that this does not hold for the aggregate. Apparently, sectors can grow at the expense of each other, but aggregate labour supply does not accommodate changes in demand that are induced by national industry-specific developments.[36] Finally, the other demand side variable, value added per worker, is also statistically insignificant in all employment equations, suggesting that employment growth is supply, rather than demand driven.

[36] In our sensitivity analysis (Appendix 3), we find that the share plays a more significant role in peripheral regions. This finding is consistent with the above argument, because labour markets tend to be tighter in core regions. In other words, labour supply is somewhat less likely to constrain employment growth in peripheral than in core regions.

7 Conclusions

Much of the population-employment interaction literature ignores housing supply, either implicitly or explicitly assuming that it will fully accommodate any changes in the regional population. However, our empirical analysis indicates that, at least in the Netherlands, housing supply is not quite as accommodative as is generally thought. Potentially related to restrictive spatial policies, this variable seems to be a major determinant of the regional population instead. Employment adjusts to the regional distribution of people in the long run, while it is only marginally affected by demand side variables. A sector-specific analysis suggests that the adjustment of employment restores equilibrium on regional labour markets, and is not predominantly driven by the demand for nontradable consumption goods. All national developments and time-invariant regional heterogeneity are controlled for, and a sensitivity analysis indicates robustness of our results to several alternative specifications.

From an economic perspective, these findings make sense. One would expect the regional demand for labour to be elastic with respect to wages, in particular in a small and open economy such as the Netherlands. On the other hand, the regional supply of labour may be quite inelastic. Migration must be an important component of the long-run regional adjustment of labour supply, but labour is known to be rather immobile, in particular in most European countries. This immobility is enhanced by rigid housing supply. Even if migration patterns would be highly sensitive to real wages, then labour supply would still be inelastic if housing supply were inelastic. Hence, employment would relatively easily adjust to the regional distribution of people, but the reverse is less likely to occur.[37]

Arguably, shifts in the regional distribution of people and jobs have been shaped significantly by the process of urban sprawl or suburbanisation. Rising incomes and falling transport costs may explain the sizeable population loss of the large Dutch cities in the past decades.[38] Our estimates confirm that housing supply and population growth have been larger in less densely built-up areas. Restrictions on construction at the boundaries of these cities as well as on some neighbouring regions may further explain the particular spatial pattern of growth that has been realised. The Flevoland region provides a nice illustration of the mechanisms we identified. Created on newly drained land and largely unaffected by building restrictions, this region has accommodated many people who desire a more spacious dwelling outside the city of

[37] Blanchard and Katz (1992) find for the US that shocks in labour demand are largely absorbed by migration in the long run, and that employment is not so wage elastic. However, we have argued that regional labour demand is likely more elastic, and migration and housing supply are less elastic in the Netherlands.

[38] These is a competing explanation for urban sprawl, generally referred to as the "flight from blight" hypothesis, which asserts that rich households have left city centers because of a lack of public goods like high-quality schools and protection against crime (cf. Nechyba and Walsh, 2004). As the provision of such local public goods is generally more evenly spread over locations in the Netherlands than in the US, and perhaps also at a higher level, this explanation seems less relevant in the context of our analysis.

Amsterdam. Although a large share of the inhabitants still commute to Amsterdam nowadays, employment in Flevoland has made a substantial adjustment to the emerged regional supply of labour.

As our analysis includes only a limited number of labour demand side variables, we can draw rudimentary conclusion at best with respect to the role of demand in determining employment growth. Nevertheless, the statistical insignificance of variables like employment density, the share and value added per worker do suggest that this role is modest. These findings contrast in particular with certain core-periphery models from the New Economic Geography literature, in which agglomeration economies determine the spatial distribution of the population through labour demand (cf. Fujita et al., 1999). Perhaps, such agglomeration forces are not always as relevant empirically as this literature tends to suggests. At least, it does appear that they have not been a major determinant of changes in the spatial distribution of economic activity in the Netherlands over the past decades.[39]

Given the limited data availability for our period of observation, the conclusion that jobs follow people has to be put into perspective as well. We have not been able to account for heterogeneity of the population in terms of, for instance, educational attainment. Higher educated workers possibly choose to live near suitable jobs. As housing supply is restrictive, they may outbid lower educated workers for scarce housing, so that aggregate population growth is not responsive to employment opportunities. Hence, the conclusion that people do not follow jobs may not hold for all subgroups of the population. Similarly, our finding that regional employment growth is mainly supply induced does not necessarily hold for all segments of the labour market.

Notwithstanding these qualifications, we think that two useful lessons can be drawn from our analysis for spatial policy. In the first place, the evidence that, in the long run, employment is mainly determined by labour supply, suggests that demand side policies, such as land subsidies for firms or investment in regional infrastructure, may not be so helpful in attracting jobs. In view of the popularity that such policies have enjoyed both in the Netherlands and in the European Union, it seems worthwhile to point this out.[40]

In the second place, a plausible reading of our findings is that people move to regions where houses are built, but houses are not necessarily built in regions were people would want to live. For example, our findings suggest that more people would have lived in densely populated

[39] In the absence of labour mobility, economies of agglomeration may still play a role trough input-output linkages. See Puga (1999) for a discussion of the role of labour mobility in models with agglomeration economies.

[40] Obviously, this conclusion may not hold in countries where labour supply exceeds demand by far. Note for instance, that the sensitivity analysis in Appendix 3 suggests that demand side variables like the share play a more significant role in peripheral regions than in the core.

areas under more accommodative housing supply schedules. Restrictive spatial policies in the Netherlands are probably an important culprit. Obviously, a full assessment of costs and benefits of such policies is far beyond the scope of our analysis, which is essentially reduced-form. Nevertheless, the costs in terms of welfare associated with a mismatch between regional demand and supply for housing are likely to be substantial. Moreover, our findings indicate that the effects of such policies spill over to other markets, such as the labour market. To the extent that agglomeration externalities in either consumption or production play a role, the incurred losses may therefore be even larger.

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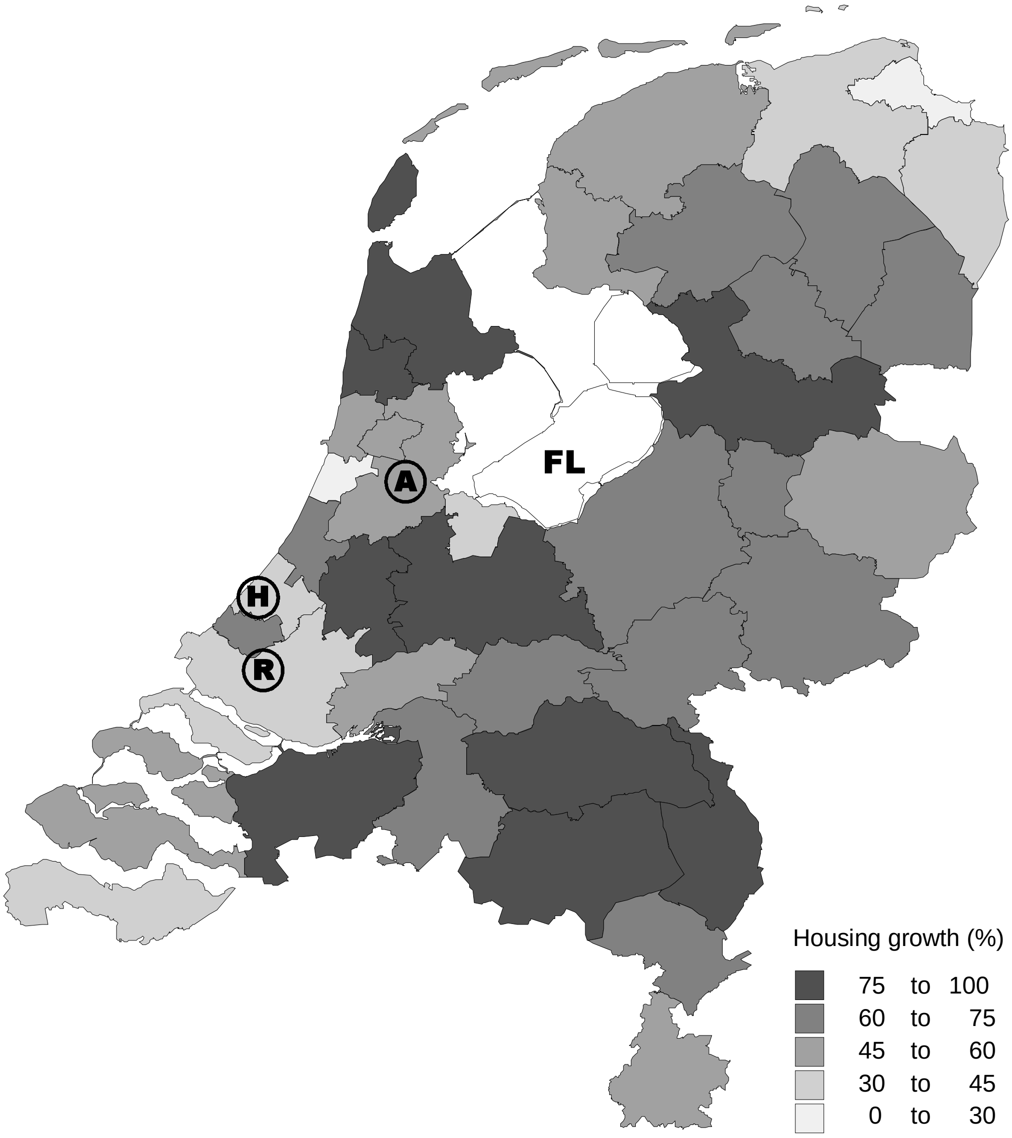
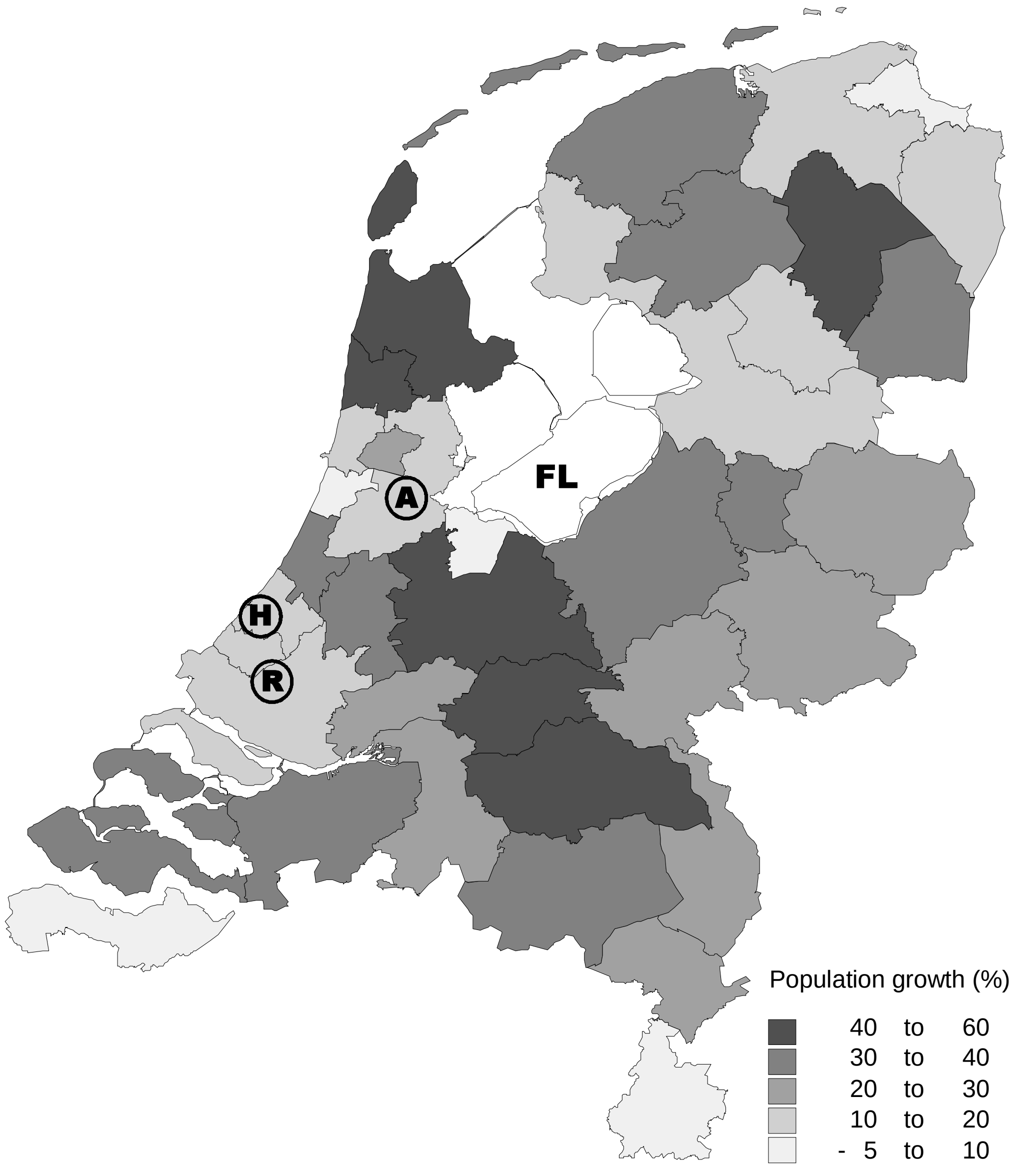
Appendix A: data and tables for exploratory analysis

Figure A.1 **Growth of the regional housing stock 1973 - 2002**



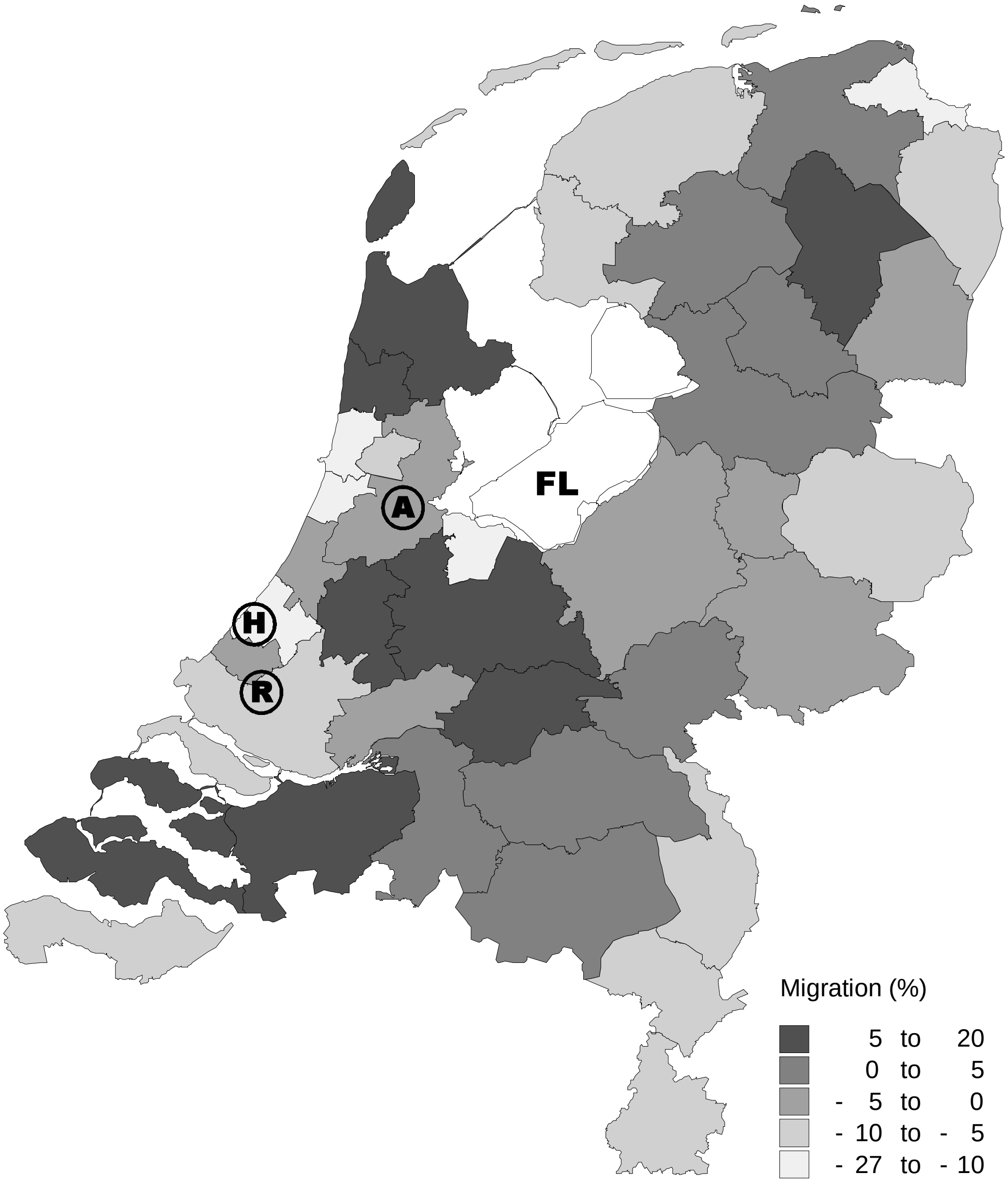
Notes: The cities of Amsterdam, The Hague and Rotterdam are denoted by A, H and R respectively. The housing stock in the region of Flevoland (FL) has increased by more than a factor 6, so it is not shown in this map.

Figure A.2 Growth of the regional population 1973 - 2002



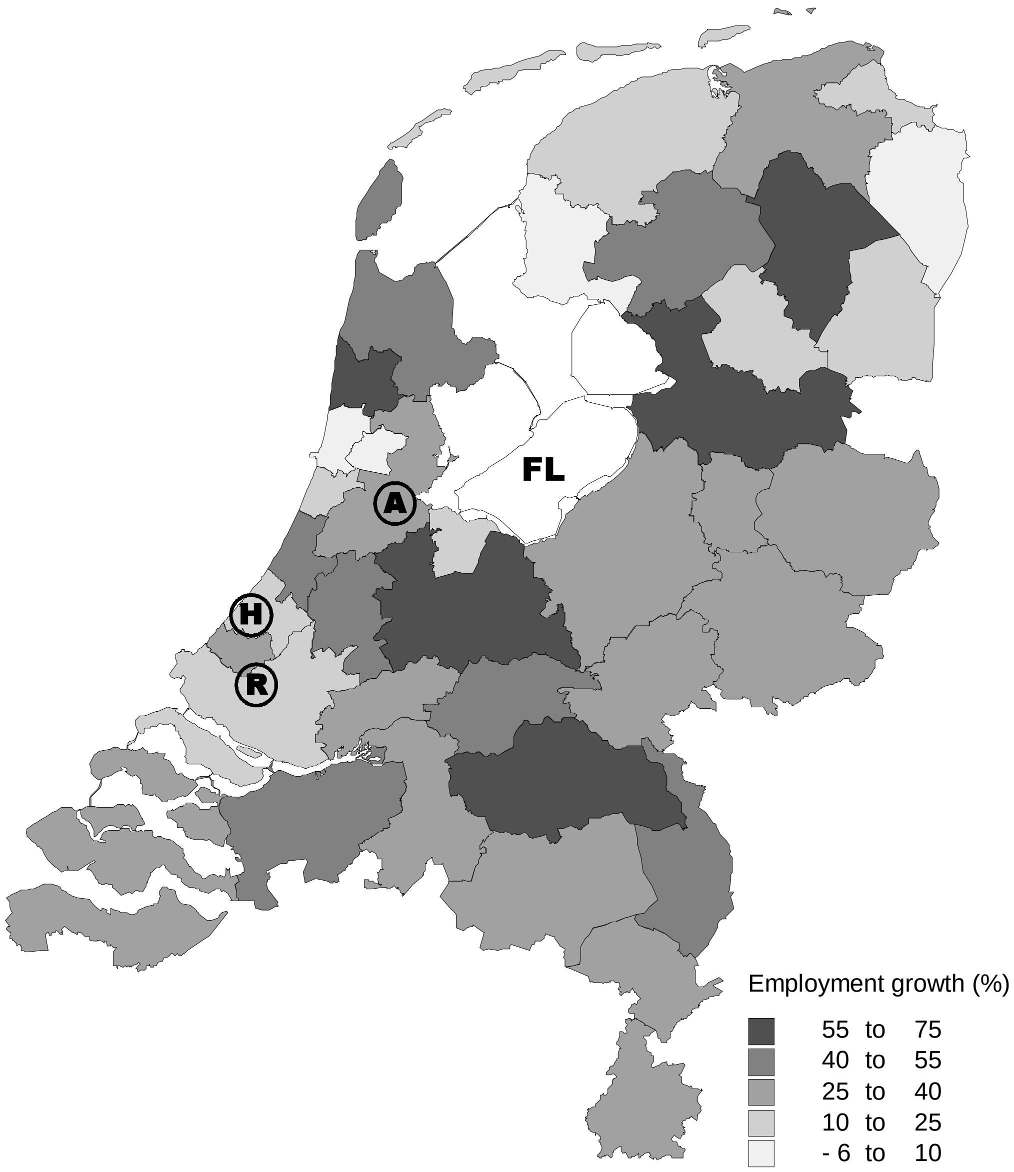
Notes: The cities of Amsterdam, The Hague and Rotterdam are denoted by A, H and R respectively. The population in the region of Flevoland (FL) has increased by almost a factor 15, so it is not shown in this map.

Figure A.3 Net internal migration rate 1973 - 2002



Notes: The migration rate is computed as total net incoming migration from 1972 until 2002, divided by the regional population in 1972. The cities of Amsterdam, The Hague and Rotterdam are denoted by A, H and R respectively. Total incoming migration in Flevoland (FL) exceeds the population in 1972 by almost a factor 10, so it is not shown in this map.

Figure A.4 Regional employment growth 1973 - 2002



Notes: The cities of Amsterdam, The Hague and Rotterdam are denoted by A, H and R respectively. Employment in the region of Flevoland (FL) has increased by almost a factor 5, so it is not shown in this map.

Table A.1 Pairwise correlations of dependent variables, yearly observations

Region and time fixed effects:	Excluded		Included	
	Coefficient	R^2	Coefficient	R^2
Housing growth $\Delta hou_{r,t}$				
Fixed effects only	–			0.745
Population growth $\Delta pop_{r,t}$	0.752 (0.064)	0.502	0.420 (0.073)	0.819
Migration $NIM_{r,t}/POP_{r,t-1}$	1.031 (0.114)	0.305	0.805 (0.039)	0.880
Employment growth $\Delta emp_{r,t}$	– 0.032 (0.009)	0.014	– 0.000 (0.007)	0.745
Population growth $\Delta pop_{r,t}$				
Fixed effects only	–			0.680
Housing growth $\Delta hou_{r,t}$	0.668 (0.038)	0.672	0.684 (0.086)	0.779
Migration $NIM_{r,t}/POP_{r,t-1}$	1.101 (0.072)	0.604	0.909 (0.061)	0.823
Employment growth $\Delta emp_{r,t}$	– 0.018 (0.011)	0.319	0.008 (0.010)	0.680
Migration $NIM_{r,t}/POP_{r,t-1}$				
Fixed effects only	–			0.271
Housing growth $\Delta hou_{r,t}$	0.292 (0.044)	0.309	0.656 (0.066)	0.656
Population growth $\Delta pop_{r,t}$	0.381 (0.049)	0.423	0.492 (0.080)	0.597
Employment growth $\Delta emp_{r,t}$	0.018 (0.008)	0.014	0.015 (0.010)	0.275
Employment growth $\Delta emp_{r,t}$				
Fixed effects only	–			0.424
Housing growth $\Delta hou_{r,t}$	– 0.286 (0.072)	0.025	– 0.017 (0.147)	0.433
Population growth $\Delta pop_{r,t}$	– 0.144 (0.113)	0.017	0.094 (0.110)	0.424
Migration $NIM_{r,t}/POP_{r,t-1}$	0.504 (0.193)	0.025	0.311 (0.161)	0.426

Notes: Estimates in left columns are obtained by bivariate regressions, including constants and controls for administrative shifts in regional borders. Estimates in right columns include region and period dummies as well. Observations are weighted to the regional housing stock, population and employment respectively, averaged over time. The outlier region of Flevoland is left out of our sample. Standard errors, reported in brackets, are robust to heteroskedasticity and autocorrelation over time.

Appendix B: Accounting for interregional commuting

In the population-employment interaction model derived in section 2 we use weighted regional population $\overline{POP}_{i,t}$ and employment $\overline{EMP}_{i,t}$, in order to account for interregional commuting. To this aim we use weight matrices W^1 and W^2, which are applied to regional employment in the first two equations, and to regional population in the third equation of (4.1) in Section 4. .

We compute $\overline{EMP}_{i,t} = \sum_j w_{ij}^1 EMP_{j,t}$, where w_{ij}^1 may be interpreted as the probability that someone working in region *j* lives in region *i*. Multiplying this probability by employment in region *j* we get the expected number of people working in *j* that live in region *i*, and summing over employment regions yields the expected working labour force in region *i*. Similarly, we compute $\overline{POP}_{i,t} = \sum_j w_{ij}^2 POP_{j,t}$, where w_{ij}^2 may be interpreted as the probability that someone living in region *j* would work in region *i*. Multiplying this probability by population in region *j* we get the expected number of people living in region *j* that potentially work in region *i* (the probability is also applied to people that do not participate). The sum over population regions yields weighted potential labour supply for production in region *i*.

In order to avoid endogeneity of the weight matrices, the elements w_{ij}^1 and w_{ij}^2 are computed using predicted, rather than observed commuting patterns. We predict commuting flows with following gravity model:

$$COM_{ij,t} = A_i B_j F(d_{ij}) \qquad \text{(B.1)}$$

The variable $COM_{ij,t}$, the number of commuters living in region *i* and working in region *j*, is explained by origin and destination-specific effects A_i and B_j, and a distance decay function $F(d_{ij})$. None of the parameters depends on the period *t*, we use the variation in commuting flows over time only to obtain more precise estimates. The distance decay function is parameterized as follows:

$$F(d_{ij}) = \exp(\alpha_i D_i^1 + \beta_i D_i^2 + \gamma_i d_{ij}) \qquad \text{(B.2)}$$

So we assume that the number of commuters between two regions decreases exponentially with distance. The dummy variable D_i^1 corrects for commuting within regions and the dummy variable D_i^2 measures border effects. In order to account for regional heterogeneity, we allow all coefficients to vary with the region of living. The parameters α_i, β_i and γ_i are estimated on 1992 – 2002 commuting data from the Dutch Labour Force Survey. Distance between two regions is measured by the average number of car kilometres travelled by commuters, because the largest share of interregional commuters travels by car.[41]

The probabilities w_{ij}^1 and w_{ij}^2 are computed using the predicted commuting flows from model B.2 in the following way:

$$w_{ij}^1 = \frac{A_i F(d_{ij})}{\sum_i A_i F(d_{ij})}, \qquad w_{ij}^2 = \frac{B_i F(d_{ji})}{\sum_i B_i F(d_{ji})}. \tag{B.3}$$

Note that $\sum_i w_{ij}^1 = 1$ and $\sum_i w_{ij}^2 = 1$, so that these weights can indeed be interpreted as probabilities.[42]

[41] Estimation results are available upon request.
[42] The matrices *W*[1] and *W*[2] differ from the spatial weight matrices that are common in spatial econometric applications **(**Anselin, 1988**)** in two perspectives. Firstly, numbers on the diagonal are smaller than one, because diagonal flows have been included in the commuting model. Secondly, computing the required probabilities amounts to column normalization, instead of the usual procedure of row normalization.

Appendix C: Sensitivity analysis

We have performed a number of specification checks to examine the robustness of our main findings.

First, we have investigated whether the inclusion of regional fixed effects is essential to our results. It turns out to be quite important to control for unobserved regional heterogeneity for our data. For example, none of the explanatory variables in the migration equation are statistically significant when we exclude the region dummies. The other equations are somewhat less sensitive, but differ significantly in their long-run behaviour. Note that these findings may be specific to our analysis, as the number of exogenous variables included is limited.

Second, we have experimented with variables excluded or included in the various equations. Excluding the employment variables from the housing equation, we found that the role of the demographic variables increased, and that housing growth adjusted somewhat towards a long-run relationship with population. Excluding the housing variables from the migration equation, we found an increased effect of population density, but no significant effect of employment variables. Housing supply variables were insignificant, when included in the employment equation. We also experimented with two other demand side variables, a measure for accessibility and a measure for regional specialization (the Herfindahl index). Both appeared statistically insignificant in the employment equation.

Third, we have experimented with various dynamic specifications. In general, entering more lags of housing, population and employment growth affected other coefficients. However, the sum of coefficients on first and second lags (second and third lags in the housing equation) was not statistically distinct from the coefficient on the first (second) lag in the original specification. Hence, including more lags does not alter our basic findings.

Fourth, we have checked the robustness to regional heterogeneity. Regions were subdivided into core and periphery regions, and we have taken up interaction effects of all variables with a periphery dummy. All interaction effects were insignificant, except for two. Migration appears to be somewhat more sensitive to employment growth in core regions, and employment growth appears to be somewhat more affected by the share in peripheral regions. We have also estimated the model including the region of Flevoland, which is treated as an outlier in our analysis. Results were robust to including observations for this region, only the long-run effect of population growth seemed to be somewhat reduced.

Finally, we have split the sample into two equal time periods. Again, interaction effects of all variables with a second period dummy were taken up. The demographic variables in the housing equation played a larger role after 1988, and adjustment of employment on regional labour markets appeared to be stronger before 1988. However, qualitative results were the same.

Given these sensitivity analyses, we may conclude that our main findings are robust to a fairly broad range of specifications.