POPULATION AGEING AND INFLATION WITH ENDOGENOUS MONEY CREATION

By Igor Fedotenkov

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The views expressed are those of the author(s) and do not
necessarily represent those of the Bank of Lithuania.

Abstract

This paper provides an explanation as to why population ageing is associated with deflationary processes. For this reason we create an overlapping-generations model (OLG) with money created by credits (inside money) and intergenerational trade. In other words, we combine a neoclassical OLG model with post-Keynesian monetary theory. The model links demographic factors such as fertility rates and longevity to prices. We show that lower fertility rates lead to smaller demand for credits, and lower money creation, which in turn causes a decline in prices. Changes in longevity affect prices through real savings and the capital market. Furthermore, a few links between interest rates and inflation are addressed; they arise in the general equilibrium and are not thoroughly discussed in literature. Long-run results are derived analytically; short-run dynamics are simulated numerically.

Santrauka

Šis straipsnis paaiškina kodėl populiacijos senėjimas yra asocijuojamas su defliaciniais procesais. Šiam tikslui mes sukūrėme persidengiančių kartų modelį, kuriame pinigai yra kuriami kreditais (vidiniai pinigai) ir vyksta prekyba tarp skirtingo amžiaus žmonių. Kitaip tariant, mes sujungėme neoklasikinį persidengiančių kartų modelį su pokeinsistine monetarine teorija. Modelis jungia demografinius faktorius, tokius kaip gimstamumas ir gyvenimo trukmė, su kainomis. Mes parodėme, kad mažesnis gimstamumas lemia mažesnę kreditų paklausą ir mažesnį pinigų kūrimą, o tai mažina kainas. Gyvenimo trukmės pokyčiai daro įtaką kainoms per realias santaupas ir kapitalo rinką. Be to, mes analizavome keletą sąryšių tarp palūkanų normų ir kainų, kurie atsiranda bendrojoje pusiausvyroje, ir šie sąryšiai iki šiol nebuvo išsamiai analizuoti mokslinėje literatūroje. Ilgojo laikotarpio rezultatai buvo gauti analitiškai, o trumpojo laikotarpio dinamika buvo analizuota skaitmeniniais metodais.

1 Introduction

Deflation is usually supposed to be harmful, because people expecting a decline in prices have incentives to cut their spending, thus reducing economic activity and leading to economic stagnation. Economic stagnation reduces incomes and induces a further decline in spending. During the recent economic crises, many central banks around the world implemented a number of measures to increase inflation and to stimulate economic activity, with different degrees of success. The problem of deflation has also increased the interest of researchers in this topic; they have discovered that population ageing is one of the main structural factors that reduces inflation (Yoon, Kim, and Lee 2014; Gajewski 2015). In this paper, in order to explain why population ageing leads to a decline in prices, we create a macroeconomic model with money created by credits. We also show that reduction of interest rates, which is sometimes performed by central banks in order to stimulate crediting, may also have a reverse effect in the medium and long run.

Up to 97 per cent of money in the UK is created by commercial banks whenever they make loans, while only 3 per cent of money is being created by the government.[2] In giving a loan, banks create new deposits, to which newly created money is transferred. When a debtor returns the credit, the money is destroyed. The processes of money creation and destruction are explained in detail by Hewitson (1995), McLeay et al. (2014), Werner (2014b) and Jakab & Kumhof (2015), and confirmed empirically (Werner 2014a; Werner 2016). We include them in an overlapping generations model (OLG). Loosely speaking, in our model the deflationary effects of population ageing come from the idea that young agents are usually liquidity-restricted: they take credits, and return them when they grow older. Consequently, population ageing reduces the number of credits and the stock of money in the economy, thus having a negative impact on prices. If demographic transition stops, the price level stabilises at its new equilibrium level over several periods. To our best knowledge, this is the first paper to introduce money creation by credits into the OLG framework.

Our model exploits the ideas that agents take credits when they are young. Fig. 1 presents distribution of credit margins in Lithuania at the end of 2014 by age. The data was taken from the PRDB database, maintained by the Bank of Lithuania. This Figure presents credits issued to natural entities in 2014 by commercial banks and does not account for credits provided by credit unions, leasing companies, etc. It also excludes loans taken and paid back in 2014. If

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two or more agents took a loan together, the loan value was divided by the corresponding number of agents. The agents' age corresponds to the end of 2014, and not to the exact date when the credit was received. The Figure shows that most loans were taken by young agents, the maximum corresponding to the age of 31 years. After the age of 31, the volume of credit margins sharply declines. The total amount of credit margins accumulated by agents younger than 40 constitutes 71.7 per cent of the total.

Figure 1: Credits by age in Lithuania, 2014
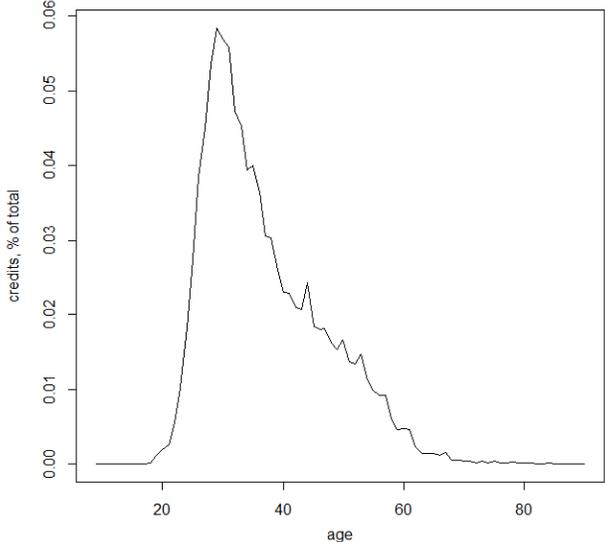
1.1 Literature review

The link between demographic factors and inflation was studied in a number of empirical and theoretical works; recent evidence shows that population ageing creates deflationary pressure. Yoon et al. (2014) analysed the IMF and World Bank data for 30 OECD countries over the period 1960–2013. They found that the population growth affects inflation in a positive way, while the share of agents in the population older than 65 has a negative impact on inflation. Gajewski (2015) focused on the data for 34 OECD countries over the period 1970–2013, and confirmed the aforementioned findings — that older societies are indeed associated with lower inflation.

The deflationary effects of population ageing in Japan where found by Anderson et al.

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(2014) and Carvalho & Ferrero (2014), with Faik (2012) making similar findings for Germany. However, Lindh & Malmberg (1998) and Lindh & Malmberg (2000) argued that only the share of agents aged 75+ in the population affects inflation in a negative way, while the young retirees (65–74) creating a positive impact. They have also found that young adults (15–29) have a positive impact on inflation. The positive effect of young retiree on inflation is explained as follows: since middle-aged agents supply savings, the older population has a negative impact on them. They assume that demand for investment funds and nominal interest rates are constant; therefore, lower savings result in an increase in prices. Similar results were also found by Juselius & Takáts (2015), who restricted their analysis to 22 OECD countries but covered the period of 1955–2010. Juselius & Takáts controlled for a large number of specifications, and reported that the share of young pensioners affects inflation in a positive way, while the share of older pensioners has a negative impact on inflation. Indeed, the inflationary effect of young pensioners is understood rather well: agents stop producing goods and begin supplying money when they retire, which leads to an increase in prices. However, the deflationary effect of older pensioners is not as clear and hence this question is the focus of our paper.

Doepke & Schneider (2006), Bullard et al. (2012) and Katagiri et al. (2014) studied the political aspects of inflation as a tool for wealth redistribution. They argued that inflation redistributes wealth between lenders and borrowers. As young agents are usually borrowers and old ones are savers, lower inflation is beneficiary for the old agents. Consequently, population ageing increases the voting power of the older generation, pressing governments to keep inflation at a low rate. However, Katagiri et al. also argued that population ageing, arising from a decline in the birth rate, shrinks the tax base and increases government expenditure thus having a positive influence on inflation. The paper by Bullard et al. is also related to our work, as they employed an overlapping generation model with money. Our model differs from this article mainly in the way how the money market is constructed. In their paper, the stock of money is exogenous and determined by the government; in our model, money is created by credits. This allows us to study a macroeconomic link between demography and inflation instead of the political one.

Adding inside money into the model essentially changes the understanding of the link between ageing and inflation, relative to the models discussed above. In our setting there is no need for a government that determines inflation for redistributive or fiscal reasons; however, demographic factors affect prices via the credit market, since a smaller share of young agents in a population reduces demand for credits. Hence, a smaller amount of money is created, having

a downward effect on prices. In fact, we do not argue that the political channels do not exist. They may exist if central banks are politically dependent on governments, and sometimes it is reasonable to admit that they are not as independent as is officially declared. In contrast to the existing literature, we instead show that there is also a direct credit channel, which does not depend on political issues.

Regarding the link between demographics and inflation, it should also be mentioned that Imam (2013) showed that population ageing makes monetary policies less effective in five developed economies: the US, Canada, Japan, UK, and Germany. He also showed that the credit channel of monetary policy transmission, which is the focus of our paper, outweighs the wealth channel. These empirical findings are well in line with the predictions of our model.

In developing our model with money created by credits, we take an OLG model, introduced by Samuelson as a starting point (Samuelson 1958). Samuelson analysed an intergenerational trade in a three-periods OLG model. He argued that the older generation may "bribe" the younger generation to support them when they become old. He showed that in this case the socially optimal interest rate is equal to the population growth. We add a number of modifications to Samuelson's model. First of all, incentives for intergenerational trade in our models arise not only from the will of the second generation to get support in future but also from the needs of the first generation: young agents are often constrained by liquidity, and they need to borrow resources from the older cohort. Second, there is no direct "bribing" in our model – we introduce a bank, which serves as an intermediary between the generations. The bank issues credits, creating fiat inside money. Money can be used for trade between generations, and they are saved in a bank account, providing a positive nominal interest rate in the next period. Such a setting allows us to analyse the interconnection between real and monetary factors, such as demography and price level.

OLG models with money were discussed in detail by Champ & Freeman (1994). In their models, money serves for savings, which are stored for the next period, as a numeraire and means of exchange, one of the results being that a switch from commodity money to fiat money can be welfare-improving, since, instead of storage, commodity can be consumed (p. 46). The other example of an OLG model with money is that of Crettez et al. (2002), who looked for optimal monetary and fiscal policies in a two-overlapping-generations model and found that one of the policies is redundant. Hiraguchi (2014) reexamined their results in a three-overlapping-generations model, finding that the optimal monetary policy follows the Friedman rule. Unfortunately, money in the previous OLG models was supposed to be exogenous, and

it was determined by a distribution of initial money endowments or government's decisions. Such a framework is not convenient for studying the link between demographic factors and inflation. However, we follow Hiraguchi in assuming that there are three periods in the model, because such a setting assures different attitudes of agents towards money in different periods, and makes money demand and supply conditions non-trivial; however, our definition of periods is different: for simplification, instead of two working periods, we assume that there is one period of childhood and another of adulthood.

Our model also relates to the research works, which study the role of banking in OLG models. Qi (1994) analysed bank liquidity and stability in OLG models. He showed that the government shall provide insurance for deposits, as there can be bank runs due to either the shortage of new deposits or excessive withdrawals. Amable et al. (2002) showed that deposit insurance and banks' entry restriction do not always maximise welfare, even if positive bankruptcy costs are assumed. Therefore, a careful assessment of costs and benefits is required. Andolfatto & Gervais (2008) created an OLG model with endogenous credit constraints, which emanate directly from a life-cycle assumption. They showed that the ability of creditors to garnish increases the amount of credits received by agents; however, it may also reduce the capital stock, leading to lower welfare. Our work differs from these articles in two main aspects – First, the topic is different; we focus on the link between demographic factors and prices. Second, in our model, the interaction between the bank and agents is performed in terms of inside money, which is in the form of the bank's records; the other models use commodity money or goods for this reason.

Creation of money through loans, which is the key feature of our model, was discussed in detail by post-Keynesian economists (Kaldor 1970; Moore 1979; Cottrell 1986; Cottrell 1994; Lavoie 2011). However, the post-Keynesian monetary theory is not accepted worldwide, largely because of its non-mathematical nature. Ignorance of mathematical equations makes verifying the theory and making quantitative predictions difficult. Moreover, its non-mathematical nature makes it difficult to see the limitations of assumptions. Our paper aims to overcome this barrier. We introduce post-Keynesian money creation into the neoclassical OLG framework. This allows us to study the effects of intergenerational trade – a process that is usually disregarded by post-Keynesians. We derive the long run results analytically and simulate the dynamics of the model in the short run.

In fact, a few attempts were made in the past to introduce mathematics into the post-Keynesian monetary theory. Cavalcanti & Wallace (1999) created a model with a post-

Keynesian money creation by credits. They showed that inside money (money created by commercial banks) can mimic outside money (money issued by someone else, such as the central bank), because they are used in a similar way. However, with outside money, the purchasing capability of a banker depends on the banker's previous trades, while with inside money, this is not the case, as the banker may create new additional money at any time. As a result, outside money creates a larger variety of outcomes. Andolfatto & Nosal (2001) argued that money created by banks is efficient because they allow exchange of goods at no costs, and the direct billing between agents is impossible because not all individuals commit to their promises. Disyatat (2011) emphasised the role of the banks as transmission mechanisms for monetary policies via their balance sheets and risk perception. Jakab & Kumhof (2015) created a DSGE model with "financing throw money creation" (FMC), and compared its performance to a model with the standard intermediation of loanable funds (ILF). They showed that, under identical shocks, FMC models predict much larger and faster effects on the bank's balance sheets and greater effects on the real economy than ILF models. They argued that predictions of FMC models are more realistic. In our paper, we assume a similar role of credits and the same money creation. But, in contrast to this literature, our model also features money demand by agents for saving reasons, as it is common in the overlapping generations models (Champ and Freeman 1994).

Apart from the link between demographic factors and price level, we also study the effects of interest rates on it. We enumerate four different effects which affect prices in the steady state. First, interest rates impact demand for money via the intertemporal allocation of consumption (the sign of the effect depending on the elasticity of substitution). The second effect comes from the fact that agents, who need to return their credits, enhance their demand for money, which leads to money appreciation and a decline in prices. The third effect is due to savings: having returned credits at a higher interest rate, agents receive smaller net incomes and they save less. This reduces their demand for money and leads to an increase in prices. The fourth effect comes from the fact that higher interest rates increase the monetary income of the older generation, in turn increasing expenditure and affecting prices in the positive way. Given a bank's zero-profit condition, second and fourth effects eliminate each other, the total effect depending on the parameter values. But, as we argue in the text, it is likely that increasing interest rates positively affect the prices in the long run. This resembles Gibson's paradox (Gibson 1923; Keynes 1930), which was observed in the short run. In our model, the link between interest rates and price level in the short run depends on parameter values, and it

may correspond or not correspond to Gibson's paradox.

The paper is organised as follows: in the following section, the model is developed and long-run results are derived; the third section presents a numerical example showing the dynamics of the model in the short run; the fourth section discusses the robustness of the results, the limitations of the model and its possible extensions. Finally, the fifth section presents the conclusion.

2   The model

We employ a discrete-time overlapping-generations (OLG) model in the Diamond-Samuelson style (Samuelson 1958; Diamond 1965) with agents who live through three periods: childhood, years of employment and retirement. Agents have children when they enter the second period of their lives.

We denote the size of the generation born in the period t by N_t. At the beginning of the working period, they have N_{t+1} children, $N_{t+1} = N_t(1 + n_{t+1})$.

Period t is populated by children (N_t), adults (N_{t-1}) and senior generation (N_{t-2}). During their childhood, agents do not receive any income and are supported by their parents, if they receive positive incomes. At the end of their childhood, young adults take a credit from a bank to buy physical goods, which are invested into physical capital. Agents at the working age inelastically supply one unit of labour. They receive incomes, if they have a positive productivity shock, and make savings-consumption decisions (their consumption is shared with their children). At the beginning of the last period, agents may die with a probability of $1 - \psi$, hence, ψ is a probability that agents live during the whole third period of their lives. Under such a construction of overlapping generations, one period lasts for approximately 25–30 years.

2.1   Banking sector

In the model, the bank has the features of a commercial bank, pension fund and insurance company since it gives risky credits to young agents of the size M at the lending interest rate $1 + r_t^l$; its liabilities circulate in the economy in the form of account records and are used as money (bank service); it holds safe deposits at the interest rate $1 + r_t^d$, which are consumed during the last period of the agent's life (pension fund); and it redistributes funds of those people who passed away before the third period of their lives to the surviving agents of the

same generation (insurance company).

At the end of the first period of their lives, agents receive credits of size M, and open accounts with deposits in the bank of the same size. The deposits are in the form of bank records. Then, young agents use these deposits to buy physical goods from the middle-aged generation, which is at the end of their second period of lives, as a result, the owner of the deposit changes. The same happens to the money stored by the older generation in their deposits. The agents from the older generation buy physical goods for consumption from the agents in the second period of their lives, and, as a result, the owner of the deposits changes as well. The generation that is in the second period of its life becomes the unique owner of the deposits in the bank. It uses the money in these deposits for two purposes. First, to return the credit that they took in the previous period, the return of these credits destroys a part of the money in the economy. Second, they continue keeping money in the bank deposit in order to use it they grow old. Hence, the relation between the interest rate on savings depends not only on the interest rate on deposits, but also on the price at which real goods are sold and bought:[3]

$$1 + r_{t+1}^s = \frac{(1 + r_{t+1}^d)\pi_t}{\pi_{t+1}}. \tag{1}$$

r^s denotes returns on savings, π being the price of physical goods. Following Disyatat (2011), we make the assumption that the bank does not make a profit, i.e the returns to loans are allocated to the deposit owners.

$$p(1 + r_t^l) = 1 + r_t^d, \tag{2}$$

where p is the probability of non-default. The logic of this nonprofit condition is the following. Suppose that at a certain point of time the bank is introduced into the model. Having issued a credit, the bank automatically creates a deposit of the same size. Credit is an asset for the bank and deposit is a liability. In the next period, assets rise by $p(1 + r_t^l)$ ($1 - p$ agents do not return the credit) and the value of liabilities increases by $1 + r_t^d$. The nonprofit condition implies that bank's assets and liabilities are equal to each other also in the beginning of the next period. This logic is presented more formally in the Appendix.

The bank's liabilities are in the form of inside money kept by agents (monetary assets), the bank's assets (credits), can be viewed as agents' liabilities. Therefore, the zero-profit condition also implies that agents' monetary assets and liabilities are equal to each other. As a result,

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[3]We do not need to assume annuity markets for now, they will be assumed later.

there is always enough money in the economy for agents to return their credits.

2.2 Production

All agents in our model are self-employed. At the end of their childhoods, agents take credits from a bank of the size M, buy physical capital with this money, and invest it in their own business, which may or may not be successful.

$$k_t = \frac{M}{\pi_{t-1}}, \tag{3}$$

where π_{t-1} denotes the price of the goods in terms of money in the period $t-1$ (agents working in the period t need to buy physical capital a period in advance). Agents supply one unit of labour during their life-time. Furthermore, an agent i, working in the period t, faces a productivity shock $A_{i,t}$. Therefore, agents produce:

$$y_{i,t} = A_{i,t}f(k_t), \quad i = 1...N_{t-1}, \tag{4}$$

where $f(k_t)$ is an increasing concave production function, $f(0) = 0$. Capital depreciates after it was used for production. Hence, agents' gross income is equal to their production.

There are two possible outcomes of the productivity shock: $A_{i,t} = 1$ with the probability p, and 0 with the probability $1-p$. We suppose that these shocks are independent in time and between agents. Therefore, if the number of agents is sufficiently large, the aggregate output is equal to

$$Y_t = \sum_{i=1}^{N_{t-1}} A_{i,t}f(k_t) = pN_{t-1}f(k_t). \tag{5}$$

Having received outputs, those agents whose productivity shock was positive need to return credits to the bank. Therefore, their net income expressed in real goods is equal to

$$w_{i,t} = f(k_t) - \frac{M}{\pi_t}(1 + r_t^l). \tag{6}$$

We need to assume that the interest rate is not too high, so that agents' real incomes would be nonnegative. Those agents, whose productivity shock was bad, cannot return the credit. They do not save or consume and, as a result, they do not participate in the economic life anymore. However, their children survive and may take credits in order to start their own

business.

Our aggregate production function Y_t resembles the standard neoclassical one with constant returns to scale. Indeed, post-Keynesian economists often use their own approach for production modeling. They assume that firms have reserves of real capital and can easily find labour in the market, which implies that supply of goods is completely determined by demand (Dutt 2011). Such an approach has advantages in certain cases. For example, imagine an economy recovering after an economic crisis, which caused a decline in production and an increase in unemployment. It is very possible that, in such a case, the firms would have some excessive amounts of real capital and could easily employ labour. However, in a three-periods OLG model, one period corresponds to 25–30 years. It is very unlikely that someone wants to keep excessive amounts of real capital for such a long period of time. Moreover, everyone can be unemployed for a year or two, but, during such a long time period, most (non-disabled) agents of working age do work if they wish to. As a result, the neoclassical-type production function, which assumes full factor employment, seems to be more reasonable in our case. It would be even more realistic to assume an endogenous labour supply, coming from utility maximisation, but we will leave it for further extensions.

2.3 Saving-consumption behaviour

We suppose that only agents with a positive productivity shock consume. Agents who have a bad shock get zero income and do not participate in economic life anymore. In their childhood, agents do not make decisions on savings-consumption. Their consumption is entirely determined by their parents. When agents enter the second period of their lives, they maximise a CES-type utility function:

$$u_{i,t} = \left[c_{i,t}^{1-\frac{1}{\sigma}} + \frac{\psi}{1+\rho} z_{i,t+1}^{1-\frac{1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{7}$$

where $c_{i,t}$ stands for consumption when middle-aged, $z_{i,t+1}-$ consumption when old, $\psi-$ probability to survive before the next period, $\sigma-$ the intertemporal elasticity of substitution, and $\rho-$ the discount factor. The budget constraints are:

$$c_{i,t} = (w_{i,t} - s_{i,t})Q(n); \tag{8}$$

$$z_{i,t+1} = \frac{(1+r_{t+1}^s)s_{i,t}}{\psi}. \tag{9}$$

$Q(n)$ is a function decreasing in population growth n, $0 \leq Q(n) \leq 1$. $Q(n)$ accounts

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for the expenses made for children. If population growth n is higher – a higher number of children reduces consumption per person in families. Agents make savings $s_{i,t}$ and invest them at the interest rate $1 + r_{t+1}^s$. Furthermore, we assume perfect annuity markets: the savings of agents who died at the beginning of the third period of their lives are allocated between the surviving agents of the same generation, increasing their total consumption. This is a technical assumption, which ensures that the savings of the deceased agents do not drop out from the model.

Substituting budget constraints to the utility function, its maximisation with respect to $s_{i,t}$ gives

$$\left(\frac{z_{i,t+1}}{c_{i,t}} \right)^{\frac{1}{\sigma}} = \frac{1 + r_{t+1}^s}{(1 + \rho)Q(n)}. \tag{10}$$

Now, using the budget constraints again, we solve for savings:

$$s_{i,t} = \frac{w_{i,t}}{1 + \psi^{-1} \left(\frac{Q(n)}{1 + r_{t+1}^s} \right)^{\sigma - 1} (1 + \rho)^\sigma}. \tag{11}$$

As only successful entrepreneurs make savings, the total savings in the economy are equal to $S_t = pN_{t-1}s_t$, or

$$S_t = \sum_{i=1}^{N_{t-1}} s_{i,t} = pN_{t-1} \frac{f(k_t) - \frac{M}{\pi_t}(1 + r_t^l)}{1 + \psi^{-1} \left(\frac{Q(n)}{1 + r_{t+1}^s} \right)^{\sigma - 1} (1 + \rho)^\sigma}. \tag{12}$$

2.4   Steady state

The bank supplies money to the economy in two ways: by issuing credits to the younger generation, and by generating returns on deposits for the older generation. In both cases, money supplied by the bank is inside money. The total amount of money received by the younger generation at time t is $N_t M$. The total amount of deposits returned to the older generation is equal to the $S_{t-1}\pi_{t-1}(1 + r_t^d)$. Therefore, the total supply of money is equal to the sum of these two values.

The demand for money is created by the middle-aged agents who have a positive technological shock. They need to return their loans: $pMN_{t-1}(1 + r_t^l)$ in total. Moreover, they save for future consumption: $S_t\pi_t$ in total. The multiplier π_t is needed to convert real savings to

monetary terms. Total demand for money is equal to the total supply:

$$pN_{t-1}M(1 + r_t^l) + S_t\pi_t = S_{t-1}\pi_{t-1}(1 + r_t^d) + N_t M. \tag{13}$$

In the Appendix we show a stronger result: the second terms on both sides of equation (13) are equal, which implies that the first terms are also equal. By inserting equation (12) into (13), dividing it by N_{t-1}, and removing the time indexes, we get an expression for the equilibrium values:

$$ps\pi[n - r^d] = M(1 + n)[1 + n - p(1 + r^l)], \tag{14}$$

Now, with the use of equation (2), we see that the terms in square brackets on both sides of the equation (14) are equal to each other and can be canceled out if $r^d \neq n$.

$$\pi = \frac{(1 + n)M}{ps}, \tag{15}$$

The equation implies that the price level is proportional to the size of the credits M and population growth $1 + n$, and depends negatively on savings and probability of a good technological shock. This is natural, because higher savings and probability of a good technological shock imply a larger supply of goods to the market, which leads to a decline in prices. In fact, under one additional assumption, it is possible to receive equation (15) not only for the steady state, but also for each period t. This result is shown in the Appendix. Now, inserting equations (3), (6) and (11) to (15) we get:

$$\frac{\pi}{M}f\left(\frac{M}{\pi}\right) = \frac{1 + n}{p}\left[1 + \psi^{-1}\left(\frac{Q(n)}{1 + r^s}\right)^{\sigma - 1}(1 + \rho)^\sigma\right] + 1 + r^l \tag{16}$$

It is easy to see that the properties of the function $f(k)$ ensure that the left side of equation (16) is increasing in π.[4] Thus, if p increases (probability of default declines), a higher number of successful firms will supply more goods (with the amount of money unchanged in the economy), leading to a decline in prices.

Increasing longevity ψ has a negative effect on the price level in the long run. This result is due to the fact, that middle-aged agents, who know that they are going to live longer, increase their savings. As a result, a rise in the supply of goods (demand for money) leads to a fall in prices.

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[4]Differentiation of the function $f(k)/k$ with respect to k gives $(kf'(k) - f(k))/k^2$, which is negative due to concavity of the function $f(k)$: $f(k) + (0 - k)f'(k) > f(0) = 0$.

A decline in fertility rate n has a double effect on the price level in the long run. First, the multiplier $(1+n)$ has a negative impact on the price level, because a smaller number of young agents take fewer credits and, hence, reduce the supply of money. Second, the effect of sharing consumption with children $Q(n)$ depends on the elasticity of intertemporal substitution σ. If consumptions at different periods of life are complements, a decline in fertility rates increases (real) savings, resulting in an increase in the supply of goods in the market and a decline in prices. If $\sigma > 1$, a decline in n leads to an increase in prices, mitigating the negative effect of the term $1+n$.

Usually the elasticity of intertemporal substitution is estimated to be lower than 1 (Weber 1970; Weber 1975; Skinner 1985; Hall 1988; Dynan 1993; Yogo 2004; Gomes and Paz 2013). Blundell et al. (1994) estimated σ equal to 0.75–0.77, the robustness check giving a wider range: 0.64–1.17, and Gomes and Ribeiro (2015) estimated it in the range 0.4–1.8. The estimates received by Hansen & Singleton (1982), using monthly data, are equivalent to an elasticity of substitution higher than unity. This implies that the case of $\sigma < 1$ is more consistent with the literature, but we will discuss the case $\sigma > 1$ as well.

An increase in interest rates affects prices in the long run in four different ways. First, higher interest rates increase money demand, because they force middle-aged agents to sell more goods in order to pay for their loans, thus having a negative effect on the price. Second, higher payments for the interest rate reduce the savings of the middle-aged agents, because having paid for the interest rate, the agents' net income decreases. As a result, demand for money declines, leading to a devaluation of money (this effect is captured by the last term $1 + r^l$ of equation (16)). Third, higher interest rates change savings due to the intertemporal preferences of the agents. If $\sigma < 1$, this effect has a negative impact on the supply of goods and drives prices up. The opposite happens if $\sigma > 1$. This effect is also visible from the equation (16). Fourth, a higher interest rate implies higher supply of money by the older generation, thus having a positive effect on prices.

The first and the fourth effects are of the opposite signs, and, under the assumption that banks make zero profits, as used in the model, they completely eliminate each other; this is visible from the derivation of equation (15) from (14). As a result, the exact effect of interest rates on the price level depends on the parameter values, but, given the empirical evidence discussed a few paragraphs earlier, it is very likely that higher interest rates increase prices in the long run.

This finding is in line with the famous Gibson's paradox, which states that there is a

positive relation between prices and interest rates (Gibson 1923; Keynes 1930). This paradox is also relevant nowadays (Cogley, Sargent, and Surico 2011; Škare and Mošnja-Škare 2015); however, the direction of this dependence is disputable (Chen and Lee 1990). In our model, we found that higher interest rates may indeed lead to an increase in prices in the long run. The short run will be analysed in the next section.

3 Short run

In this section we perform simulations to illustrate the short-run dynamics of the model under population ageing. But, before making simulations, we need to assume specific functional forms and parameter values. The values of variables in the initial steady state are summarised in the Appendix.

3.1 Parameters

First of all, we assume a Cobb-Douglass production per worker function: $f(k_t) := k_t^{\alpha}$, with $\alpha = 0.4$. According to the OECD data on labour shares, this parameter for capital intensity is between the UK (0.341) and the US (0.485) in 2010. Next, we assume the following function adjusting consumption $Q(n) := (2 + n)^{-1/2}$, where $2 + n$ stands for one adult plus $1 + n$ children. Such a function is in line with the equivalence scales used in OECD (2011) (square root of a household size).

Discount rate ρ is set at the 0.3478 level. Since the period in the model is approximately equal to 30 years, this value of ρ corresponds to the annual discount rate of 1 per cent. Such a value is similar to that used by Börsch-Supan et al. (2006) but is larger than the discount factor estimated by Giglio et al. (2015) for long periods of time.

In the benchmark case, we use the longevity parameter $\psi = 0.9$. For comparison, according to the data of the World Health Organization, the probability to live longer than 65 years was equal to 0.89 in Germany and the UK and 0.9 in Ireland in 2012. Also, we assume population growth $n = 0.2$; in annual terms this corresponds approximately to 0.6 per cent population growth due to fertility. Further we will simulate an increase of ψ from 0.9 to 0.95, and a permanent decline in n from 0.2 to 0.

We assume a 2 per cent annual interest rate on deposits; it corresponds to 81.14 per cent in 30 years. In the benchmark case, probability of firms' success p equals to 0.5. From the first glance, such a low probability of success seems to be unrealistic. However, if probability

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of the bad shock is the same each year, and does not depend on these probabilities at the other periods, the yearly probability of default is equal to 0.023. Such a value is even smaller than most probabilities of default calculated by commercial banks for credit risk management. This gives an interest rate on loans equal to 262.27 per cent per 30 years or 4.38 per cent in annual terms. We will present simulations for an increase in p from 0.5 to 0.6, which leads to a decline in annual interest rate on loans up to 3.22 per cent per year.

We normalise credit size M to unity. Since dynamics may depend on the intertemporal elasticity of substitution, we perform simulations for three parameter values of σ: $\sigma = 0.5, 1, 2$.

3.2 Simulations

Decline in fertility

First, we simulate a decline in fertility. We assume that, before the period 0, the system is in its equilibrium. At the period $t = 0$, there is a permanent decline of n from 0.2 to 0. The effect of such a decline is shown in Fig. 2.

A smaller number of the younger generation, results in that they take fewer credits and less money is supplied to the market. This immediately reduces the price level. The further dynamics are mainly determined by the developments in savings and capital-labour ratios. A smaller fertility rate induces an increase in the capital-labour ratio, because the smaller number of middle-aged agents shares the amount of the real capital accumulated by the previous generation. The higher capital-labour ratio raises production, and, as a result, contributes to a further decline in prices.

When the new equilibrium is achieved, the decline in prices stops, thus implying that, according to our model, deflation caused by population ageing is temporal. However, the transition period in the case of $\sigma = 0.5$ is rather long: keeping in mind that one period in our model is 25–30 years long, six periods of transition correspond to 150–180 years. With a larger σ, the visual transitional period is shorter.

Increase in longevity

The short-run effects of increased longevity are shown in Fig. 3. We suppose that middle-aged agents at the period 0 find out that they are going to live longer and adjust their savings to account for this development. Their probability to survive before the third period of their lives increases from 0.9 to 0.95. We assume that this increase is expected, because in

Figure 2: Decline in fertility
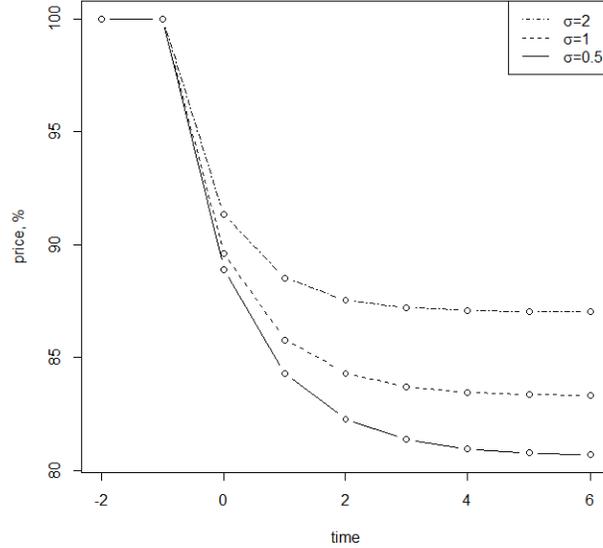
practice population ageing is a slow process, thus, agents have opportunities to make necessary adjustments in their savings-consumption behaviour. However, we suppose that increasing longevity of middle-aged agents was not taken into account by the previous generations.

The qualitative impact of increased longevity is similar to that of a declined fertility rate; however, the reasons are slightly different: increasing longevity of the middle-aged agents at the period $t = 0$ leads to an increase in their savings. This raises the supply of goods to the market, leading to a decline in prices. Then, higher savings increase capital-labour ratios, which leads to a further increase in income and savings and a decline in prices.

Decline in interest rates

In our model, at least one interest rate is exogenous. In more general settings, interest rates often decline with population ageing (e.g. see van Groezen & Meijdam 2008). Therefore, it is also interesting to study the effects of declining interest rates on inflation. As population ageing is a permanent process, there is no need to study a temporal increase in longevity or fertility rates. However, interest rates are rather volatile. Therefore, we consider two cases:

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Figure 3: Increase in longevity
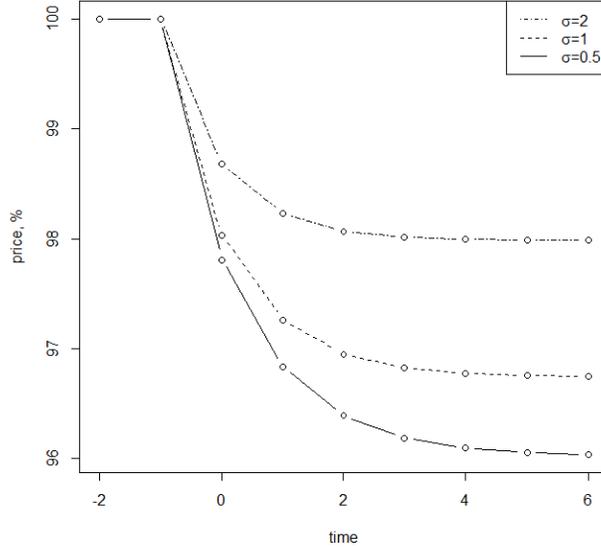
first, a decline in interest rates is temporal, second – the decline is permanent. In both cases, we suppose that at time $t = 0$ agents sign contracts for loans and deposits with the bank, at an interest rate different from the previous generations. This means that the actual decline in interest rates happens at the period $t = 1$. We simulate a decline in the deposit interest rate from 2 per cent per year to 1 per cent, which implies a decline in r_d from 81.14 per cent to 34.78 per cent per 30 years. Consequently, according to the bank's zero-profit condition, r_l changes from 262.27 per cent per 30 years to 169.57 per cent. In the case of a temporal decline, at the period $t = 2$, the interest rates return to their previous values.

The effects of a temporal decline in interest rates are shown in Fig. 4. The effect on prices at the period $t = 0$ highly depends on the elasticity of intertemporal substitution. If consumptions in the second and third periods of agents' life are substitutes, agents prefer to consume more at the first period of their lives, leading to a decline in savings and smaller supply of goods. This raises prices. If $\sigma < 1$, the savings/consumption behaviour of agents at $t = 0$ is the opposite: they prefer to save more. This enhances the supply of goods to the market and leads to a decline in prices. If $\sigma = 1$, expected changes in the interest rate do not affect prices at the period $t = 0$. Therefore, depending on σ, the model may correspond or

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not correspond to Gibson's paradox in a very short run.

Figure 4: Temporal decline in interest rate
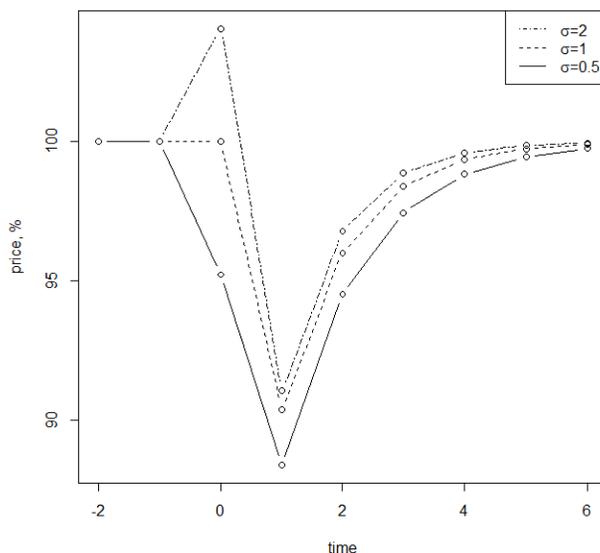
Lower interest rates at $t = 1$ imply that agents returning their credits need less money for paying their credits. However, this effect is eliminated by lower supply of money by the older generation due to smaller interest rates. The main effect playing a role is that having paid for the credits, agents that are in the second period of their lives at time $t = 1$ obtain more goods, and they may afford higher savings, which leads to a higher supply of goods and a decline in their prices. Indeed, the extent to which they increase their savings also depends on the elasticity of substitution. They know that in the next period the interest rate is going to be high again, therefore, if $\sigma < 1$ they consume more at the period $t = 1$, and if $\sigma > 1$ they prefer to increase their savings relatively to the case of $\sigma = 1$. At the following periods the system returns to its initial equilibrium.

Fig. 5 presents the effects of the permanent decline in interest rates. In fact, the effects at $t = 0$ and $t = 1$ are similar to the temporal decline. The important difference at $t = 1$ is that savings/consumption decisions of the adult agents at this period expect to have lower interest rates as well. This affects their intertemporal allocation of resources, implying that in case of $\sigma > 1$ the decline in prices is smaller, and in $\sigma < 1$ it is deeper than in the case of the

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Figure 5: Permanent decline in interest rate
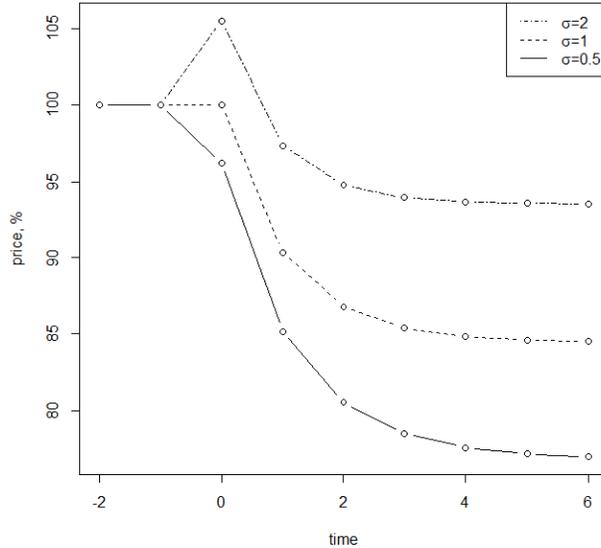
temporal shock. At the later periods the system continues converging to its new equilibrium.

It is also interesting to get see if a decline in interest rates affects prices in two economies with different demographic factors in the same way. In fact, the decisions of the European Central Bank affect interest rates in the whole Eurozone, but countries have a different demographic structure; therefore, we may expect different effects on inflation across the EU.

In Fig. 6, we present the effects of a temporal decline in interest rates when fertility rates are different ($n = 0.2$ and $n = 0$). The experiment is designed in the same manner as before, but now it is performed for two cases, i.e. $\sigma = 0.5$ and $\sigma = 2$. In both cases, lower fertility rate results in lower changes in price levels at $t = 0$, implying that changes in interest rates affect prices at a smaller degree when the society is old. This is so, because smaller share of agents populating the economy take credits. This result is in line with the empirical findings of Imam (2013), who showed that monetary policy is less efficient when an economy has an older society. In the following periods an older society leads to a deeper decline in prices. However, the difference between the two profiles is small.

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Figure 6: Temporal decline in interest rate

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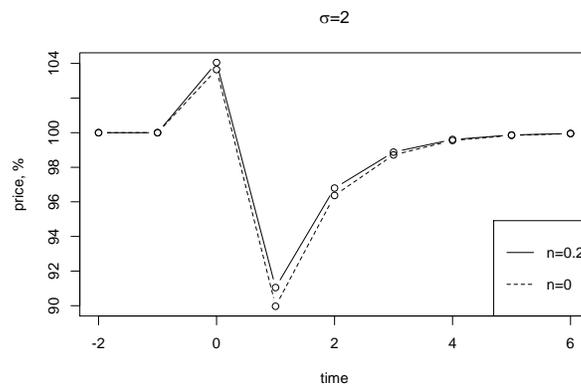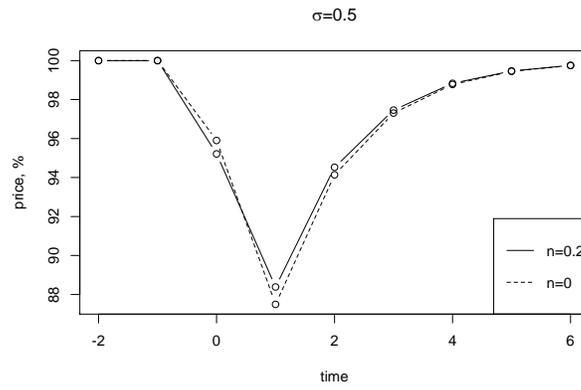
Increase in the probability of a good productivity shock

It is also interesting to find the effects of a change in p – probability that an individual entrepreneur faces a positive productivity shock. Fig. 7 shows the effects of an increase in p from 0.5 to 0.6 at the time $t = 1$, which is expected at $t = 0$. We suppose that this shock is expected, since otherwise the bank would receive positive profits, violating the non-profit condition. It is also possible to assume that the shock is unexpected, and the interest rate on loans adjusts after the shock is realised to satisfy the bank's zero-profit condition. In this case, prices do not change at $t = 0$, the further dynamics being qualitatively the same.

Figure 7: Increase in probability of success: Prices
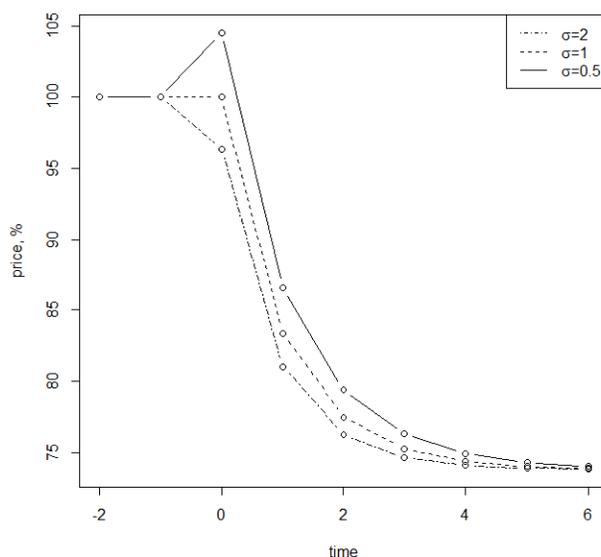
In order to understand the dynamics of the prices in Fig. 7, we also plot the dynamics of savings s_t in Fig. 8. The complication here is that the interest rate on savings depends on the price, and the price level depends on savings, because they determine the supply of goods to the market. The simplest dynamics are when $\sigma = 1$. In this case, changes in interest rates do not affect savings. As a result, the fact that at $t = 1$ the probability of a good shock increases does not affect savings at $t = 0$. Thus, capital-labour ratios at time $t = 1$ do not change, and the incomes of agents with a good technological shock remain the same. As

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Figure 8: Increase in probability of success: savings
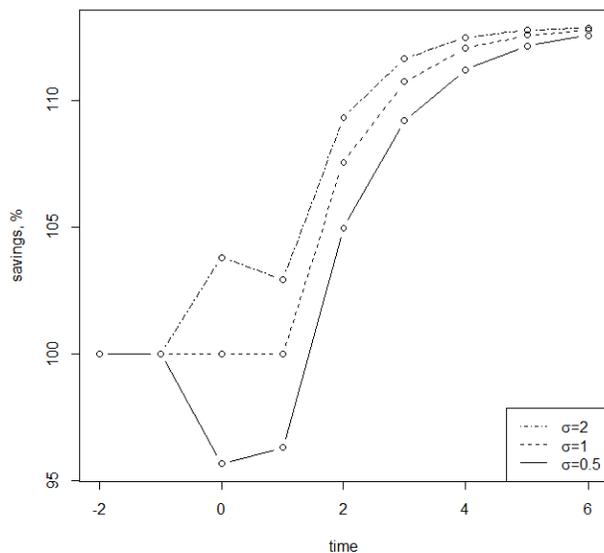
equation (11) implies, unchanged incomes determine that the savings of agents who have a good technological shock do not change again. However, the number of agents with a good technological shock increases in this case; therefore, the total amount of savings and the total supply of goods to the market increase as well. Hence, the price declines at $t = 1$. Higher total savings lead to a higher amount of capital and enhancement of income, higher incomes giving rise to higher savings and cheaper goods. The process continues until the system converges to its new steady state.

In case of $\sigma \neq 1$, the short-run dynamics are different. First, consider the periods $t \geq 2$. As agents expect a decline in prices, this increases their interest rates on savings, because, in the next period, agents will be able to buy more goods (equation (1)). This raises savings, when $\sigma > 1$, and reduces them when $\sigma < 1$, relatively to $\sigma = 1$. As a result, in case $\sigma > 1$, more goods are supplied to the market and their price is lower than in the case of $\sigma = 1$. The opposite happens when $\sigma < 1$.

At time $t = 1$, the decline in price happens because the number of agents with a good technological shock increases, they create higher total savings, and more goods are supplied to the market, which has a negative effect on their price. Moreover, also as for periods $t \geq 2$

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future interest rates on savings play a role.

Because of equation (1), decline in price at $t = 1$ affects not only r_1^s but also r_2^s. As agents sell goods at lower prices at $t = 1$, they get fewer money, and this reduces returns to savings they get at $t = 2$. Consequently, agents reduce their individual savings relative to the previous period, if $\sigma > 1$, and increase them, if $\sigma < 1$. Indeed, returns to savings are also affected by π_2. Its decline has the opposite effect on interest rates and savings than the decline of π_1. The fact that $\pi_2 < \pi_1$ ensures that individual savings are higher than in the initial equilibrium, when $\sigma > 1$, and smaller, when $\sigma < 1$ at $t = 1$.

4 Robustness and possible extensions

The model developed in this paper relies on a number of assumptions. Some of them are realistic, while others are not. For example, in this model we assumed that the bank gives credits for investment purposes only. Indeed, this assumption is not very restrictive, and the main message of the paper does not change if we introduce consumption credits (as long as credits are given mainly to the younger generation). This is a rather realistic condition, because older agents accumulate more savings, and, as a result, their demand for credits declines, while younger agents often enter the market being liquidity constrained. Consequently, if we add consumption credits, the results should not change qualitatively: higher share of young agents leads to a higher amount of credits, hence money supply increases, and this leads to higher prices. Moreover, in the long run, the inflationary effect of consumption credits may be even more pronounced, because investment credits directly increase production in the next period, while the effects of consumption credits are not so clear.

The most unrealistic assumption is that all the agents in the economy are self-employed. According to the OECD data, only 6.6 per cent of labour force was self-employed in the United States in 2013, but in other countries this percentage was higher: 25.0 per cent in Italy, 27.4 per cent in South Korea, 52.6 per cent in Colombia. If an assumption that all agents are self-employed is changed to a more realistic one i.e. that only an exogenous portion of agents are entrepreneurs and the others work in their firms, the main message of the paper would not change: the younger population implies a higher number of entrepreneurs, which enlarges the number of credits given by the bank, hence, more money is created which leads to a higher price level. But, in reality, it is likely that the number of entrepreneurs is endogenous. An even more realistic assumption would be to assume an endogenous number of entrepreneurs, by

assuming that there is a need for certain minimal amount of real capital that the entrepreneurs possess in order to create their own firms. If the share of entrepreneurs in population depends positively on capital-labour ratios, this weakens the results of the model, because population ageing leads to capital deepening, and increases the share of entrepreneurs in the population. To preserve the results, there is a need for the introduction of consumption credits, that not only entrepreneurs, but also workers can get credits.

An endogenous share of entrepreneurs may also depend on the interest rate on loans. If credits are costly and entrepreneurs are risk-averse, high interest rates may disgust potential entrepreneurs from investment and have a negative effect on the amount of money in the economy. As a result, the link between interest rates and the price level may not be as pronounced as we described. However, modeling an endogenous choice of being or not being an entrepreneur requires a certain degree of heterogeneity of agents. Otherwise, either all agents would become entrepreneurs or nobody. If the number of entrepreneurs depends on the interest rate, it is also possible to introduce a government or a central bank into the model, which might affect interest rates on loans. This refinement would give a rise to a possibility of studying political and budgetary pressures for inflation in the style of Katagiri et al. (2014), but with a more realistic monetary policy. This requires a more sophisticated model, which would be a good extension of the present paper.

5 Conclusions

In this paper, we combined a neoclassical overlapping-generations model with the post-Keynesian endogenous money creation via credit markets. We showed that population ageing in terms of an increase in longevity and decline in fertility leads to a decline in prices. The main deflationary impact of declined fertility rates follows from the fact that a smaller number of young agents take fewer credits and this leads to a decline in the stock of money created by the banking sector. The secondary effect comes from the fact that, if the intertemporal elasticity of substitution is smaller than unity, a smaller number of children increases consumption in families per person and, as a result, agents afford to create higher savings, which has a positive effect on the goods supply to the market. Increasing the supply drives prices down. The effect of an increase in longevity on prices is the following; as agents know that they will live longer, they need to create higher savings. They supply more goods to the market, which leads to deflation.

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In addition, we found a couple of other interesting features disregarded in previous models. For example, higher interest rates may have a positive effect on inflation in the medium and long run, because they increase spending of the old generation. Moreover, higher interest rates reduce savings of agents, who need to return credits, having a negative impact on the supply of goods, which in turn leads to an increase in prices. However, the model is simplistic; thus, there is a need for further research in order to reveal a more elaborate link between demographic factors, interest rates and inflation.

Conflict of Interest

Acknowledgments

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Appendix 1

Proposition. Under the assumptions of the model, and assuming that at time t_0, the bank was introduced and it didn't exist before,

$$\pi_t = \frac{(1 + n_t)M}{ps_t} \tag{17}$$

holds.

Proof As we suppose that the bank was introduced at the period t_0, $N_{t_0}M$ credits were issued for the young generation, simultaneously creating a deposit of the same size. They bought physical capital and transferred this money to the generation born at $t = t_0 - 1$, therefore $N_{t_0}M = S_{t_0}\pi_{t_0}$. By multiplying this equality by the bank's nonprofit condition (2) at time $t_0 + 1$, we receive $pN_{t_0}M(1 + r^l_{t_0+1}) = S_{t_0}\pi_{t_0}(1 + r^d_{t_0+1})$. By inserting this condition to equation (13) we obtain $N_{t_0+1}M = S_{t_0+1}\pi_{t_0+1}$. Continuing this process telescopically, we get $N_tM = S_t\pi_t$ for any t, $t > t_0$. Equation (17) is received from $S_t = pN_{t-1}s_t$ and $N_t = N_{t-1}(1 + n_t)$. ∎

Appendix 2

Table 1: Steady state values in the benchmark case

	variable	value
Capital per worker	k	0.0230
Output per worker	y	0.2211
Income per worker	w	0.1378
Price of goods	π	43.491
Interest rate on deposits	$1 + r_d$	1.8114
Interest rate on savings	$1 + r_s$	1.8114
Interest rate on loans	$1 + r_l$	3.6227
Savings per worker	s	0.0552