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# Demographic Change and Real House Prices: A General Equilibrium Perspective

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**Abstract**

This paper analyzes the effects of demographic changes on the long-run pattern of real house prices in an overlapping generations general equilibrium model with housing-wealth effects. It is demonstrated that declines in the birth rate and in population growth, associated with increases in life expectancy, generate disinflation and a fall in the real interest rate, triggering a rise in real house prices over the long run. The positive relationship between contemporary demographic trends and real house price trends observed in the United States and in the OECD countries is thus not puzzling, but is perfectly consistent with dynamic macroeconomic theory. In this context, *ceteris paribus*, falling prices in the housing market are possible only when self-fulfilling boom-bust dynamics, unrelated to demographic fundamentals, occur.

**JEL Classification:** E10; E31; J11; G12; R21; R30.

**Keywords**: Demographic Change; Real House Prices; Macroeconomic Dynamics.

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# 1 Introduction

The effects of major demographic changes on the long-run path of real house prices have received considerable attention in the literature. In a seminal paper, Mankiw and Weil (1989) predicted that, in the two decades since 1987, real house prices in the United States could fall by 3 percent per year, on average, due to both the 'baby bust' and 'baby boomers' liquidating their housing and financial assets. On the contrary, after the dramatic rise in house prices observed between 1970 and 1980, the real price of housing continued to increase over the long run, in sharp contrast with the Mankiw-Weil forecast. On average, it increased by 3.2 percent per year between 1987 and 2006, by 1.5 percent between 1987 and 2017—a period which includes the 2007-2011 price bust occurred over the financial crisis—and, remarkably, by 4.8 percent between 2012 and 2017, in the post-crisis period.[1] An analogous upward trend in real house prices is also visible in the OECD countries as a group.[2]

Such a 'puzzle' has been explored mainly in partial equilibrium frameworks.[3] The contribution of the present paper is to provide an explanation based on a general equilibrium macroeconomic model where demographic factors and housing-wealth effects are explicitly incorporated. Specifically, we examine the long-run impact of demographic change on real house prices in an overlapping generations setting of the type originally proposed

[1]Data are from FRED, https://fred.stlouisfed.org/series/QUSR628BIS.

[2]Specifically, in the OECD countries the real price of housing increased by 2.2 percent per year in 1987-2006, by 1.5 percent in 1987-2015, and by 2 percent in 2012-2015. Data are from the OECD, https://www.oecd.org/eco/outlook/focusonhouseprices.htm. See also the empirical contribution of Takáts (2012).

[3]In particular, Miles (2012) focuses on the positive impact of increased population density on real prices in the housing market. Krainer (2005) emphasizes the role played by housing demand and supply elasticities, as well as by the presence of 'myopic' market participants, whose behavior does not respond to price changes. In such a context, even though large numbers of baby-boomer houses are expected to be for sale in the future, myopic households would not 'see' this, hence not forcing prices down. DiPasquale and Wheaton (1994) rely on a 'stock-flow' model of the housing market which predicts that evolving demographic forces should reduce the real appreciation of houses, not trigger significant real price declines *à la* Mankiw-Weil.

in the seminal work by Yaari (1965), then further developed by Blanchard (1985) and Weil (1989), and here extended, for our purposes, in order to include monetary variables and internalize housing in the households' asset menu. The resulting model proves to be a useful setup for making aggregate demand sensitive to housing wealth effects—as predicted by much empirical evidence (Iacoviello, 2004, 2012; Campbell and Cocco, 2007; Muellbauer, 2007; Dvornak and Kohler, 2007; Carroll, Otsuka and Slacalek, 2011; Zhu *et al.*, 2019)—and for formalizing transparently the interactions between demographic forces and house-price dynamics.

There is an extensive body of research, both empirical and theoretical, examining the interactive nexus between housing markets and macroeconomic variables. Leung (2004) and Leung and Ng (2018) provide prominent literature reviews, before and after the global financial crisis. According to Leung (2004), although housing was not included in traditional macroeconomics, there is a growing recognition about the importance of the connections between housing markets and the macroeconomy (see, among others, Chang, 2000; Leung, 2003, 2017; Davis and Heathcote, 2005; Iacoviello, 2005; Iacoviello and Minetti, 2008; Chang, Chen and Leung, 2011; Karsten, Krueger and Mitman, 2013; Cesa-Bianchi, Cespedes and Rebucci, 2015; Davis and Van Nieuwerburgh, 2015; Piazzesi and Schneider 2016; Favilukis, Ludvigson and Van Nieuwerburgh, 2017). According to Leung and Ng (2018), although a general decrease in the relationships among housing market variables and macroeconomic variables occurred after the global financial crisis with respect to business cycle frequencies, there still exist particularly significant interactions over the medium run—especially with reference to macro-financial variables.

Theoretically, however, the existing general equilibrium frameworks (see, eg., Iacoviello, 2005, 2010, and references therein) are typically based on Ramsey-type infinitely lived optimizing agents, hence overlooking the potential nexus between demographic factors and house-price dynamics—the objective of this paper. Prominent exceptions are the life-cycle setup proposed by Iacoviello and Pavan (2013), which however abstracts from endogenous housing prices, and the overlapping generations settings elaborated by Galí (2014, 2018), which focus instead on the possible occurrence of asset-price bubbles, unconnected to 'fundamentals'.

In the macroeconomic literature—it should be emphasized—there are relevant attempts to investigate the effects of the 'retirement wave' of baby boomers, with a particular focus on stock price dynamics.[4] Using an overlapping generations general equilibrium model with rational expectations, Abel (2001) argues in favor of the plausible occurrence of an anticipated decline in the price of capital when baby boomers retire, which is shown not to be attenuated by the introduction of a bequest motive. In an overlapping generations setting *à la* Diamond (1965), further including a social security system, Abel (2003) reinforces these theoretical arguments, showing that the price of capital is mean-reverting, so that the initial increase in the price of capital is followed by a decrease.

Overlapping generations setups to study the macroeconomic effects of demographic changes are also remarkably employed in the theoretical works of d'Albis (2007) and Hock and Weil (2012). D'Albis (2007) analyzes the impact of the population growth rate on steady-state capital per capita and finds that the functional relationship between those two variables is non-monotonic (see also Gan and Lau, 2010). Hock and Weil (2012) analyze the effects of population aging, due to declining fertility and rising elderly life expectancy, on consumption decisions, and investigate the related feedback effects. They highlight how decreases in consumption associated with greater elderly life expectancy might be offset by endogenous increases in the fertility rate.

[4]For an empirical study on baby boomers' wealth holdings—including housing wealth—see Lusardi and Mitchell (2007).

Markedly, the macroeconomic consequences of the ongoing demographic transition in the context of overlapping generations models are further studied with reference to the question of how the population aging relates to the observed decrease in the real interest rate in the United States (Gagnon, Johannsen and David Lopez-Salido, 2016), Japan (Sudo and Takizuka, 2018), and other developed economies (Carvalho, Ferrero and Nechio, 2016).

For our purposes, it is worth pointing out that while the literature on the interplay among housing and the macroeconomy typically abstracts from demographic variables, the above literature on the macroeconomic implications of demographic changes, on the other hand, abstracts from housing markets and monetary variables. The present analysis is an effort to fill this gap. In particular, the contribution of this paper is twofold. First, we extend in an analytically tractable way the overlapping generations framework *à la* Yaari (1965)-Blanchard (1985)-Weil (1989) in order incorporate monetary variables and housing-wealth effects. Second, using the discipline of the proposed general equilibrium optimizing setup, we demonstrate that evolving demographic changes—declines in the birth rate and in population growth, associated with increases in life expectancy—*per se* tend to dampen aggregate demand and boost saving, thereby triggering deflationary dynamics. When the monetary policy emphasis is placed on stabilizing inflation, real interest rates fall. Declines in the rate of real interest turns to sustain agents' housing demand and thus prices. In other words, the demographic transition of the type observed in developed economies generates a situation of real house-price increases and not of real house-price decreases. In this environment, *ceteris paribus*, falling prices in the housing market are possible only when self-fulfilling boom-bust dynamics—unrelated to demographic 'fundamentals' and associated to 'off-equilibrium' arbitrary revisions in house-price expectations—take place.

Thus, overall, the present study provides a novel perspective to explain the nexus between demographic change and housing price change, based upon the implied interactions with macroeconomic variables. The findings demonstrated in this paper give sound theoretical foundations to the view that employing a general equilibrium setting, whereby interest rate and inflation dynamics enter the analysis, might be essential for a general characterization of the effects of the demographic transition on real house-price dynamics. The setup here presented could then be used as a fruitful benchmark for more complex analysis along the foregoing lines.

The scheme of the paper is as follows. Section 2 sets forth the macroeconomic model. Section 3 analyzes the issue of equilibrium dynamics and derives the connections between demographic factors and real house prices. Section 4 provides a summary of the main findings and concludes.

## 2 The Model

For our purposes, in this section we formulate a monetary version of the Yaari (1965)-Blanchard (1985)-Weil (1989) overlapping generations framework, extended in order to include housing in the agents' asset menu. Each individual is assumed to face a common and constant instantaneous probability of death, $\mu > 0$, and population grows at a constant rate $n$. At each instant $t$ a new generation is born, and the birth rate is $\beta = n + \mu$. Denoting by $N(t)$ total population at time $t$, with $N(0) = 1$, the size of the generation born at time $t$ is $\beta N(t) = \beta e^{nt}$, and the size of the surviving cohort born at time $s \leq t$ is $\beta N(s) e^{-\mu(t-s)} = \beta e^{-\mu t} e^{\beta s}$. Population at time $t$ is given by $N(t) = \beta e^{-\mu t} \int_{-\infty}^{t} e^{\beta s} ds$. Following Blanchard (1985), there is no dynastic altruism, implying that real and financial wealth of newly born individuals is zero. Agents are assumed to supply one unit of labor inelastically, which for analytical convenience is transformed one-for-one into output.

The representative agent of the generation born at time $s \leq 0$ chooses the time path of consumption, $\overline{c}(s,t)$, real money balances, $\overline{m}(s,t)$, and housing, $\overline{h}(s,t)$, to maximize the expected lifetime utility function

$$E_0 \int_0^{\infty} \left[\alpha \log \Lambda \left(\overline{c}(s,t), \overline{m}(s,t)\right) + (1-\alpha) \log \overline{h}(s,t)\right] e^{-\rho t} dt, \tag{1}$$

where $E_0$ is the expectation operator conditional on period 0 information, $\rho > 0$ is the pure rate of time preference, and $\Lambda(\cdot)$ is a strictly increasing, concave, and linearly homogenous function. As in Reis (2007), consumption and real money balances are Edgeworth complements, that is, $\Lambda_{cm} > 0$. Following Cushing (1999), the elasticity of substitution between the two is lower than unity. Since the probability at time 0 of surviving at time $t \geq 0$ is $e^{-\mu t}$, the expected lifetime utility function (1) results in

$$\int_0^{\infty} \left[\alpha \log \Lambda \left(\overline{c}(s,t), \overline{m}(s,t)\right) + (1-\alpha) \log \overline{h}(s,t)\right] e^{-(\mu+\rho) t} dt. \tag{2}$$

Private agents accumulate their assets, $\overline{a}(s,t)$, in the form of real money balances, interest bearing public bonds, $\overline{b}(s,t)$, and housing-wealth, $q(t)\overline{h}(s,t)$, where $q(t)$ measures the relative house price. We have thus $\overline{a}(s,t) = \overline{b}(s,t) + \overline{m}(s,t) + q(t)\overline{h}(s,t)$. The instantaneous budget constraint is of the following form:

$$\begin{aligned} \dot{\overline{a}}(s,t) &= \left(R(t) - \pi(t) + \mu\right) \overline{a}(s,t) + \overline{y}(s,t) - \overline{\tau}(s,t) - \overline{c}(s,t) - \\ &\quad - R(t)\overline{m}(s,t) + \left[\frac{\dot{q}(t)}{q(t)} - \left(R(t) - \pi(t)\right)\right] q(t)\overline{h}(s,t), \end{aligned} \tag{3}$$

where $R(t)$ denotes the nominal interest rate, $\pi(t)$ the inflation rate, $\overline{y}(s,t)$ output, and $\overline{\tau}(s,t)$ real lump-sum taxes net of public transfers. Following Yaari (1965), the term $\mu\overline{a}(s,t)$ consists in an actuarial fair payment that individuals receive from a perfectly competitive life insurance company in exchange for their total wealth at the time of death. Specifically, insurance companies, operating under perfect competition, collect real and financial assets from deceased individuals, and pay fair premia to current generations. The presence of the life insurance market is meant to rule out the possibility for individuals of passing away leaving unintended bequests to their heirs. It is worth emphasizing that assuming actuarial bonds issued by financial intermediaries would yield equivalent results (see Blanchard, 1985). Therefore, because the asset menu incorporates housing equity, in the present overlapping generations setup the Yaary-Blanchard-type premia associated to the actuarially fair scheme imply the occurrence of reverse mortgage.[5]

Agents are precluded to engage in Ponzi's games, implying

$$\lim_{t\to\infty} \overline{a}(s,t)e^{-\int_0^t (R(j)-\pi(j)+\mu)dj} \geq 0. \tag{4}$$

Next denote by $\overline{z}(s,t)$ total consumption at time $t$ for the representative agent born at time $s$, defined as physical consumption plus the interest forgone on real money holdings, that is,

$$\overline{z}(s,t) = \overline{c}(s,t) + R(t)\overline{m}(s,t). \tag{5}$$

It follows that the agent's maximizing problem can be solved by employing a two-stage procedure (see Deaton and Muellbauer, 1980, and Marini and van der Ploeg, 1988). In the first stage, specifically, individuals solve an intratemporal problem of choosing the

[5]See, for instance, Chinloy and Megbolugbe (1994), Mayer and Simons (1994), Eschtruth and Tran (2001), Davidoff and Welke (2005) Shan (2011), and Davidoff, Gerhard and Post (2017). The assumption of reverse mortgages in our framework is primarily made in order to microfound in a rigorous and, at the same time, intuitive and mathematically tractable way the occurrence housing-wealth effects on consumption within an overlapping generations environment *à la* Yaari (1965)-Blanchard (1985)-Weil (1989). It is worth emphasizing that, according to Haurin *et al.* (2016), the number of eligible households for the adoption of reverse mortgages in the United States is growing substantially, for approximately 80 percent of households age 62 or over are homeowners (Poterba, Venti and Wise, 2011), and a large proportion of them have substantial equity in their homes (Consumer Finance Protection Bureau, 2012; Sinai and Souleles, 2013).

efficient allocation between consumption and real money balances to maximize function $\Lambda(\cdot)$, for a given level of total consumption. At optimum, the marginal rate of substitution between consumption and real money balances must equal the nominal interest rate, that is, $\Lambda_m(\overline{c}(s,t),\overline{m}(s,t))/\Lambda_c(\overline{c}(s,t),\overline{m}(s,t)) = R(t)$. Since preferences are linearly homogenous, the foregoing optimality condition is of the following form:

$$\overline{c}(s,t) = \Gamma(R(t))\,\overline{m}(s,t), \tag{6}$$

where $\Gamma'(R(t)) > 0$.

In the second stage, agents solve an intertemporal optimizing problem of choosing the time paths of total consumption, $\overline{z}(s,t)$, and housing, $\overline{h}(s,t)$, to maximize their lifetime utility function (2), given the constraints (3), (4) and the optimal intratemporal equation (6). Appendix A provides analytical details. Optimality implies

$$\dot{\overline{z}}(s,t) = (R(t) - \pi(t) - \rho)\,\overline{z}(s,t), \tag{7}$$

$$\frac{(1-\alpha)}{\alpha}\frac{\overline{z}(s,t)}{q(t)\overline{h}(s,t)} = (R(t) - \pi(t)) - \frac{\dot{q}(t)}{q(t)}, \tag{8}$$

$$\lim_{t\to\infty} \overline{a}(s,t)e^{-\int_0^t (R(j)-\pi(j)+\mu)dj} = 0. \tag{9}$$

Using condition (8) into the instantaneous budget constraint (3), integrating forward, and applying the transversality condition (9) and the dynamic equation (7), total consumption turns to be a linear function of total wealth:

$$\overline{z}(s,t) = \alpha(\mu+\rho)\left(\overline{a}(s,t) + \overline{k}(s,t)\right), \tag{10}$$

where $\overline{k}(s,t) \equiv \int_t^\infty (\overline{y}(s,t) - \overline{\tau}(s,t))\,e^{-\int_t^v (R(j)-\pi(j)+\mu)dj}dv$ measures human wealth, i.e., the present discounted value of after-tax labor income. From (5), (6), and (10), it then follows that

$$\overline{c}(s,t) = \frac{\alpha(\mu+\rho)}{L(R(t))}\left(\overline{a}(s,t) + \overline{k}(s,t)\right). \tag{11}$$

Now, combining (5), (6) and (7), we can express the optimal time path of individual consumption as

$$\dot{\overline{c}}(s,t) = \left[(R(t) - \pi(t) - \rho) - \frac{L'(R(t))}{L(R(t))}\dot{R}(t)\right]\overline{c}(s,t), \tag{12}$$

where $L(R(t)) \equiv 1 + R/\Gamma(R(t))$ and $L'(R(t)) > 0$. From (12), the optimal consumption growth rate is identical across all generations. Function $L(R(t))$ is assumed to obey $L(0) = 1$, $L(\infty) = +\infty$, $L'(0) = \infty$ and $L'(\infty) = 0$. Such properties apply, for instance, if one assumes that $\Lambda(\overline{c}(s,t), \overline{m}(s,t))$ is a CES function.

### 2.1 Evolution of Aggregate Variables

Define the population aggregate for a generic variable at individual level $\overline{x}(s,t)$ as $X(t) \equiv \beta e^{-\mu t}\int_{-\infty}^{t}\overline{x}(s,t)e^{\beta s}ds$. The corresponding quantity in per capita terms is indicated as $x(t) \equiv X(t)e^{-nt} = \beta\int_{-\infty}^{t}\overline{x}(s,t)e^{\beta(s-t)}ds$.

Assume that each agent faces identical age-independent income and net tax flows, so that $\overline{y}(s,t) = \overline{y}(t)$ and $\overline{\tau}(s,t) = \overline{\tau}(t)$, consistently with Blanchard (1985). Consequently—using $\overline{a}(t,t) = 0$ and $\overline{c}(t,t) = [\alpha(\mu+\rho)/L(R(t))]\,\overline{k}(t,t)$—the budget constraint, the optimal time path of consumption and the optimal time path of house prices expressed in per capita terms are given by, respectively,

$$\begin{aligned}\dot{a}(t) &= (R(t) - \pi(t) - n)\,a(t) + y(t) - \tau(t) - c(t) - \\ &\quad -R(t)m(t) + \left[\frac{\dot{q}(t)}{q(t)} - (R(t) - \pi(t))\right]q(t)h(t), \end{aligned} \tag{13}$$

$$\dot{c}(t) = \left[ (R(t) - \pi(t) - \rho) - \frac{L'(R(t))}{L(R(t))} \dot{R}(t) \right] c(t) - \frac{\alpha \beta (\rho + \mu)}{L(R(t))} a(t), \tag{14}$$

$$\frac{\dot{q}(t)}{q(t)} = (R(t) - \pi(t)) - \frac{(1-\alpha)}{\alpha} \frac{L(R(t))c(t)}{q(t)h(t)}, \tag{15}$$

Appendix B gives analytical details. From (14), it is clear that the rate of change of per capita consumption depends upon the level of wealth $a(t)$, because future cohorts' consumption is not valued by agents currently alive. In particular, the setup features the property that older generations are wealthier than younger generations, and thus consume more and save less. Only in the limiting case in which the birth rate $\beta$ is equal to zero, per capita consumption dynamics follows the standard Euler equation prevailing in the infinitely-lived representative agent paradigm (see, e.g., Benhabib, Schmitt-Grohé and Uribe, 2001).

### 2.2 Macroeconomic Policy Regimes

The flow budget constraint of the government in per capita terms is given by[6]

$$\dot{b}(t) + \dot{m}(t) = (R(t) - \pi(t) - n)\, b(t) - \tau(t) - (\pi(t) - n)\, m(t), \tag{16}$$

which, following Benhabib, Schmitt-Grohé and Uribe (2001) and Canzoneri, Cumby, and Diba (2010), can be written as

$$\dot{\ell}(t) = (R(t) - \pi(t) - n)\, \ell(t) - s\,(t)\,, \tag{17}$$

where $\ell(t) = b(t) + m(t)$ are total government liabilities and $s\,(t) = \tau(t) + R(t)m(t)$ is the primary surplus inclusive of interest savings from the issuance of money.

To close the model, one needs to specify the fiscal and monetary policy regimes. In or-

[6]For simplicity and without loss of generality, we set public consumption equal to zero.

der to concentrate on the implications of intergenerational housing-wealth effects and provide a direct and transparent analysis on the interactions between demographic forces and house price dynamics, following Futagami, Iwaisako and Ohdoi (2008) and Maebayashi, Hori and Futagami (2017), the fiscal authority is assumed to adopt a policy targeting the real value of government liabilities, consistently with the adjustment rule

$$\dot{\ell}(t) = -\phi\left(\ell(t) - \ell^{*}\right), \tag{18}$$

where $\phi > 0$ and $\ell^{*}$ is the target level of government liabilities.[7] Therefore, given such a targeting rule, combining (17) and (18), the government must adjust the primary surplus according to

$$s\left(t\right) = \left(R(t) + \phi - \pi(t) - n\right)\ell(t) - \phi\ell^{*}. \tag{19}$$

The monetary authority adopts a conventional Taylor-rule framework, by controlling the nominal interest rate $R(t)$ according to a feedback policy rule of the form

$$R(t) = T(\pi(t)), \tag{20}$$

where function $T(\cdot)$ is a continuous, strictly increasing, strictly positive, and differentiable function. Following Taylor (1993, 2012, 2014), we assume $T'(\pi(t)) > 1$. This constraint is meant to ensure that, whenever policy-makers observe symptoms of inflationary pressure, they will tighten policy sufficiently to ensure an increase in the real rate of interest.

[7] Given the supply of money $m\left(t\right)$, which in equilibrium endogenously adjusts to the demand of money, $m(t) = c(t)/\Gamma(R(t))$—since in our model the monetary authority controls the nominal interest rate $R(t)$—(18) sets down the issuance of government bonds $b\left(t\right) = \ell(t) - m\left(t\right)$.

### 2.3 Equilibrium

Because the central focus of this paper is to analyze the role played by demographic factors for the determination of *long-run* housing prices, total output $\overline{y}(t)$ and housing supply $\bar{h}(t)^s$ are assumed to grow at the rate of population growth $n$, without loss of generality. Per capita output and housing are thus constant, and can be normalized to unity, $y(t) = y = h^s = 1$, for analytical convenience. Equilibrium in the goods market requires that $c(t) = y = 1$. Equilibrium in the housing market requires that $h(t) = h^s = 1$. Equilibrium in the money market implies $m(t) = c(t)/\Gamma(R(t)) = 1/\Gamma(R(t))$.

From the law of motion of per capita consumption (14), the equilibrium real interest rate is given by

$$R(t) - \pi(t) = \rho + \frac{L'(R(t))}{L(R(t))}\dot{R}(t) + \frac{\alpha\beta(\rho+\mu)}{L(R(t))}\left(q(t) + \ell\,(t)\right). \tag{21}$$

Then, using the policy rule (20), in equilibrium inflation dynamics obey

$$\dot{\pi}(t) = \frac{1}{L'(T(\pi(t)))T'(\pi(t))}\left[\begin{array}{c} \left(T(\pi(t)) - \pi(t) - \rho\right) L(T(\pi(t))) \\ -\alpha\beta(\rho+\mu)\left(q(t) + \ell\,(t)\right) \end{array}\right], \tag{22}$$

while, from (15), real house price dynamics obey

$$\dot{q}(t) = \left(T(\pi(t)) - \pi(t)\right) q(t) - \frac{(1-\alpha)}{\alpha} L\left(T(\pi(t))\right). \tag{23}$$

## 3 Demographics and Real House Prices

This section first analyzes the dynamic properties of our model, and then concentrates on the links between demographic factors and real house prices. Linearizing the dynamic equations (22) and (23) around a steady state $(\pi^*, q^*, \ell^*)$ and using (18), we obtain the system

$$\begin{pmatrix} \dot{\pi}(t) \\ \dot{q}(t) \\ \dot{\ell}(t) \end{pmatrix} = J \begin{pmatrix} \pi(t) - \pi^* \\ q(t) - q^* \\ \ell(t) - \ell^* \end{pmatrix}, \tag{24}$$

where

$$J = \begin{pmatrix} J_{11} & -\frac{\alpha\beta(\rho+\mu)}{L'(T(\pi^*))T'(\pi^*)} & -\frac{\alpha\beta(\rho+\mu)}{L'(T(\pi^*))T'(\pi^*)} \\ J_{21} & \rho + \alpha\beta(\rho+\mu)\frac{(q^*+\ell^*)}{L(T(\pi^*))} & 0 \\ 0 & 0 & -\phi \end{pmatrix}, \tag{25}$$

with

$$J_{11} = \frac{(T'(\pi^*) - 1)\, L\,(T(\pi^*))}{L'\,(T(\pi^*))\, T'(\pi^*)} + \alpha\beta(\rho+\mu)\frac{(q^* + \ell^*)}{L\,(T(\pi^*))} > 0,$$

$$J_{21} = \left(T'(\pi^*) - 1\right) q^* - \frac{(1-\alpha)}{\alpha} L'\,(T(\pi^*))\, T'(\pi^*).$$

One eigenvalue of the Jacobian matrix $J$ is $-\phi < 0$, and the remaining two eigenvalues are obtained from the sub-matrix

$$K = \begin{pmatrix} J_{11} & -\frac{\alpha\beta(\rho+\mu)}{L'(T(\pi^*))T'(\pi^*)} \\ J_{21} & \rho + \alpha\beta(\rho+\mu)\frac{(q^*+\ell^*)}{L(T(\pi^*))} \end{pmatrix}. \tag{26}$$

The determinant and the trace of $K$ are

$$\det K = \begin{Bmatrix} \frac{L(T(\pi^*))}{L'(T(\pi^*))T'(\pi^*)} \left[\rho + \alpha\beta(\rho+\mu)\frac{(q^*+\ell^*)}{L(T(\pi^*))}\right] \\ +\alpha\beta(\rho+\mu)\frac{q^*}{L'(T(\pi^*))T'(\pi^*)} \end{Bmatrix} \left(T'(\pi^*) - 1\right)$$

$$+\alpha\beta(\rho+\mu)\frac{\ell^*}{L\,(T(\pi^*))}\rho + \alpha\beta(\rho+\mu)\frac{(q^* + \ell^*)}{L\,(T(\pi^*))} > 0,$$

$$\mathrm{tr} J = J_{11} + \rho + \alpha\beta(\rho+\mu)\frac{(q^* + \ell^*)}{L\,(T(\pi^*))} > 0.$$

Since both the determinant and the trace of $K$ are positive, the real parts of the roots of $K$ are positive. Because both $\pi(t)$ and $q(t)$ are 'jump' variables and $\ell(t)$ is a predetermined variable, equilibrium determinacy prevails. That is, around $(\pi^*, q^*, \ell^*)$ there exists a unique equilibrium converging asymptotically to the steady state. In particular, the only trajectory of $(\pi(t), q(t), \ell(t))$ converging asymptotically to $(\pi^*, q^*, \ell^*)$ is given by the following saddle-path solution:

$$\pi(t) = \pi^* + \frac{\alpha\beta(\rho+\mu)\left[\phi + \rho + \alpha\beta(\rho+\mu)\frac{(q^*+\ell^*)}{L(T(\pi^*))}\right]}{L'(T(\pi^*))\,T'(\pi^*)\det(K+\phi I)}\left(\ell(t) - \ell^*\right), \tag{27}$$

$$q(t) = q^* - \frac{\alpha\beta(\rho+\mu)J_{21}}{L'(T(\pi^*))\,T'(\pi^*)\det(K+\phi I)}\left(\ell(t) - \ell^*\right), \tag{28}$$

$$\ell(t) = \ell^* + \left(\ell(0) - \ell^*\right)e^{-\phi t}, \tag{29}$$

where $I$ is the $2 \times 2$ identity matrix.

It follows that, even in the presence of housing-wealth effects, a monetary policy stance in the spirit of Taylor (1993, 2012, 2014) exhibits the usual stabilizing properties. Simple intuitions follow. Suppose that the occurrence of an exogenous shock brings about an upward deviation of inflation from the target. If monetary policy satisfies Taylor's restriction $T' > 1$, the real interest rate increases and house prices decrease. Aggregate consumption declines because of both the increase in the real interest rate and the decrease in house prices, which generates a negative wealth effect. The associated fall in aggregate demand causes prices to decrease, hence dampening the initial inflationary pressure. Suppose also that an exogenous shock leads to high level of house prices. Aggregate demand and thus inflation are stimulated via the positive wealth effect on aggregate consumption. Under the Taylor-rule framework, the real interest rate increases and house prices decrease, thereby inducing aggregate stability.

The steady-state equilibrium for inflation and real house prices can be obtained by setting $\dot{\pi}(t), \dot{q}(t) = 0$ in equations (22) and (23), which yields[8]

$$T(\pi^*) - \pi^* - \rho = \frac{(1-\alpha)\,\beta(\rho+\mu)}{(T(\pi^*) - \pi^*)} + \alpha\beta(\rho+\mu)\frac{\ell^*}{L(T(\pi^*))}, \tag{30}$$

$$q^* = \frac{(1-\alpha)}{\alpha}\frac{L\left(T(\pi^*)\right)}{(T(\pi^*) - \pi^*)}. \tag{31}$$

From (30),

$$\frac{\partial \pi^*}{\partial n} = \frac{\frac{(1-\alpha)(\rho+\mu)}{(T(\pi^*)-\pi^*)} + \alpha(\rho+\mu)\frac{\ell^*}{L(T(\pi^*))}}{\left[1 + \frac{(1-\alpha)\beta(\rho+\mu)}{(T(\pi^*)-\pi^*)^2}\right](T'(\pi^*) - 1) + \alpha\beta(\rho+\mu)\frac{L'(T(\pi^*))T'(\pi^*)\ell^*}{(L(T(\pi^*)))^2}} > 0, \tag{32}$$

$$\frac{\partial \pi^*}{\partial \mu} = \frac{\frac{(1-\alpha)[(\rho+\mu)+\beta]}{(T(\pi^*)-\pi^*)} + \alpha\left[(\rho+\mu)+\beta\right]\frac{\ell^*}{L(T(\pi^*))}}{\left[1 + \frac{(1-\alpha)\beta(\rho+\mu)}{(T(\pi^*)-\pi^*)^2}\right](T'(\pi^*) - 1) + \alpha\beta(\rho+\mu)\frac{L'(T(\pi^*))T'(\pi^*)\ell^*}{(L(T(\pi^*)))^2}} > 0, \tag{33}$$

$$\begin{aligned} \frac{\partial \pi^*}{\partial \beta} &= \frac{\partial \pi^*}{\partial n + \partial \mu} = \left[\left(\frac{\partial \pi^*}{\partial n}\right)^{-1} + \left(\frac{\partial \pi^*}{\partial \mu}\right)^{-1}\right]^{-1} \\ &= \left\{ \begin{array}{c} \frac{\left[1+\frac{(1-\alpha)\beta(\rho+\mu)}{(T(\pi^*)-\pi^*)^2}\right](T'(\pi^*)-1)+\alpha\beta(\rho+\mu)\frac{L'(T(\pi^*))T'(\pi^*)\ell^*}{(L(T(\pi^*)))^2}}{\frac{(1-\alpha)(\rho+\mu)}{(T(\pi^*)-\pi^*)}+\alpha(\rho+\mu)\frac{\ell^*}{L(T(\pi^*))}} \\ +\frac{\left[1+\frac{(1-\alpha)\beta(\rho+\mu)}{(T(\pi^*)-\pi^*)^2}\right](T'(\pi^*)-1)+\alpha\beta(\rho+\mu)\frac{L'(T(\pi^*))T'(\pi^*)\ell^*}{(L(T(\pi^*)))^2}}{\frac{(1-\alpha)[(\rho+\mu)+\beta]}{(T(\pi^*)-\pi^*)}+\alpha[(\rho+\mu)+\beta]\frac{\ell^*}{L(T(\pi^*))}} \end{array} \right\}^{-1} > 0. \end{aligned} \tag{34}$$

The impact of demographic factors on equilibrium real house prices can now be derived as

$$\begin{aligned} \frac{\partial q^*}{\partial n} &= \frac{\partial q^*}{\partial \pi^*}\frac{\partial \pi^*}{\partial n} \\ &= \frac{(1-\alpha)}{\alpha}\frac{L'\left(T(\pi^*)\right)T'(\pi^*)\left(T(\pi^*) - \pi^*\right) - L\left(T(\pi^*)\right)\left(T'(\pi^*) - 1\right)}{\left(T(\pi^*) - \pi^*\right)^2}\frac{\partial \pi^*}{\partial n} < 0, \end{aligned} \tag{35}$$

[8] The steady state equilibrium is unique. Indeed, the steady-state level of $\pi$ is given by the solution to $T(\pi) - \pi - \rho = (1-\alpha)\,\beta(\rho+\mu)/\left(T(\pi) - \pi\right) + \alpha\beta(\rho+\mu)\ell^*/L(T(\pi))$. Since in the steady state it must be that $T(\pi) - \pi = \left[(1-\alpha)\,L\left(T(\pi)\right)/q\right] > 0$, the left-hand-side of the foregoing equation is positive and increasing in $\pi$, while the right-hand-side is positive and decreasing in $\pi$. Consequently, steady-state uniqueness applies.

$$
\begin{aligned}
\frac{\partial q^*}{\partial \mu} &= \frac{\partial q^*}{\partial \pi^*}\frac{\partial \pi^*}{\partial u} &(36)\\
&= \frac{(1-\alpha)}{\alpha}\frac{L'\left(T(\pi^*)\right)T'(\pi^*)\left(T(\pi^*)-\pi^*\right)-L\left(T(\pi^*)\right)\left(T'(\pi^*)-1\right)}{\left(T(\pi^*)-\pi^*\right)^2}\frac{\partial \pi^*}{\partial u} < 0,
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial q^*}{\partial \beta} &= \frac{\partial q^*}{\partial \pi^*}\frac{\partial \pi^*}{\partial \beta} &(37)\\
&= \frac{(1-\alpha)}{\alpha}\frac{L'\left(T(\pi^*)\right)T'(\pi^*)\left(T(\pi^*)-\pi^*\right)-L\left(T(\pi^*)\right)\left(T'(\pi^*)-1\right)}{\left(T(\pi^*)-\pi^*\right)^2}\frac{\partial \pi^*}{\partial \beta} < 0,
\end{aligned}
$$

if

$$
L\left(T(\pi^*)\right)\left(T'(\pi^*)-1\right) > L'\left(T(\pi^*)\right)T'(\pi^*)\left(T(\pi^*)-\pi^*\right). \tag{38}
$$

Appendix C shows that condition (38) is largely satisfied for any empirically plausible model's parameterization, as the term $L'\left(T(\pi^*)\right)T'(\pi^*)\left(T(\pi^*)-\pi^*\right)$ is proved to be robustly close to zero.

Therefore, equations (35)-(37) clearly imply that there is no puzzle at all about the observed interrelationship between evolving demographic changes and real house price long-run behavior. Declines in the birth rate and in population growth, associated with increases in life expectancy $1/\mu$, cause real house prices to increase over the long run. The positive comovement between contemporary demographic trends and real house price trends—observed in the United States and in the OECD countries—can thus be explicable by an optimizing macroeconomic model where a nontrivial demographic profile is taken fully into account.

The mechanism at work behind our analytical results is as follows. The demographic transition of the type detected in advanced economies over the last decades is—once a macroeconomic perspective is properly allowed for—an independent source of deflationary pressures. This is because declines in the birth rate and in the rate of population growth, in conjunction with increases in longevity, tend to dampen aggregate demand and spur aggregate saving. When the monetary policy regime is based on inflation targeting, real interest rates fall. The decline in the rate of real interest triggers an excess demand in the housing market and thus real house price increases are necessary to restore equilibrium.

Of course, the foregoing analysis has deliberately restricted attention on the links between demographic and macroeconomic 'fundamentals'. It has explicitly ruled out, it should be said, the theoretical consideration of potential self-fulfilling explosive paths—bubbles—in real house prices, due to the occurrence of 'off-equilibrium' arbitrary revisions in agents' expectations, unrelated to 'fundamentals'. In such a context, Brito, Marini and Piergallini (2016) show that falling prices in the housing market are well possible when self-fulfilling boom-bust dynamics occur. The analysis of such an additional scenario would, nevertheless, lead away from the interrelations between demographic trends and real house price trends, the subject of this study. This scenario is consistent, however, with the paper's key point: once a macroeconomic general equilibrium perspective is adopted, the demographic transition—*per se*—may well be an independent source of real house price increases.

## 4 Conclusions

The alleged impact of demographic changes on the long-run behavior of real house prices is a widely discussed issue from a partial-equilibrium perspective, but is largely unexplored from a general-equilibrium perspective.

Our overlapping generations macroeconomic model with housing-wealth effects appears to be capable of explaining the positive relationship between contemporary demographic trends and real house price trends observed in the United States and in the OECD countries after 1987—in contrast with the original Mankiw-Weil (1989) prediction in favor of downward real house price trends triggered by the demographic transition.

Declines in the birth rate and in population growth, associated with increases in life expectancy, are shown to be an independent source of deflationary pressures, for they tend to dampen aggregate demand and spur aggregate saving. When the monetary policy objective is controlling inflation, the associated fall in real interest rates brings about an excess demand in the housing market, and so real house price increases are necessary to restore equilibrium. Busts in real house prices may well occur as a result of 'off-equilibrium' arbitrary revisions in agents' expectations—unrelated to demographic 'fundamentals'.

## Appendix A

Employing the definition of total consumption, $\overline{z}(s,t) \equiv \overline{c}(s,t) + R(t)\overline{m}(s,t)$, and the optimal intratemporal condition (6), we have

$$\log \Lambda \left(\overline{c}(s,t), \overline{m}(s,t)\right) = \log \upsilon(t) + \log \overline{z}(s,t), \tag{39}$$

where $\upsilon(t) \equiv \Lambda \left( \frac{\Gamma(R(t))}{\Gamma(R(t))+R(t)}, \frac{1}{\Gamma(R(t))+R(t)} \right)$ is the same for all generations. As a result, the intertemporal optimization problem assumes the following form:

$$\max_{\{\overline{z}(s,t),\, \overline{h}(s,t)\}} \int_0^\infty \left[\alpha \left(\log \upsilon(t) + \log \overline{z}(s,t)\right) + (1-\alpha) \log \overline{h}(s,t)\right] e^{-(\mu+\rho)t} dt, \tag{40}$$

subject to (3), and given $\overline{a}(s,0)$. The optimality conditions are thus given by (7)-(9). Hence, the individual budget constraint (3) becomes

$$\begin{aligned}
\dot{\overline{a}}(s,t) &= (R(t)-\pi(t)+\mu)\,\overline{a}(s,t)+\overline{y}(s,t)-\overline{\tau}(s,t) \\
&\quad -\overline{z}(s,t)+\left[\frac{\dot{q}(t)}{q(t)}-(R(t)-\pi(t))\right]q(t)\overline{h}(s,t) \\
&= (R(t)-\pi(t)+\mu)\,\overline{a}(s,t)+\overline{y}(s,t)-\overline{z}(s,t)-\frac{1-\alpha}{\alpha}\overline{z}(s,t) \\
&= (R(t)-\pi(t)+\mu)\,\overline{a}(s,t)+\overline{y}(s,t)-\frac{1}{\alpha}\overline{z}(s,t). \qquad (41)
\end{aligned}$$

Integrating forward (41), using the transversality condition (9) and the law of motion of total consumption (7), total consumption can be expressed a linear function of total wealth, given by (10). From (6),

$$\overline{z}(s,t)=L(R(t))\overline{c}(s,t), \qquad (42)$$

where $L(R(t))\equiv 1+R(t)/\Gamma\left(R(t)\right)$. Time-differentiating (42) yields

$$\dot{\overline{z}}(s,t)=L'(R(t))\overline{c}(s,t)\dot{R}(t)+L(R(t))\dot{\overline{c}}(s,t). \qquad (43)$$

Thus, the law of motion for individual consumption results in (12).

# Appendix B

The per capita aggregate wealth is, by definition, given by

$$a(t)=\beta\int_{-\infty}^{t}\overline{a}(s,t)e^{\beta(s-t)}ds. \qquad (44)$$

Differentiating with respect to time implies

$$\dot{a(t)} = \beta\overline{a}(t,t) - \beta a(t) + \beta \int_{-\infty}^{t} \dot{\overline{a}}(s,t)e^{\beta(s-t)}ds, \tag{45}$$

where $\overline{a}(t,t)$ is equal to zero by assumption. Using (3) yields

$$\begin{aligned} \dot{a(t)} &= -\beta a(t) + \mu a(t) + (R(t) - \pi(t))\, a(t) + y(t) - \tau(t) - c(t) \\ &\quad -R(t)m(t) + \left[\frac{\dot{q}(t)}{q(t)} - (R(t) - \pi(t))\right] q(t)h(t) \\ &= (R(t) - \pi(t) - n)\, a(t) + y(t) - \tau(t) - c(t) \\ &\quad -R(t)m(t) + \left[\frac{\dot{q}(t)}{q(t)} - (R(t) - \pi(t))\right] q(t)h(t). \end{aligned} \tag{46}$$

Using (8) and (42), the per capita aggregate consumption is given by

$$c(t) = \frac{\alpha(\mu+\rho)}{L(R(t))}\left(a(t) + k(t)\right), \tag{47}$$

where $k(t) = \int_t^\infty (y(t) - \tau(t))\, e^{-\int_t^v (R(j)-\pi(j)+\mu)dj} dv$ is the per capita aggregate human wealth. Next, differentiate with respect to time the definition of per capita aggregate consumption. We obtain

$$\dot{c(t)} = \beta\overline{c}(t,t) - \beta c(t) + \beta \int_{-\infty}^{t} \dot{\overline{c}}(s,t)e^{\beta(s-t)}ds. \tag{48}$$

Notice that $\overline{c}(t,t)$ denotes consumption of the newborn generation. Because $\overline{a}(t,t) = 0$, (11) implies

$$\overline{c}(t,t) = \frac{\alpha(\mu+\rho)}{L(R(t))}\overline{k}(t,t). \tag{49}$$

Substituting (12), (47) and (49) into (48) results in the time path of per capita aggregate consumption given by (14).

## Appendix C

Suppose $\Lambda\left(\overline{c}(s,t),\overline{m}(s,t)\right)$ is a CES function, in line with Galí (2008) and Walsh (2017):

$$\Lambda\left(\overline{c}(s,t),\overline{m}(s,t)\right)=\left[\delta\overline{c}(s,t)^{\frac{\varepsilon}{\varepsilon-1}}+(1-\delta)\,\overline{m}(s,t)^{\frac{\varepsilon}{\varepsilon-1}}\right]^{\frac{\varepsilon-1}{\varepsilon}}, \tag{50}$$

with $0<\delta,\varepsilon<1$, where $\varepsilon$ represents the elasticity of substitution between real money holdings and consumption. It thus follows

$$\frac{\overline{m}(s,t)}{\overline{c}(s,t)}=\frac{1}{\Gamma(R\,(t))}=\left(\frac{\delta}{1-\delta}\right)^{-\varepsilon}R\,(t)^{-\varepsilon}, \tag{51}$$

$$L\left(R\,(t)\right)=1+\left(\frac{\delta}{1-\delta}\right)^{-\varepsilon}R\,(t)^{1-\varepsilon}, \tag{52}$$

$$\begin{aligned} L'(R\,(t)) &= (1-\varepsilon)\left(\frac{\delta}{1-\delta}\right)^{-\varepsilon}R\,(t)^{-\varepsilon} \\ &= (1-\varepsilon)\,\frac{\overline{m}(s,t)}{\overline{c}(s,t)}. \end{aligned} \tag{53}$$

Consistently with the standard literature on monetary theory and policy (e.g., Woodford, 2003), assume an interest rate rule of the form

$$R\,(t)=T\left(\pi\,(t)\right)=\tilde{r}+\tilde{\pi}+\psi\left(\pi\,(t)-\tilde{\pi}\right),$$

where $\tilde{r}$ and $\tilde{\pi}$ are the central bank's targets for the real interest rate and the inflation rate, and $\psi>1$ is the policy parameter conforming to the Taylor (1993, 2012, 2014)'s principle. Hence, condition (38) becomes

$$\left\{1+\left(\frac{\delta}{1-\delta}\right)^{-\varepsilon}\left[\tilde{r}+\tilde{\pi}+\psi\left(\pi^{*}-\tilde{\pi}\right)\right]^{1-\varepsilon}\right\}(\psi-1)$$
$$> \quad (1-\varepsilon)\left(\frac{\delta}{1-\delta}\right)^{-\varepsilon}\left[\tilde{r}+\tilde{\pi}+\psi\left(\pi^{*}-\tilde{\pi}\right)\right]^{-\varepsilon}\psi\left[\rho+(\psi-1)\left(\pi^{*}-\tilde{\pi}\right)\right].$$

For U.S. annual data, in the monetary policy literature it is common to set $\delta = 0.95$, $\varepsilon = 0.4$, $\tilde{r} = \rho = 0.04$, $\tilde{\pi} = 0.02$, $\psi = 1.5$ (see, e.g., Walsh, 2017), and $1 - \alpha = 0.1$ (see, e.g., Iacoviello, 2005). In line with United Nations World Population Prospects (2017 Revision) for 2015-2020,[9] we set $n = 0.0071$ and $\mu = 0.01256$, implying a life expectancy at birth of 79.62 years and a birth rate of 0.02. Equation (30) thus pins down $\pi^* = 0.027$. Therefore,

$$A_1 = \left\{1+\left(\frac{\delta}{1-\delta}\right)^{-\varepsilon}\left[\tilde{r}+\tilde{\pi}+\psi\left(\pi^{*}-\tilde{\pi}\right)\right]^{1-\varepsilon}\right\}(\psi-1) = 0.53,$$

$$\begin{aligned} A_2 &= (1-\varepsilon)\left(\frac{\delta}{1-\delta}\right)^{-\varepsilon}\left[\tilde{r}+\tilde{\pi}+\psi\left(\pi^{*}-\tilde{\pi}\right)\right]^{-\varepsilon}\psi\left[\rho+(\psi-1)\left(\pi^{*}-\tilde{\pi}\right)\right] \\ &= 0.035. \end{aligned}$$

Hence, condition (38) is largely verified. Three critical parameters must be evaluated in order to check the robustness of the above findings: the elasticity of substitution between real money balances and consumption $\varepsilon$, the weight of money relative to consumption in the utility function $1 - \delta$, and the weight of housing relative to the consumption-money aggregate in the utility function $1 - \alpha$.

Within the plausible set of $\varepsilon$–values $\varepsilon \in (0.1, 0.9)$, $A_1$ is no less than 0.52, and $A_2$ is no

[9]https://population.un.org/wpp/.

more than 0.038. Within the plausible set of $\delta$–values $\delta \in (0.5, 0.95)$, $A_1$ is no less than 0.53, and $A_2$ is no more than 0.11. Within the plausible set of $\alpha$–values $\alpha \in (0.5, 0.9)$, $A_1$ is, again, no less than 0.53, and $A_2$ is no more than 0.037.

Thus, condition (38) appears to be robustly satisfied. As a consequence, the implications derived in Section 3 are not affected in any fundamental dimension.

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