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Demand, Markups and the Business Cycle

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Abstract

We generalize the demand side of a Real Business Cycle model introducing non-homothetic preference aggregators over differentiated final goods. Under monopolistic competition this generates markups which vary with consumption. We estimate a flexible preference specification through Bayesian methods and obtain substitutability across goods increasing with consumption. The closed-economy model magnifies the propagation of shocks through additional substitution effects on labor supply and consumption. In an open-economy framework, it also generates positive comovements of output, labor and investment and reduces consumption correlation between countries. In particular, a positive shock in the Home country improves its terms of trade, which promotes consumption in the Home country but also production in the Foreign country.

Key words: RBC, non-homothetic preference aggregators, variable markups, international macroeconomics.

JEL Codes: E1, E2, E3, F4.

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1 Introduction

Real Business Cycle (RBC) models have been quite successful at reproducing important aspects of the propagation of aggregate shocks in closed and open economies. Still, it is well known that they can hardly replicate some key facts. Closed economy models (Kydland and Prescott, 1982) fail to reproduce all the variability of output emerging in the data, mainly because of a limited reaction of consumption and labor supply to technology shocks, and they generate too much consumption smoothing compared to the evidence. Open economy models (Backus *et al.*, 1992) imply an unrealistic negative correlation of output, labor and investment across countries because of a strong incentive to shift production from less to more productive countries, and an excessive correlation of consumption across countries due to risk sharing. Moreover, most extensions of the baseline models with multiple goods and constant markups are unable to replicate realistic fluctuations in relative prices and the terms of trade. As is well known, nominal price rigidities, more pervasive imperfections in the labor and financial markets, endogenous entry of firms, distortionary taxes and trade costs have been useful at solving some of these anomalies (King and Rebelo, 1999; Obstfeld and Rogoff, 2000).

In this work we argue that a standard flexible price model with monopolistic competition can contribute to solve the above inconsistencies if we adopt a more general microfoundation of the demand side that delivers variable markups and additional intertemporal substitution mechanisms.[2] These are absent within the traditional Dixit and Stiglitz (1977) model based on constant elasticity of substitution (CES) preferences, which generates constant markups that are neutral on the propagation of shocks under flexible prices (Blanchard and Kiyotaki, 1987). Instead, non-homothetic preferences over the final goods generate an elasticity of substitution (and therefore a demand elasticity) that changes with the consumption level and induces firms to modify their desired markups in response to a shock.[3] In particular, when substitutability increases in consumption an expansionary shock reduces the markups under monopolistic competition and increases even more the real wages, thereby promoting both consumption and labor supply, and raising profits. This has key consequences for the mentioned anomalies because it magnifies the propagation of shocks, increases the variability of consumption and, in an open economy, generates positive spillovers across countries while reducing the cross-correlation of consumption. Of course,

[2]For recent developments on the microfoundation of monopolistic competition see Dixit (2017) in the *Special Issue in Honor of 40 Years of the Dixit-Stiglitz Model* of *Research in Economics* and the other articles there.

[3]Non-homothetic preference aggregators are typically used in models of structural change (Herrendorf, Rogerson and Valentinyi, 2014; Matsuyama, 2017), and are gaining rapid adoption in macroeconomic models with monopolistic competition (Ravn *et al.*, 2008, Etro, 2016, and Boucekkine *et al.*, 2017) and international trade models with monopolistic competition (Bertoletti *et al.*, 2018, Arkolakis *et al.*, 2019) for their ability to generate incomplete pass-through and pricing to market. As is well known non-homotheticity precludes studying heterogeneous consumers in a simple way, but the analysis of the role of heterogeneous agents for the business cycle falls beyond the scope of our work.

from an empirical point of view, markups of prices over marginal costs are unobserved and therefore hard to estimate: the evidence on the cyclical properties of markups in the data is mixed, with important studies, such as Bils (1987), Murphy *et al.* (1989), Rotemberg and Woodford (1999) and Chevalier *et al.* (2003) supporting the view that markups are broadly countercyclical, and more recent ones, such as Nekarda and Ramey (2013) and Anderson *et al.* (2018) supporting the opposite view. While we are not directly contributing to this open empirical debate, we want to emphasize the role of demand in shaping the variability of markups on final goods in their consumption level and, through that, on aggregate fluctuations.

We start our theoretical analysis by studying a closed economy model which departs from a standard RBC framework by replacing the CES intratemporal preference aggregator over the final goods with a directly additive aggregator. This delivers simple markup rules under monopolistic competition that depend on aggregate consumption and therefore change over the business cycle. Variable markups deliver modified Euler and labor supply equations that take into account the fluctuations of prices and real wages over time. For illustrative purposes the quantitative analysis is based on a bi-power specification that nests CES preferences as a special case and can deliver markups either increasing or decreasing in the consumption level. We provide an empirical model validation exercise which uses standard calibration for the technological parameters and Bayesian estimates for the preference parameters (in the spirit of Schorfheide, 2000, Fernandez-Villaverde and Rubio-Ramirez, 2004, and Smets and Wouters, 2007). The estimation is based on U.S. data and its aim is to verify if these data can be consistent with non-homothetic preferences and, if so, what are their implications for markups:[4] the results support an intratemporal elasticity of substitution among varieties that is increasing in consumption, which under monopolistic competition leads to countercyclical markups. To gauge the role of markup variation for the transmission of technology shocks, we compare the quantitative performance of the model under monopolistic competition with its equivalent under perfect competition. The variability of output increases substantially, mainly due to an increase in the reactivity of labor supply, while consumption becomes marginally more volatile compared to perfect competition. Overall, the model with variable markups outperforms the standard RBC model in matching second moments of the business cycle.

We then extend the analysis to an international RBC framework with two identical countries and directly additive preferences over the differentiated goods. Countries can trade goods but not inputs and are subject to correlated shocks as in Backus *et al.* (1992). We assume segmented markets for goods so that firms can choose different prices for each market (as in Betts and Devereux, 2000), and incomplete financial markets. We first focus on the case of financial autarky (Cole and Obstfeld, 1991; Heathcote and Perri, 2002). The model generates positive comovements of output, labor and investment and reduces

[4] The idea is that when the demand elasticity depends on the level of consumption, firms may desire to change their markups in response to a shock, and by estimating the preference parameters, we circumvent the difficulties involved in the estimation of unobserved markups.

drastically the correlation of consumption between countries. These outcomes are due to endogenous pricing to market under monopolistic competition. A positive temporary technology shock in the Home country, by reducing Home markups, improves the Home terms of trade and depreciates the real exchange rate. This leads to an expansion in relative Home consumption, while promoting production, investment and labor supply also in the Foreign country to exploit the increased profitability of exports. Similar results emerge if we allow for intertemporal trade in non-contingent bonds (Kollman, 1995), in which case we also obtain countercyclical net exports, due to the fact that the domestic shock increases cheaper imports more than expensive exports.

Endogenous markup variation has been extensively studied in macroeconomics. As is well known, standard New-Keynesian models generate countercyclical markups due to price stickiness, because expansionary shocks tend to increase nominal costs while some prices remain unchanged, but our focus on flexible price models abstracts from the impact of inflation.[5] Rotemberg and Woodford (1992, 1999) have obtained countercyclical markups under implicit collusion. A recent literature has shown that endogenous entry of firms can generate countercyclical markups under general homothetic preferences (Bilbiie *et al.*, 2012, 2016) or oligopolistic competition (Jaimovich and Floetotto, 2008; Etro and Colciago, 2010),[6] but these mechanisms originate on the supply side (i.e. through entry) and we want to show that the demand side alone can generate variable markups with relevant aggregate consequences. Our work is related to Ravn *et al.* (2006), who have considered monopolistic competition with deep habits at the good level, where intertemporal links in consumption imply countercyclical markups, and, most of all, to Ravn *et al.* (2008), who adopt a Stone-Geary preference specification with subsistence consumption to generate countercyclical markups under monopolistic competition. We compare our to this and other specifications to exemplify the role of preferences in affecting business cycles.

On the open economy front, Ghironi and Melitz (2005) have generated variable average prices (but not variable markups) through endogenous entry of heterogeneous firms, while Davis and Huang (2011) have analyzed the business cycle implications of markups that vary between countries because of trade costs and imperfect competition among a fixed number of firms. However, these works build on CES preferences and we are not aware of international RBC models featuring endogenously variable markups due to changes of demand over the business cycle, which contributes to explain co-movements of relative prices and aggregate variables across countries.

The work is organized as follows. Section 2 presents the baseline model for a closed economy. Section 3 discusses our quantitative approach, based on a

[5] Since homothetic aggregators generate constant markups under flexible prices, also the implicitly additive aggregator introduced by Kimball (1995) cannot generate variable markups in the absence of price stickiness. See Cavallari (2018) on the role of non-homothetic preferences for inflation and monetary policy.

[6] On the aggregate consequences of endogenous entry and markups see also, among others, Campbell (1998) and Cavallari (2013a,b).

combination of calibration and estimation techniques, and evaluates the propagation of technology shocks, concluding with a brief discussion of extensions to other preferences and entry. Section 4 extends the model to two countries to analyze international business cycles under financial autarky and then with bond trade across countries. Section 5 concludes.

2 RBC when demand matters

In this section we analyze a closed economy DSGE model. The supply side is standard: capital K_t and labor input L_t are entirely employed by a perfectly competitive sector producing an intermediate good with a Cobb-Douglas production function $Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}$ where A_t is total factor productivity and $\alpha \in (0,1)$. The intermediate good is the *numeraire* of the economy and can be used to invest in capital accumulation, under a depreciation rate $\delta \in [0,1]$, or to produce a variety of downstream final goods with a linear technology under monopolistic competition. Preferences over these final goods determine the demand system and are at the core of the impact of demand on the business cycle.

2.1 Preferences

We consider a unit mass of identical consumers with the following intertemporal utility function:

$$\mathbb{U} = \mathbb{E}\left[\sum_{t=1}^{\infty} \beta^{t-1} \left(\log U_t - \frac{\upsilon l_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}\right)\right] \tag{1}$$

where $\mathbb{E}[\cdot]$ is the expectations operator, $\beta \in (0,1)$ is the discount factor, l_t is labor supply, $\varphi \geq 0$ is the Frisch elasticity, $\upsilon \geq 0$ is a scale parameter for the disutility of labor and U_t is a utility functional of the consumption of final goods, which is assumed symmetric on a given unitary mass of goods. We will assume that this intratemporal utility is directly additive:

$$U_t = \int_0^1 u(C_{jt})dj \tag{2}$$

where the subutility $u(C)$ satisfies $u'(C) > 0$ and $u''(C) < 0$. The traditional specification used in macroeconomics is based on a power subutility for each good such as $u(C) = \frac{\theta}{\theta-1} C^{\frac{\theta-1}{\theta}}$ with $\theta > 1$: this delivers "log-CES" homothetic preferences where θ can be interpreted as the intratemporal elasticity of substitution between goods while the intertemporal elasticity is unitary (due to the logarithmic transformation of the consumption index). Contrary to this, the other directly additive specifications imply non-homotheticity of the intratemporal preferences: for instance, our quantitative exercise will assume $u(C) = \gamma C + \frac{\theta}{\theta-1} C^{\frac{\theta-1}{\theta}}$ where the parameter γ generates non-homotheticity as long as it differs from zero.

However, our theoretical results apply to any general symmetric and well-behaved preference aggregators that are not directly additive (see Bertoletti and Etro, 2016). Examples analyzed elsewhere include GAS preferences, originally introduced by Pollak (1972) and Gorman (1970, 1987), which deliver a demand system depending on a common aggregator and include directly additive as well as indirectly additive aggregators and implicit CES aggregators (see Bertoletti and Etro, 2017, 2018) discussed later on.

One can also consider alternative monotonic transformations of the intratemporal preferences, which of course modify the nature of intertemporal preferences. A useful normalization of the intratemporal directly additive aggregator is:

$$U_t = u^{-1}\left[\int_0^1 u(C_{jt})dj\right] \tag{3}$$

which ensures that U_t has the same units as C_{jt}, and, in case of symmetric consumption, is actually equal to the consumption level (since $u(U) = u(C)$).[7] While this monotonic transformation changes with the underlying subutility, it delivers again the log-CES preferences in case of power sub-utilities, and it is going to be neutral on monopolistic competition pricing and on intertemporal substitutability (whose elasticity is constant at the unitary level). For these reasons, it will be useful for comparison purposes.

2.2 Pricing and equilibrium

When the market for final goods is characterized by monopolistic competition, each variety i is sold at price p_{it} chosen in each period by firm i to maximize profits $\pi_{it} = (p_{it} - 1)\, C_{it}$ taking as given the aggregator of the strategies of the other firms. Notice that the marginal cost is unitary in terms of the intermediate good. Each consumer has the same endowment of capital and owns the same fraction of stocks of the firms. Therefore, the consumer receives the dividends, $\Pi_t = \int_j \pi_{jt} dj$, and the remuneration of the inputs with wage w_t and interest rate r_t in units of intermediate goods.

In each period, the consumer chooses spending on each variety C_{it}, labor supply l_t and the future stock of capital K_{t+1} to maximize utility under the resource constraint:

$$K_{t+1} = K_t(1-\delta) + w_t l_t + r_t K_t + \Pi_t - \int_0^1 p_{jt} C_{jt} dj \tag{4}$$

where $\delta \in [0, 1]$ is the depreciation rate, and total profits and all prices are taken as given. The FOCs for each C_{it} is:

$$\frac{\partial U_t / \partial C_{it}}{U_t} = \lambda_t p_{it} \tag{5}$$

and the FOCs for l_t and K_{t+1} are:

$$\upsilon l_t^{\frac{1}{\varphi}} = \lambda_t w_t \quad \text{and} \quad \lambda_t = \beta \mathbb{E}[R_{t+1} \lambda_{t+1}] \tag{6}$$

[7] We are grateful to a referee for suggesting this alternative normalization.

where the Lagrange multiplier λ_t corresponds to the marginal utility of income and $R_{t+1} = 1 + r_{t+1} - \delta$.

Each firm producing a variety i maximizes profits:

$$\pi_{it} = (p_{it} - 1)\, C_{it} = \frac{C_{it} \partial U_t / \partial C_{it}}{\lambda_t U_t} - C_{it}$$

with respect to the consumed quantity C_{it} considering only its direct effect on the demand: namely, both the marginal utility of income λ_t and the preference aggregator U_t are taken as given. The FOCs for each firm i provide the symmetric equilibrium monopolistic price as:

$$p(C_t) = \frac{1}{1 - \epsilon(C_t)} \tag{7}$$

where we defined the elasticity of the marginal sub-utility evaluated under symmetry as $\epsilon(C) \equiv \frac{-u''(C)C}{u'(C)}$.

As shown in Bertoletti and Etro (2016), in general the relevant elasticity is the reciprocal of the *intratemporal elasticity of substitution* between a good i and any other good j:

$$\vartheta(C) \equiv -\frac{\partial \ln(C_i/C_j)}{\partial \ln p_i} = -\left(\frac{\partial \ln(p_i/p_j)}{\partial \ln C_i}\right)^{-1} = \frac{1}{\epsilon(C)}$$

evaluated under symmetry ($C_i = C_j = C$).[8] We assume $\epsilon(C) < 1$ to insure a positive markup: this imposes a restriction on the sub-utilities, such that $u'(C)C$, i.e. the marginal revenue, is positive. Moreover, the SOCs require the marginal revenue to be locally decreasing as well. Both these conditions are satisfied if $u'(C)C$ is increasing and concave in consumption, as we will assume. Nevertheless, the elasticity $\epsilon(C)$ can be either increasing or decreasing in consumption, with $p'(C) \gtrless 0$ if and only if $\epsilon'(C) \gtrless 0$. In the case of CES preferences (as with any homothetic preferences), the elasticity is constant and the markups are constant as well. Instead, when a directly additive utility is characterized by a decreasing index of relative risk aversion, markups are decreasing in consumption.[9] This will be the relevant case in our quantitative application: intuitively, when consumption of each variety is limited, the substitutability between goods is low and when consumption of each variety increases, the different varieties become more substitutable.

The symmetric equilibrium allows us to solve for the Lagrange multiplier $\lambda_t = (\partial U_t / \partial C_t)/U p(C_t)$ and to rewrite the FOCs as follows:

$$l_t = \left[\frac{w_t \psi(C_t)}{\upsilon C_t p(C_t)}\right]^{\varphi}$$

[8] These are indeed the Morishima elasticities, that are the relevant elasticities of perceived demand under monopolistic competition for any symmetric preferences.

[9] An old conjecture by Marshall suggests the demand of a good should be more elastic at a lower price or a higher level of consumption. However, this is unrelated to the impact of changes in aggregate consumption on the perceived substitutability between goods, which can either remain constant (as with CES preferences), decrease or increase. The last case emerges if consumers that become richer also become less lovers of differentiation or risk.

$$\frac{\psi(C_t)}{C_t p(C_t)} = \beta \mathbb{E} \left\{ R_{t+1} \frac{\psi(C_{t+1})}{C_{t+1} p(C_{t+1})} \right\}$$

where we defined the elasticity of the intratemporal utility as $\psi(C) \equiv \frac{\partial U}{\partial C} \frac{C}{U(C)}$, which is just the elasticity of the sub-utility under the directly additive aggregator (2).

The assumption of a directly additive aggregator (2) delivers a simple characterization of the *elasticity of intertemporal substitution*.[10] Taking the logs of the Euler equation and differentiating provides the following expression for this elasticity in our context:

$$\chi(C_t) \equiv -\frac{\partial \ln C_t}{\partial \ln p(C_t)} = \frac{1}{1 - \psi'(C_t) C_t / \psi(C_t)} \tag{8}$$

which is assumed positive and implies $\chi(C) \gtreqless 1$ if $\psi'(C) \gtreqless 0$. Accordingly, an increase in the current price level or, equivalently, in the expected interest rate increases consumption more than proportionally when the elasticity of utility is increasing in consumption.

With the directly additive aggregator (2) we have $\psi'(C_t)C_t/\psi(C_t) = 1 - \psi(C) - \epsilon(C)$ delivering:

$$\chi(C_t) = \frac{1}{\psi(C) + \epsilon(C)}$$

Notice that the intertemporal elasticity can change with aggregate consumption, as documented empirically by Attanasio and Browning (1995), but the lack of a direct relation between the signs of the derivatives of $\psi(C)$ and $\epsilon(C)$, excludes a direct relation with markup cyclicality. Attanasio and Browning (1995) and subsequent studies have argued that the intertemporal elasticity increases with the level of consumption, but without further assumptions we cannot say whether the elasticity $\chi(C)$ is increasing or decreasing in consumption. However, the intertemporal elasticity is always lower than the intratemporal elasticity since $\chi(C) < 1/\epsilon(C)$. In case of CES preferences $\psi(C) = 1 - 1/\theta$ is constant and the intertemporal elasticity of substitution is unitary. Notice that under the transformation (3), one can verify that $\psi(C) = 1$ is constant for any subutility $u(C)$, therefore the intertemporal elasticity of substitution is unitary again.

The markets for the factors of production are perfectly competitive. Market clearing in the labor market $L_t = l_t$ implies the wage $w_t = (1-\alpha)A_t(K_t/L_t)^\alpha$ in units of intermediate goods, and market clearing in the capital market implies the rental rate $r_t = \alpha A_t (K_t/L_t)^{\alpha-1}$. The symmetric equilibrium total profits $\Pi_t = [p(C_t) - 1] C_t$ allow us to solve for the resource constraint as:

$$K_{t+1} = K_t(1-\delta) + A_t K_t^\alpha L_t^{1-\alpha} - C_t \tag{9}$$

which is the same as under perfect competition because all profits are rebated to consumers. Using these conditions we can rewrite the modified labor supply

[10] We are grateful to Paolo Bertoletti for pointing out a relevant definition for this case.

and Euler conditions as follows:

$$L_t = \left[\frac{(1-\alpha) A_t K_t^{\alpha} \psi(C_t)}{\upsilon C_t p(C_t)} \right]^{\frac{\varphi}{1+\alpha\varphi}} \tag{10}$$

$$\frac{\psi(C_t)}{C_t p(C_t)} = \beta \mathbb{E} \left\{ \frac{\left[1 - \delta + \alpha A_{t+1} K_{t+1}^{\alpha-1} L_{t+1}^{1-\alpha}\right] \psi(C_{t+1})}{C_{t+1} p(C_{t+1})} \right\} \tag{11}$$

which emphasizes the role of variable markups in affecting the business cycle.[11] When the pricing function $p(C)$ implies countercyclical markups, a boom generates a larger increase in labor supply and a shift toward current consumption. Both mechanisms are due to intertemporal substitution effects: lower prices today compared to tomorrow induce a temporary increase in the real wage which promotes labor supply, and make temporarily more convenient to consume final goods. These are the key mechanisms at work.

Our main purpose is to compare monopolistic and perfect competition to show that variable markups can contribute in a substantial way to explain the propagation of shocks in a flexible price model. Here perfect competition should be referred to the market for each good, which is served by multiple firms (rather than a single one) taking as given the price: this, of course, would imply marginal cost pricing for each good. Therefore, under perfect competition we simply replace $p(C) = 1$ in the labor supply equation (10) and in the Euler equation (11).[12]

3 Quantitative analysis

While our theoretical results are general and point out a role of demand in shaping the business cycle, to perform a quantitative analysis we need to adopt a specific functional form for the preferences. To clarify the relation between the traditional CES assumption and our more general environment and obtain closed form solutions for our equilibrium equations, we have selected a simple specification that nests CES preferences. Therefore, our results should be interpreted in terms of the ability of our demand-side mechanism to improve

[11] The analysis of a balanced growth pact is not our focus, but the model is consistent with a constant growth rate of consumption and capital and constant labor supply in the long run as long as the rato $\psi(C)/p(C)$ is bounded, in which case the balanced growth path is asymptotically equivalent to the traditional one with a CES aggregator and constant markup. This condition is immediately satisfied in our specification below. The extension to endogenous entry *à la* Bilbiie *et al.* (2012) could also preserve markup variability along the balanced growth path. An alternative would be the adoption of a habit stock term *à la* Jaimovich and Rebelo (2009). We are grateful to a referee on this point.

[12] It is standard to verify that the perfectly competitive equilibrium corresponds to the efficient allocation that would be chosen by a social planner. This emphasizes that variable markups can generate two inefficiencies: one is an intratemporal distortion of labor supply - $p(C_t) > 1$ in (10) - and the other is an intertemporal distortion of the savings decision - $p(C_{t+1}) \neq p(C_t)$ in (11). In principle, one can avoid this cost of the business cycle by introducing a labor income subsidy and a capital income tax. See Bilbiie *et al.* (2016) and Etro (2008) for a related discussion on optimal dynamic taxation.

the performance of a standard RBC model, and not as a literal endorsement of a particular specification. We will conclude the section by discussing few extensions.

We adopt a polynomial specification of the sub-utility which combines a linear and a power function:

$$u(C) = \gamma C + \frac{\theta}{\theta - 1} C^{\frac{\theta-1}{\theta}} \quad \text{with } \theta > 1 \tag{12}$$

Of course this "bi-power" sub-utility nests the CES case for $\gamma = 0$. The restriction $\theta > 1$ implies that the marginal revenue is positive and is necessary and sufficient for the marginal revenue to be decreasing in consumption, which ensures the second order condition for profit maximization is satisfied (i.e. $u'(C)C = \gamma C + C^{\frac{\theta-1}{\theta}}$ is increasing and concave). The elasticity of substitution between goods is:

$$\vartheta(C) = \theta(1 + \gamma C^{\frac{1}{\theta}})$$

and is increasing (decreasing) in consumption if $\gamma > (<)\ 0$. While in principle both cases are possible, our focus, supported empirically in the next section, is on the case of $\gamma > 0$. This was originally introduced by Bertoletti *et al.* (2017) in the static analysis of monopolistic competition under the label of *IES preferences* due to the increasing elasticity of (intratemporal) substitution ($\epsilon'(C) < 0$ and $\vartheta'(C) > 0$).

The specification (12) generates the following pricing rule:

$$p(C_t) = \frac{\theta(1 + \gamma C^{\frac{1}{\theta}})}{\theta(1 + \gamma C^{\frac{1}{\theta}}) - 1} \tag{13}$$

and the assumption $\theta > 1$ is sufficient to have positive prices, markups and (finite) profits when $\gamma > 0$, while we need $\theta > (1 + \gamma C^{\frac{1}{\theta}})^{-1}$ when $\gamma < 0$. Therefore, markups are decreasing (increasing) in consumption if $\gamma > (<)\ 0$.

The elasticity of the subutility is:

$$\psi(C) = \frac{1 + \gamma C^{\frac{1}{\theta}}}{\frac{\theta}{\theta-1} + \gamma C^{\frac{1}{\theta}}}$$

and is increasing (decreasing) in consumption if $\gamma > (<)\ 0$. This implies that the elasticity of intertemporal substitution can be computed as:

$$\chi(C) = \frac{1 + \gamma C^{\frac{1}{\theta}} + \frac{1}{\theta-1}}{1 + \gamma C^{\frac{1}{\theta}} + \frac{\frac{\theta}{\theta-1} + \gamma C^{\frac{1}{\theta}}}{\theta(1+\gamma C^{\frac{1}{\theta}})}}$$

which is greater (smaller) than one if $\gamma > (<)\ 0$. Given the opposite signs of $\psi'(C)$ and $\epsilon'(C)$, the sign of the derivative of $\chi(C)$ is not obvious, but tedious algebra can show that $\chi'(C) \gtreqless 0$ if $\gamma \gtreqless 0$. Accordingly, the elasticity of intertemporal substitutability is increasing in consumption exactly when the intratemporal elasticity of substitution between goods is also increasing in consumption.

For calibration purposes, there have been many empirical attempts at estimating a constant intratemporal elasticity of substitution at the basis of CES aggregators, while there is no available evidence on the structural parameters of more general preference aggregators as the one used here. Similarly, a wide literature has focused on the estimation of a constant elasticity of intertemporal substitution (see Havranek *et al.*, 2015, for a recent meta-analysis). Nevertheless, microeconometric studies of consumers' behavior that consider general intratemporal preferences, starting with Attanasio and Browning (1995), suggests that homotheticity is unlikely to hold, and the elasticity of intertemporal substitution is far from constant. Moreover, Attanasio and Browning (1995) offer evidence that this elasticity depends on aggregate consumption and is actually increasing in the level of consumption. The subsequent literature examining different countries is consistent with these findings, providing estimates of the intertemporal elasticity of substitution that are positively correlated with income (Havranek *et al.*, 2015). In what follows we provide indirect support for these results.

3.1 Estimation

Our strategy for providing an empirically plausible parameterization of consumption utility in the absence of direct evidence relies on a combination of calibration and econometric estimation techniques. The estimation applies Bayesian methods as in Fernandez-Villaverde and Rubio-Ramirez (2004) and Schorfheide (2000). The exercise has a twofold objective. First, it is meant to provide reasonable values for the parameters γ and θ of the preference specification that will be used for the scope of illustrating the potential of our macroeconomic mechanism. Second, it provides a formal test of the capacity of models with increasing versus constant elasticity to fit macro data.

We impose dogmatic priors on the parameters α, β, δ, and υ using values that are common in related business-cycle studies. Table 1 presents the calibrated parameter values. The capital share is $\alpha = 0.33$. The discount factor is $\beta = 0.99$, corresponding to a real interest rate of 4% per annum. The depreciation rate is $\delta = 0.025$ to match the 10% rate of capital depletion per year found in US data. We normalize the scale parameter for the disutility of labor υ so that the steady-state value of employment is $L = 1$ under any experiment: this insures that the steady state is identical for all specifications with either perfect or monopolistic competition. The steady state value of total factor productivity is normalized as $A = 1$. Accordingly, the steady state capital is $K \approx 13.5$ and the steady state consumption is $C \approx 2.3$ for any preference specification. The simulations will focus on a productivity shock that follows an AR(1) process in logs $\ln A_t = \rho \ln A_{t-1} + \epsilon_t$, where the innovation ϵ_t is distributed as a normal variable with zero mean and variance σ^2.

We also calibrate four non-structural parameters representing the standard deviation of measurement errors on the observables. We assume these errors are mutually orthogonal stochastic processes, each of them is orthogonal to the technology shock, and impose that they can absorb no more than 10 percent of the variance of the corresponding observable time series, i.e. output Y, consumption C, employment L and labor share Ψ_L. In this way, measurement errors can capture potential misspecification of the theoretical model, while not obscuring the role of structural shocks (see Sargent, 1989).

Table1: Calibration, baseline model

Parameter	α	β	δ	σ_Y^{me}	σ_C^{me}	σ_L^{me}	σ_Ψ^{me}
Value	0.33	0.99	0.025	0.20	0.17	0.06	0.12

We estimate the remaining parameters with US data on output, consumption, employment, and the labor share over the period 1966Q1-2008Q2.[13] Specifically, we estimate the parameters governing the utility of consumption, γ and θ, together with the Frisch elasticity φ, and the parameters defining the stochastic process of the productivity shock, the standard deviation σ and persistence ρ. We also estimate four non-structural parameters representing the persistence of AR(1) measurement errors on the observables, ρ_Y, ρ_C, ρ_L, and ρ_Ψ.

Data sources and filtering are as follows (with further details in the Appendix). The time series for GDP, and consumption are from the US Department of Commerce, Bureau of Economic Analysis (BEA). As in Smets and Wouters (2007), real personal consumption expenditure includes durable goods. Series for hours, employment, and the labor share are from the US Bureau of Labor Statistics (BLS). As in Chang *et al.* (2002), we stress the limited coverage of the non-farm business sector relative to GDP, and multiply the index of average hours worked for the non-farm business sector (All persons) by civilian employment (16 years and over). The labor share of the business sector Ψ_L is measured as an index with base year 2012 (from the BLS). All series are seasonally adjusted. The aggregate variables are expressed in per capita terms, at constant prices with base year 2012, and are linearly detrended in logarithmic terms using the symmetric band pass filter of Christiano and Fitzgerald (2003) with periods of oscillation between 6 and 32. All observable variables are demeaned by subtracting the respective sample average.

The measurement equation is:

$$Z_t = \begin{bmatrix} d\log Y \\ d\log C \\ d\log L \\ d\log \Psi_L \end{bmatrix} = \begin{bmatrix} y_t - y_{t-1} \\ c_t - c_{t-1} \\ l_t - l_{t-1} \\ \psi_{Lt} - \psi_{Lt-1} \end{bmatrix} + \begin{bmatrix} e_y \\ e_c \\ e_l \\ e_{\psi_L} \end{bmatrix}$$

where $d\log x$ stands for 100 times the filtered log of each variable x, lower-case letters denote log-linearized variables, and e_x are AR(1) measurement errors.

An overview of the priors is in Table 2. The prior distributions on structural parameters are quite diffuse: γ has a normal distribution with mean 2 and standard deviation 0.5, θ and φ have gamma distributions with mean 1.2

[13] We overlook the Great Recession period to avoid excessive volatility.

and 1, and standard deviation 0.3 and 0.25, respectively. The prior mean of γ reflects our preference for an increasing elasticity of substitution across goods. Later on we discuss the consequences of relaxing this assumption. The prior mean of θ is above unity for consistence of the model, while the density includes the lower range of values that are entertained in macro studies. However, it is worth repeating that the intratemporal elasticity of substitution in our model is $\vartheta(C) = \theta(1 + \gamma C^{\frac{1}{\theta}})$, and depends not only on θ but also on γ and the level of consumption. The prior means of γ and θ together with steady-state consumption imply an intratemporal elasticity of 5.8 with a markup around 20%. The prior mean for φ is in the low range of values considered in business cycle studies, and the density reveals the extent of uncertainty that surrounds estimates of the Frisch elasticity.[14] We impose diffuse priors also on the parameters of the shock process and of measurement errors. All the autoregressive coefficient have beta distributions with mean 0.5 and standard deviation 0.15. The standard error of the structural innovation has an inverse gamma distribution with mean 0.005 and standard deviation 1.

Table 2: Estimation results, baseline model

Estimated parameters			
Symbol	Prior (P1, P2)	Posterior	
		Mode (st.err)	Mean [5th; 95th %ile]
γ	N(2, 0.5)	1.99 (0.48)	1.9910 [1.0562; 2.9629]
θ	G(1.2, 0.3)	1.12 (0.29)	1.2425 [0.6850; 1.8502]
φ	G(1, 0.25)	0.93 (0.22)	0.9624 [0.5449; 1.4431]
σ	IG(0.005, 1)	0.0021 (0.001)	0.0026 [0.0012; 0.0046]
ρ	B(0.5, 0.15)	0.51 (0.17)	0.5054 [0.2458; 0.7872]
Measurement errors			
ρ_Y	B(0.5, 0.15)	0.90 (0.026)	0.8827 [0.8328; 0.9328]
ρ_C	B(0.5, 0.15)	0.88 (0.027)	0.8976 [0.8487; 0.9463]
ρ_L	B(0.5, 0.15)	0.87 (0.028)	0.8724 [0.8160; 0.9305]
ρ_{Ψ_L}	B(0.5, 0.15)	0.87 (0.029)	0.8668 [0.8196; 0.9243]
Log marginal likelihood 139.7579			

Notes: B, beta; N, normal; G, gamma; IG, inverse gamma distributions. P1, mean and P2, standard deviation for all distributions. Posterior moments are computed using 10.000 draws from the distributions simulated by the Random Walk Metropolis Hastings algorithm.

First, we estimate the mode of the posterior distribution, by maximizing the log posterior function, which combines the prior information on the parameters with the likelihood of the data. In a second step, we use the two-block Random Walk Metropolis Hastings algorithm to fully characterize the posterior distribution and evaluate the marginal likelihood of the model. The generated

[14] The wage elasticity of labor supply exhibits ample variability across workers, with estimates ranging from zero to more than one (see Keane, 2011). The range considered in business cycle studies is between 1 and 4. The standard RBC model of King and Rebelo (1999), for instance, assumes an elasticity of 2.

Markov chain of parameters passes all the requirements of convergence.[15] Table 2 presents key statistics of the prior and posterior distributions.

The estimation yields posterior means given by $\gamma = 1.99$ and $\theta = 1.24$. A positive value for γ implies an elasticity of substitution that is increasing in the level of consumption while monopolistic markups are countercyclical. This and the value for θ imply an elasticity of substitution between goods fluctuating around a steady state value of $\vartheta(2.3) \approx 6.1$, which lies in the middle of the range of values entertained in macroeconomics, though above the assumption of Bilbiie *et al.* (2012) and similar models with variable markups. Notice that the elasticity of intertemporal substitution in steady state is $\chi(2.3) = 1.4$, marginally higher than the usual unitary elasticity associated with log preferences and well within the range of empirically relevant values (Havranek *et al.* 2015). The steady state markup is around 16%, at the lower end of the interval for the average price markup found in US data, and in line with estimates based on micro data.[16] Compared to large-scale DSGE models, our estimate of the markup is low - for instance, Smets and Wouters (2007) find a markup of 60%. A reason is that we focus on monopoly distortions, overlooking other frictions like nominal rigidity and financial constraints that may contribute to increase markups. We view the ability to reproduce plausible markups in a simple setup as an important advantage of our specification.

The result that the elasticity predicted by the model is increasing with the level of consumption is not a consequence of the assumption of monopoly distortions, nor it is an artifact of our specification of preferences. In fact, shutting off the monopoly distortions in the baseline model by setting $p(C) = 1$ and keeping all parameter values and prior assumptions unchanged results in an almost identical posterior distribution for γ (column *Perfect Competition prior* in Table 3). Assuming perfect competition, a positive γ captures only changes in the curvature of the utility function over time that have the effect of strengthening intertemporal substitution of consumption and labor. The results in Table 3 suggest that these mechanisms are not rejected by the data.

Similar conclusions hold when we consider a version of the model where the elasticity of intertemporal substitution is fixed at unity independently from the behavior of the intratemporal elasticity, which is obtained using the normalization given by the monotonic transformation in (3). The estimation hangs on the same prior assumptions considered in the baseline model (column *Constant EIS prior* in Table 3), and delivers an almost identical estimate of parameter γ, while both the average markup and the Frisch elasticity are higher.

[15] The estimations are done with Dynare. A sample of 10.000 draws is created. The Hessian resulting from the optimization procedure is used for defining the transition probability function that generates the new draw. A step size of 1.10 results in an acceptance rate of around 25% for each block. Two methods are used to test the stability of the sample. The first convergence diagnostic is based on Brooks and Gelman (1998) and compares between and within moments of multiple chains. The second method is a graphical test based on the cumulative mean minus the overall mean.

[16] Markup estimates based on macro data range between 15% and 35%, see Rotemberg and Woodford (1999) and Basu and Fernald (1997). Micro estimates point to much lower values (see Boulhol, 2008).

Finally, given the scope of the analysis, which focuses on non-homothetic preferences, it is important to gauge the extent to which models with constant and variable intratemporal substitutability fit the data. For this purpose, we have estimated the model under the assumption of a constant intratemporal elasticity of substitution, namely with a CES aggregator, by imposing a strict prior of γ equal to zero while keeping all other parameter values and prior assumptions unchanged (column *CES prior* in Table 3). A constant elasticity of substitution results in a marginal likelihood well below the marginal likelihood in the baseline specification. The Bayes factor, measuring the odds the data prefer the model with an increasing elasticity, is $2.998\,4 \times 10^7$.[17] According to Jeffreys (1998), a Bayes factor of this size provides *decisive* evidence in favor of the IES model. We can conclude that our specification of preferences, characterized by an increasing elasticity of substitution, is not rejected by the data.

Table 3: Estimation results, alternative models

Estimated parameters			
	Perf. Comp. prior	*Constant EIS prior*	*CES prior*
	post Mean [5th; 95th%ile]	post Mean [5th; 95th%ile]	post Mean [5th; 95th%ile]
γ	1.946 [0.939; 2.725]	2.041 [1.025; 2.897]	0.003 [0.003; 0.003]
θ	1.289 [0.681; 1.891]	1.128 [0.588; 1.644]	1.054 [1.054; 1.054]
φ	0.946 [0.310; 1.178]	0.997 [0.536; 1.539]	0.948 [0.540; 1.431]
σ	0.001 [0.001; 0.001]	0.003 [0.001; 0.005]	0.003 [0.001; 0.005]
ρ	0.863 [0.779; 0.954]	0.524 [0.267; 0.865]	0.528 [0.261; 0.819]
Measurement errors			
ρ_Y	0.882 [0.82; 0.932]	0.881 [0.833; 0.933]	0.500 [0.886; 0.836]
ρ_C	0.899 [0.846; 0.948]	0.898 [0.851; 0.963]	0.896 [0.843; 0.947]
ρ_L	0.872 [0.815; 0.927]	0.870 [0.813; 0.922]	0.874 [0.814; 0.926]
ρ_{Ψ_L}	0.866 [0.810; 0.918]	0.867 [0.810; 0.919]	0.868 [0.813; 0.918]
Logmarg. lik. 139.754		Logmarg. lik. 139.818	Logmarg. lik. 122.542

Notes: Posterior moments are computed using 10.000 draws from the distributions simulated by the Random Walk Metropolis Hastings algorithm.

3.2 Macroeconomic dynamics

We start with an intuitive illustration of the transmission mechanism at work in the model by means of impulse response functions. To stress the role of market structure, we contrast the dynamics under perfect and monopolistic competition. Then, we evaluate the performance at replicating the volatility in our data.

[17] The Bayes factor is calculated with the Laplace approximation described in Geweke (1999, 2005).

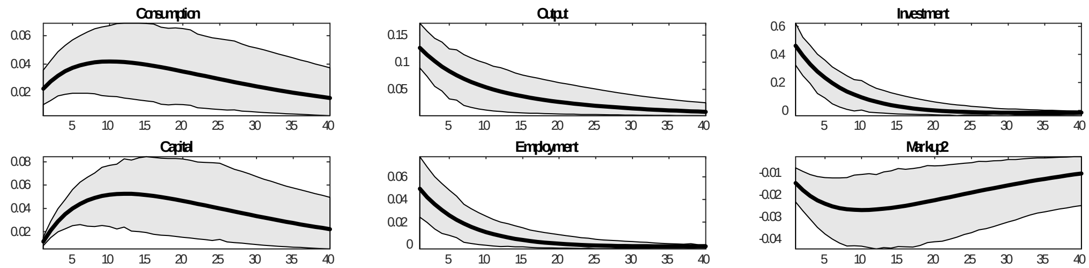

Figure 1: Posterior IRF to a one standard deviation shock to productivity, baseline model (IES with monopolistic competition).

Figures 1 and 2 display the impulse responses in the wake of a productivity shock in the IES model under monopolistic and perfect competition, respectively. In each figure, the y-axis indicates the mean responses in percent deviation from the posterior mean, together with 95% confidence intervals, while the quarters elapsed since the occurrence of the shock are on the x-axis. A response of, say, 0.01 means a 1 percent change.

In the baseline model, variable markups contribute to amplifying the propagation of the productivity shock. Consumption and labor are higher over the whole transition compared to the model estimated under the assumption of perfect competition. On impact, for instance, consumption and labor supply increase by, respectively, 2.18 and 4.96 percent under monopolistic competition and by 1.33 and 4.83 percent with perfect competition. These responses reflect the incentive for households to anticipate their consumption plans and labor efforts in periods when prices are low and wages are high compared to the future. As a consequence of this behavior, production, capital accumulation and investments are also boosted. Notice that the shock reduces markups on impact, while the inverse-U pattern of consumption generates an additional downward pressure, and it takes a long time before markups revert toward their initial level.

It is worth stressing that the role of markup variability for the propagation of shocks does not depend on the specific parameterization of consumption utility. In simulations where γ varies between 0.5 and 2.5 while all other parameters are kept constant, the responses of output and its components at any horizon are larger under monopolistic competition, and the size of these response is only marginally affected by the value of γ. Clearly, with $\gamma = 0$ markups are constant and the dynamics of the model becomes independent of markups.

The extent to which monopoly distortions increase macro volatility can be

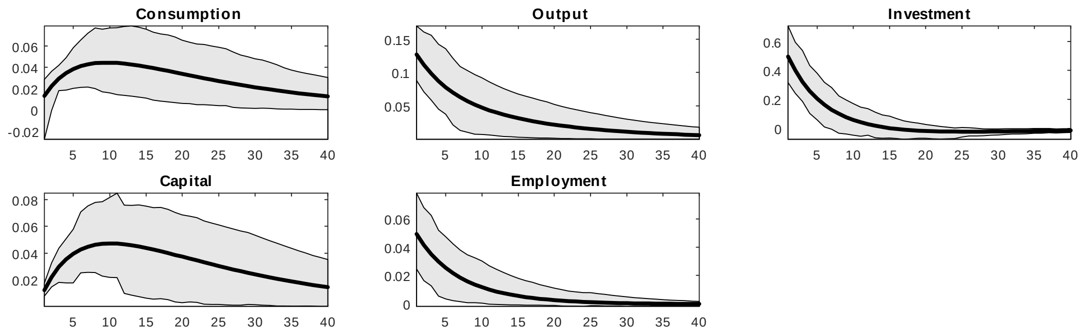

Figure 2: Posterior IRF to a one standard deviation shock to productivity (IES model with perfect competition).

assessed quantitatively by looking at the theoretical moments under monopolistic and perfect competition. Table 4 displays the posterior standard deviations in the baseline model with IES preferences and monopolistic competition, in the IES model under perfect competition, in the model with normalized IES preferences (unitary intertemporal elasticity) and monopolistic competition, and in the CES model, together with the standard deviation of the observable variables in our data.

Table 4: Comparing model and data

Standard Deviation	Y	C	L	Ψ_L
IES Mon. Comp.	0.5394	0.2064	0.2487	0.1510
IES Perf. Comp.	0.4066	0.1473	0.1792	0.1063
Normalized IES Mon. Comp.	0.5630	0.3170	0.2480	0.1793
CES	0.3998	0.1357	0.1718	0.0010
Data	0.6536	0.5355	0.1882	0.4072

Notes: Empirical moments are computed using US data from 1966Q1 to 2008Q2. Standard deviations are reported in percentage points. Model moments are computed as the median based on 10.000 draws from the posterior distribution.

The baseline model explains 83% of the volatility of output in the data against 55% of the model under perfect competition, 54% of the model with CES preferences and 86% in the version with constant intertemporal elasticity. The performance under monopolistic competition, either with variable or with constant intertemporal elasticity, fares advantageously compared to perfect competition also in terms of the volatility of consumption and the labor share, while the volatility of employment is higher than the data. In all cases, standard deviations under monopolistic competition are significantly higher than with perfect competition, supporting the conclusion that monopoly distortions indeed increase macro volatility. We stress that the magnitude of amplification is only marginally affected by the specification of intertemporal elasticity, and the overall goodness of the fit is very similar for the baseline and the normalized model.

3.3 Business cycle properties

So far we have argued that increasing elasticity and countercyclical markups generate intertemporal substitution effects that amplify the propagation of shocks compared to models with constant elasticity and constant markups. We now turn to investigate the extent to which these amplification mechanisms can help explain stylized business cycle facts. In particular, we are interested in assessing the performance of our model compared to a standard RBC model. For ease of comparison, we consider the classical business cycle facts summarized in King and Rebelo (1999), and simulate alternative specifications that feature increasing and constant elasticity of substitution, as well as perfect and monopolistic competition. The stochastic simulations are based on a first-order approximation around the deterministic steady state, which is common to all specifications, and is perturbed by an identical innovation.[18] In all simulations, the theoretical variables are HP filtered with a quarterly smoothing parameter of 1600 for consistence with business cycle data and previous studies.

The time unit in the model is a quarter. The baseline calibration closely follows that in King and Rebelo (1999), except for the parameters governing consumption utility, which are set at their posterior values. The parameters that are common to all specifications are: $\alpha = 0.33$, $\beta = 0.99$, $\delta = 0.025$, $\varphi = 2$, $\rho = 0.979$, and $\sigma = 0.0072$. An increasing elasticity is obtained by setting γ and θ at their posterior mean: in the baseline IES model with monopolistic competition $\gamma = 1.99$ and $\theta = 1.24$, in the IES model with perfect competition $\gamma = 1.92$ and $\theta = 1.23$, and in the normalized IES model with monopolistic competition $\gamma = 2.04$ and $\theta = 1.13$. To replicate the CES model we simply set $\gamma = 0$, because in this case the dynamics of the model becomes independent of parameter θ and of the form of competition, perfect or monopolistic (because markups are constant and labor supply is normalized to one in steady state). Accordingly this model represents the standard RBC framework. The exercise can be interpreted as a sensitivity analysis on the parameters governing consumption utility.[19]

[18] Simulations are made with Dynare. We have also experimented a second-order approximation as described in Schmitt-Grohe and Uribe (2004), without noticeable consequences for the results.

[19] We have also considered a calibration in which the parameters governing both consumption and labor utility are set at their respective posterior mean values. The relative performance of the various specifications considered remains unaltered.

Table 5 reports selected theoretical moments together with US data from King and Rebelo (1999). The baseline specification features IES preferences under monopolistic competition. Other specifications consider IES preferences under perfect competition, IES preferences under monopolistic competition and intertemporal elasticity normalized at unity, and CES preferences (here the form of competition is irrelevant). The values in the table are the medians across 1000 simulations, each 2100 periods long.

Table 5: Moments, closed economy

	Standard deviation				
	IES Mon. Comp.	**IES** Perf. Comp	**Normalized IES** Mon. Comp.	**CES** (RBC)	**Data**
Y	1.52	1.45	1.38	1.30	1.84
L	0.84	0.74	0.63	0.54	1.79
C	0.55	0.55	0.55	0.53	1.35
I	4.98	4.53	4.12	3.84	5.30
	Correlation with output				
	IES Mon. Comp.	**IES** Perf. Comp	**Normalized IES** Mon. Comp.	**CES** (RBC)	**Data**
L	0.98	0.99	0.98	0.98	0.88
C	0.84	0.90	0.94	0.95	0.88
I	0.99	0.99	0.99	0.99	0.80
	1^{st} auto-correlation				
	IES Mon. Comp.	**IES** Perf. Comp	**Normalized IES** Mon. Comp.	**CES** (RBC)	**Data**
Y	0.74	0.74	0.74	0.73	0.84
L	0.72	0.72	0.72	0.72	0.88
C	0.86	0.83	0.80	0.79	0.80
I	0.72	0.72	0.72	0.72	0.87

Notes: Empirical moments are from King and Rebelo (1999). Standard deviations are reported in percentage points. Model moments are computed as the median based on 1000 simulations.

The baseline model generates a volatility of output and investment that is fairly close to the data both in absolute and relative terms. The Kydland-Prescott ratio, i.e. the fraction of output variability explained by the model, is 0.84 against 0.77 in King and Rebelo (1999). The model fares advantageously relative to the standard RBC model also in terms of the volatility of labor, though both labor and consumption are still smooth compared to the data. The cyclicality of consumption is very close to the data, overcoming a well-known difficulty of standard models in this respect. Like the standard RBC model, the model generates too procyclical investments and labor. The first-order auto-correlation demonstrates the capacity to capture the persistence in the data.[20]

[20] As mentioned the model generates countercyclical markups. While the evidence on this

It is instructive to consider the performance of alternate specifications to gain further insights about the role of preferences and market structure. The model with CES preferences behaves like a standard RBC model with perfect competition. Consumption, employment and investments are too smooth compared to the data, and the Kydland-Prescott ratio is 0.71. Introducing IES preferences while retaining perfect competition helps increase the variability of output and labor (with a Kydland-Prescott ratio 0.79) due to the slightly more than unitary and increasing elasticity of intertemporal substitution; nevertheless, the variability of output and labor is substantially increased when monopolistic competition is added. Alternatively, under monopolistic competition, replacing CES preferences with IES preferences while keeping the intertemporal elasticity constant, through the normalization (3), helps to increase volatility, though the effect is small.[21] Overall these outcomes point at the presence of monopolistic competition together with IES preferences as useful ingredients for explaining macroeconomic dynamics, supporting the relevance of our mechanism based on markup fluctuations.

3.4 Other preferences and endogenous entry

Our quantitative analysis can be easily extended to other intratemporal preferences. For instance, we have experimented with other generalizations of CES aggregators. Following Ravn *at al.* (2008), we have considered Stone-Geary aggregators with:

$$U_t = \int_0^1 (C_{jt} - \bar{C})^{\frac{\theta-1}{\theta}} dj$$

where the common minimum (subsistence) level of consumption $\bar{C} > 0$ delivers $\epsilon(C) = C/\theta(C - \bar{C})$ and therefore a countercylical markup under the condition $\theta > C/(C - 2\bar{C})$, needed for a decreasing marginal revenue. We have considered the normalization (3) to compare models with a constant unitary elasticity of intertemporal substitution, and we have calibrated the minimum level of consumption to reproduce one third of steady-state income $\bar{C} = 0.92$ as in Ravn *et al.* (2008), and set $\theta = 10.2$ to match the same steady state markup as in out baseline model (16%), while all other parameters are the same as in the baseline calibration. The standard deviations of consumption, output, employment and investment become equal to, respectively, 0.55, 1.36, 0.62, and 4.08, with an increase in variability compared to the CES model that is in line with our normalized IES specification. However, the performance of the Stone-Geary spefication with a flexible intertemporal substitutability, as in Ravn *et al.* (2008), is actually worse. The reason is that the elasticity of intertemporal substitution $\chi(C) = \frac{C-\bar{C}}{C}$ is smaller than unity in this case.

is not definitive, the model can also capture a negative correlation between current GDP and future markups observed in the data (the contemporaneous correlation between these variables is -0.89 and remains negative up to five lags).

[21] Simulations of the model with constant intertemporal elasticity where we set $\varphi = 2.4$, while all other parameters are unchanged, give moments very similar to those in the baseline specification.

We have also considered intratemporal preferences that are not directly additive. An extension of the CES aggregator, which gives additional weight to total consumption, is represented by:

$$U_t = \frac{\left(\int_0^1 C_{jt}^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}}{1 - \bar{s}\int_0^1 C_{jt} dj}$$

which corresponds to an additive indirect utility $V_t = \int_0^1 (s_{jt} - \bar{s})^{1-\theta} dj$, where s_j is the price-expenditure ratio of good j (Bertoletti and Etro, 2017). One can now derive $\epsilon(C) = (1 - \bar{s}C)/\theta$ and again countercyclical markups as long as $\bar{s} \in (0, 1/C)$. We have adopted a normalization analogous to (3) to fix a unitary intertemporal elasticity, and set $\theta = 3.8$ and $\bar{s} = 0.16$ to match a steady state markup of 16%. The simulations yield standard deviations close to those in the baseline model, with a standard deviation of 0.55 for consumption, 1.35 for output, 0.61 for employment and 4.06 for investments. In this case, allowing for an endogenous intertemporal elasticity improves substantially the performance of the model since $\chi(C) = \frac{1-\bar{s}C}{1-2\bar{s}C}$ is larger than unity. In principle, a more flexible specification of preferences allows one to better fit the behavior of inter- and intra-temporal substitutability and generate more powerful amplification mechanisms.

A related and important extension of our model should move from an exogenous (and unitary) set of goods provided in the market to an endogenous mass n_t associated with an intratemporal utility such as:

$$U_t = \int_0^{n_t} u(C_{jt}) dj$$

Endogenizing the mass of entrants in an equation of motion *à la* Bilbiie *et al.* (2012), with entry costs in labor, would add a new dimension of investment in new varieties to the analysis of the business cycle (see Etro, 2018). While this extension is beyond the scope of this section, few remarks can be useful since the model of Bilbiie *et al.* (2012) already moved beyond CES preference aggregators by using homothetic aggregators, which generate markups that depend on the number of goods and are independent of consumption of each good: accordingly, a positive shock promotes investment in new varieties, which directly affects the markups (possibly in a countercyclical way, as under translog preferences). Our model with directly additive preference aggregators, instead, generates markups that are independent of the number of firms and depend on the consumption of each good: accordingly, a positive shock promotes investment in new varieties and changes the consumption of each good, which affects the markups (possibly in a countercyclical way). In both these cases, the propagation of the business cycle through the endogenous entry process would be amplified by countercyclical markups due to the same intertemporal substitution mechanisms that we have emphasized until now. Nevertheless, notice that the substantial amplification mechanisms generated by endogenous entry under monopolistic competition with CES preferences would remain active also under preferences that generate procyclical markups, which in this case woud be in line with the findings of Nekarda and Ramey (2013).[22]

With more general intratemporal preferences that are neither homothetic nor directly additive, the markups would depend on both the number of goods and the consumption level, delivering richer propagation mechanisms (see Etro, 2018, for a discussion). For these reason, we believe the role of demand (through preferences) in affecting markups and endogenous entry deserves further investigation.

4 International business cycle

This section explores the role of monopolistic competition and endogenous pricing to market for the transmission of shocks across countries in an international real business cycle (IRBC) model *à la* Backus *et al.* (1992, BKK).[23]

We develop the simplest extension of our framework to a symmetric two-country economy. To build intuitions, we begin by analyzing the model under the assumption of "financial autarky" in Cole and Obstfeld (1991). When there are no markets for international asset trade, all trade must be *quid pro quo.* Then, we introduce trade in a riskless bond in order to investigate intertemporal trade. By allowing consumers to borrow and lend in international markets, the presence of the bond can favor the flow of savings toward higher returns on investment.

4.1 International trade under financial autarky

The world economy comprises now two countries, home h and foreign f, each one populated by a unit mass of consumers identical in preferences and income. The utility function in country $i = h, f$ follows the same directly additive IES specification considered before, with consumption C^i_{jt} for good j and labor supply l^i_t in period t. There is a unit mass of imperfectly substitutable varieties, all of which are traded in world markets. Each good $j \in [0, \frac{1}{2}]$ is produced by a monopolist at home and sold in both countries and each good $j \in [\frac{1}{2}, 1]$ is produced by a monopolist in the foreign country and sold in both countries. Any variety is imperfectly substitutable with any other variety, and symmetry of the preferences implies the elasticity of substitution among varieties is independent of the country of origin and destination of each variety.[24] Home and foreign markets,

[22] Moreover, models with endogenous entry and balanced growth due to technological progress are consistent with variable markups also in the long run because markups change with the number of goods and their individual consumption (rather than aggregate consumption).

[23] See also Backus *et al.* (1994) and the early survey in Baxter (1995). In the literature on international RBC with monopolistic competition, Ghironi and Melitz (2005) have studied the role of firms' heterogeneity and entry and Davis and Huang (2011) have studied the role of variable markups due to imperfect competition and trade costs, always retaining the assumption of CES preferences.

[24] This is the same assumption as in models based on pure CES preferences such as Betts and Devereux (2000) or Ghironi and Melitz (2005). More recent models based on nested CES

however, are segmented, therefore under monopolistic competition each firm can sell its own variety at different prices in the two markets.[25]

The Cobb-Douglas production functions in each country $i = h, f$ are $Y_t^i = A_t^i (K_t^i)^\alpha (L_t^i)^{1-\alpha}$. The intermediate goods produced with these technologies in each country can be used either to produce final goods with a one-to-one technology or to create new capital. Neither labor, nor capital or the intermediate goods are tradable. Only the final goods can be traded, as in static one-sector models of international trade *à la* Krugman (1979), who indeed used directly additive preferences.[26]

Let the vector $\mathbf{A}_t \equiv [A_t^h, A_t^f]$ represent the technology shocks in the domestic and foreign economies. As in conventional parameterization of the IRBC model, these shocks follow a trend-stationary AR(1) process:

$$\mathbf{A}_{t+1} = \mathbf{\Lambda} \mathbf{A}_t + \boldsymbol{\epsilon}_{t+1} \tag{14}$$

where $\mathbf{\Lambda}$ is a 2×2 matrix of coefficients describing the autocorrelation properties of the shocks, and the innovations in the vector $\boldsymbol{\epsilon}_t$ are serially independent, multivariate, normal variables with the variance and covariance matrix $\mathbf{\Omega}$. The shocks in the two economies are stochastically related through the off-diagonal elements of $\mathbf{\Lambda}$ and $\mathbf{\Omega}$: a productivity shock in, say, the home country can spill over in later periods on foreign productivity. The choice of stationary shocks reflects the desire to focus on preferences as the main departure from an otherwise standard IRBC model. Non-stationarity in fact would decrease the speed of transmission of shocks across countries, and lead to higher volatility of international prices (see Rabanal *et al.*, 2011). Later on we will discuss the implications of non-stationary shocks.

Following Corsetti *et al.* (2007), we find it convenient to express all prices in units of the local intermediate good. Labor and capital market clearing in each country implies $w_t^i = (1-\alpha) A_t^i (K_t^i / L_t^i)^\alpha$ and $r_t^i = \alpha A_t^i (K_t^i / L_t^i)^{\alpha - 1}$. The residents of each country hold a riskless bond B_t^i, which is denominated in the local numeraire, and pays a real return (also in units of the local numeraire) i_t^i at the end of period t but known at time $t-1$. Each consumer of a country can only hold national bonds and own stocks of national firms, which give right to receive (the same fraction of) the profits of all the domestic firms $\Pi_t^i = \int_j \pi_{jt}^i dj$ as dividends. Therefore, the resource constraint in country i is:

$$K_{t+1}^i + B_{t+1}^i = K_t^i (1-\delta) + B_t^i (1 + i_t^i) + w_t^i l_t^i + r_t^i K_t^i + \Pi_t^i - \int_0^1 p_{jt}^i C_{jt}^i dj \tag{15}$$

preferences feature a constant elasticity of substitution between home and foreign baskets of goods which can be different, and typically lower, than the elasticity between differentiated goods from the same country. While this asymmetry can be important for the international transmission of shocks, we abstract from it to focus on the new channels deriving from non-homothetic preferences.

[25] Perfect competition, instead, implies that each variety is sold at the marginal cost of the producer in both countries.

[26] Notice that markups are determined by the endogenous number of firms in the Krugman (1979) model, while they change over time in our model due to the consumption dynamics on a fixed number of goods.

where p^i_{jt} is the price of good j in terms of country i's numeraire. So p^h_{jt} , for instance, denotes the units of home intermediate goods that are exchanged for unit of good j. The FOCs for labor, capital and bonds are, respectively:

$$\upsilon\left(l^i_t\right)^{\frac{1}{\varphi}} = \lambda^i_t w^i_t, \quad \lambda^i_t = \beta\mathbb{E}[(1 + r^i_{t+1} - \delta)\lambda^i_{t+1}] \quad \text{and} \quad \lambda^i_t = \beta(1 + i^i_{t+1})\mathbb{E}[\lambda^i_{t+1}] \tag{16}$$

The returns on real and financial investment coincide under perfect foresight. With financial autarky and incomplete markets, this coincidence is true *ex ante* but does not hold for every state of nature.

The first order conditions for consumption of good j, C^i_{jt}, can be derived as $u'(C^i_{jt})/\int u(C^i_{jt})dj = \lambda^i_t p^i_{jt}$. Notice that the perceived inverse demand is the same for any good purchased in the domestic market, wherever the good comes from. Each home firm j has profits derived from home and foreign sales:

$$\pi^h_{jt} = \left(\frac{u'(C^h_{jt})}{\lambda^h_t \int_0^1 u(C^h_{jt})dj} - 1\right) C^h_{jt} + \left(\frac{\varepsilon_t u'(C^f_{jt})}{\lambda^f_t \int_0^1 u(C^f_{jt})dj} - 1\right) C^f_{jt}$$

where the exchange rate ε_t is defined as units of home intermediate good per unit of foreign intermediate good. This is a classic situation where a firm is active in two segmented markets at home and abroad and fixes prices for each market in the consumers' currency. Profit maximization requires choosing C^h_{jt} and C^f_{jt}. This gives the following expressions for the prices for home and foreign sales (in units of the home intermediate good):

$$p^h_{jt} = \frac{1}{1 - \epsilon(C^h_t)} \quad \text{and} \quad \varepsilon_t p^f_{jt} = \frac{1}{1 - \epsilon(C^f_t)}$$

A similar problem holds for the foreign firms and implies the prices $p^f_{jt} = 1/[1 - \epsilon(C^f_t)]$ and $p^h_{jt}/\varepsilon_t = 1/[1 - \epsilon(C^h_t)]$ in terms of the foreign intermediate goods. Using the exchange rate to express all goods sold in a given market in units of the local numeraire, it is immediate to see that home and foreign goods sell at an identical local price. We can therefore conclude that the price in country $i = h, f$ in units of this country's intermediate good is:

$$p^i(C^i_t) = \frac{1}{1 - \epsilon(C^i_t)} \tag{17}$$

Notice that the home firm j sells its products at a different price at home and abroad outside the steady state (and except for the case of CES preferences), despite facing identical marginal costs for domestic and foreign sales. The reason why firms do not fully pass-through changes in marginal costs into their prices is because the markup depends on the demand elasticity they face in each market. In our setup with non-homothetic preferences, the elasticity depends on the level of consumption that prevails in a given period in each country.[27] Firms therefore price-to-market in response to country-specific ag-

[27] This resonates well with the empirical findings by Hummels and Lee (2018), which emphasize income elasticities of demand that differ from unity and change with consumption and across countries.

gregate shocks. Consider for instance a rise in home productivity that leads home consumption above foreign consumption for a while. With IES preferences the elasticity of intratemporal substitution is temporarily higher at home, so that prices are temporarily reduced in the Home country compared to the Foreign country.[28]

Following the same steps as in the one country model, we can recover expressions for the Lagrange multipliers and derive the labor supply and Euler equations for each country:

$$L_t^i = \left[\frac{w_t^i \psi(C_t^i)}{\upsilon C_t^i p^i(C_t^i)}\right]^{\varphi} \quad \text{and} \quad \frac{\psi(C_t^i)}{C_t^i p(C_t^i)} = \beta \mathbb{E}\left\{\frac{R_{t+1}^i \psi(C_{t+1}^i)}{C_{t+1}^i p^i(C_{t+1}^i)}\right\}$$

with $R_{t+1}^i = 1 + r_{t+1}^i - \delta$. The model is closed with the resource constraints in the home and foreign country. Aggregate profits at home are:

$$\Pi_t^h = \frac{\left(p_t^h - 1\right) C_t^h + (\varepsilon_t p_t^f - 1) C_t^f}{2}$$

Using this and the market clearing condition in the financial market, $B_t^h = 0$ for any t, and recognizing that trade is balanced under financial autarky, $\varepsilon_t p_t^f C_t^f = p_t^h C_t^h$, the resource constraint in the home country reads as:

$$K_{t+1}^h = K_t^h(1-\delta) + Y_t^h - \frac{C_t^h + C_t^f}{2} \tag{18}$$

where the last term represents the amount of profits net of expenditure available in the country. A similar procedure yields the resource constraint in the foreign country $K_{t+1}^f = K_t^f(1-\delta) + Y_t^f - (C_t^h + C_t^f)/2$. Notice that international profit flows under monopolistic competition generate an interdependence between economies that is absent under perfect competition. In the latter case, profits are zero and the resource constraint reduces to the accounting identity for closed economies $K_{t+1}^i = K_t^i(1-\delta) + Y_t^i - C_t^i$.

Two mechanisms of international interdependence characterize the system. The first is the technology spillover stressed by BKK. Under their specification, shocks to productivity decay slowly while a shock originating in one country transmits rapidly enough to the trading partner so that virtually all shocks are almost common in practice. With this productivity process, wealth effects are small: all is needed for foreign individuals to follow a consumption path almost as high as in the economy experiencing a positive shock is to wait for the shock to spillover on their country's productivity.

[28] We should remark that in steady state consumers have the same preferences and income, therefore this model is not useful to examine why prices are systematically different between countries with different income levels. Instead, the model can explain temporary deviations from relative purchasing power parity observed in the data. Notice that earlier flexible price models have mainly focused on the role of trade costs and price rigidities to explain these deviations (since with CES preferences, frictions are necessary for pricing to market). See Betts and Devereux (2000) and Ghironi and Melitz (2005) *inter alia*.

The second mechanism - specific to our setting - emphasizes profit spillovers. A boom in one country spreads its effects abroad by generating an increase in the profits of its trading partners. When a country experiences a boom, in fact, profitability increases for both the local firms and the foreign firms that export to this country. In addition, variable markups generate fluctuations in international prices that affect the extent to which world expenditure and profits switch across borders. Consider the home terms of trade, defined as the price of home exports relative to the price of home imports:

$$TOT_t = \frac{\varepsilon_t p_t^f}{p_t^h} = \frac{1-\epsilon(C_t^h)}{1-\epsilon(C_t^f)} \tag{19}$$

A boom in the home country increases the substitutability between goods consumed in the home market and reduces their prices compared to the price of goods sold in the foreign market, whereby appreciating the home terms of trade. The appreciation in turn produces a wealth effect that increases the impact response of home consumption. As will be apparent soon, this helps reduce the correlation with foreign consumption relative to the standard IRBC model. Clearly, the terms of trade would be constant with CES preferences or under perfect competition.

Finally, consider the consumption-based real exchange rate RER_t, defined as the ratio of home to foreign consumer prices. In the model the real exchange rate is linked to a country's terms of trade by the following expression $RER_t = p_t^h/\varepsilon_t p_t^f = 1/TOT_t$. With countercyclical markups, the RER depreciates in response to a rise in home productivity, implying the home consumption basket becomes cheaper. A real depreciation is consistent with evidence documenting a low and even negative correlation between relative consumption and the RER for most OECD countries (e.g., Backus and Smith,1993).

4.2 Macro dynamics under financial autarky

The simulations are based on the same functional form used in the one country model (12), which yields analogous Euler and labor supply equations for each country. The calibrated parameters are as before, with the exception of the parameters of the productivity process. For comparison with the standard international RBC model, we follow BKK and set the following coefficients for the matrix $\mathbf{\Lambda}$:

$$\mathbf{\Lambda} = \begin{bmatrix} 0.906 & 0.088 \\ 0.088 & 0.906 \end{bmatrix}$$

The variance and covariance matrix is symmetric across countries, with the standard deviation of the innovations equal to 0.00852, and the correlation between innovations equal to 0.258 (later on, we will discuss the implications of assuming highly persistent shocks as in Baxter and Crucini, 1995). The preference parameters are re-estimated under prior assumptions analogous to those in Table 2, and set at the value of the corresponding posterior means, which are

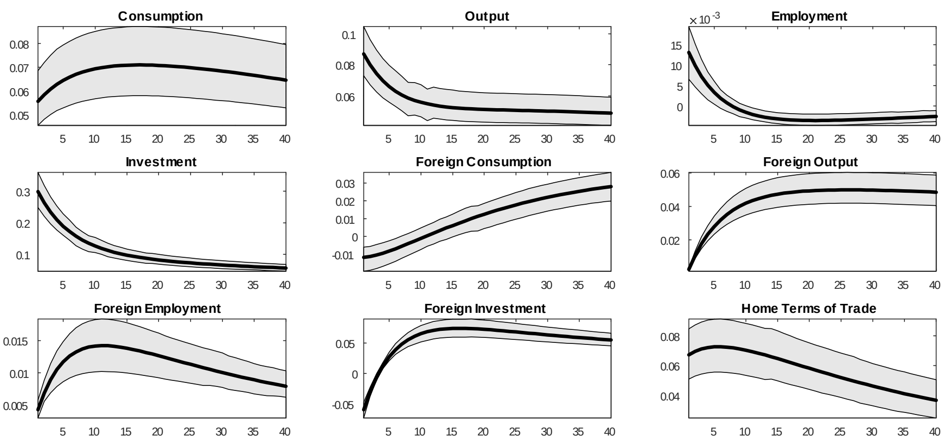

Figure 3: Posterior impulse responses to a positive shock to Home productivity. Shaded areas are 95% confidence intervals. IES model under monopolistic competition.

now $\gamma = 1.91$, $\theta = 1.54$ for the baseline model, and $\gamma = 1.96$, $\theta = 1.52$ under perfect competition.[29]

The impulse responses in Figure 3 illustrate the international transmission of a positive shock to home productivity in the baseline model with IES preferences and monopolistic competition. The productivity rise leads to an increase in domestic output and its components. Labor supply also increases. The shock spreads its effects abroad through the technology spillover and the increased profitability of foreign firms exporting their products to the home market. The latter is a new effect compared to perfectly competitive IRBC models *à la* BKK, and is associated with a decline of markups in the home country (recall that markups are countercyclical and profits are procyclical in our setup). Positive profit spillovers help increase the correlation of output across countries.

The productivity rise in the Home country generates an appreciation of the home terms of trade, reflecting the decline of markups in the Home country. Notice that this is the opposite of what happens in traditional models where the relative abundance of home goods tends to depreciate the home terms of trade. The behavior of the terms of trade is important for understanding the way shocks propagate in the world economy. An appreciation of the home terms of trade, in fact, boosts relative Home consumption and helps reduce the correlation of consumption across countries compared to perfectly competitive RBC models *à la* BKK.

We now turn to the ability of the model to replicate stylized facts of the inter-

[29] The values of γ and θ together with steady state consumption yield a steady state markup of around 18%.

national business cycle, focusing as before on preferences and market structure. Table 6 reports theoretical moments in models with IES and CES preferences under both monopolistic and perfect competition. Notice that (contrary to the case of a closed economy) the market structure is now important also under CES preferences because monopolistic competition generates cross-border profit flows that are absent under perfect competition (the behavior of the CES model, however, remains independent of parameter θ as in closed economy). For ease of comparison, the table also reports theoretical moments in the model with perfect competition of BKK,[30] and EU-US data over the period 1973-2001 from Ambler *et al.* (2004), and data for the period 1954-1989 from BKK (in parenthesis). The top panel reports the correlations between home and foreign variables while the bottom panel refers to home variables.

In the data output, consumption, investment and employment are positively correlated across countries and the comovements of output are by far the largest.[31] The workhorse international business cycle model fails to reproduce these facts, showing very small or even negative comovements for output, investments and labor, and excessive correlation for consumption (the so-called *comovement puzzle*). In addition, consumption is more correlated than investments and labor, and all these variables are more correlated than output (the *quantity anomaly*). The reasons of these failures are well known: negative or small comovements reflect a strong incentive to move resources in the country where they are more productive (in the BKK model), while consumption smoothing in front of technology spillovers induces consumption to move similarly in the two countries. Many candidates have been proposed to alleviate these puzzles, yet they have been mostly unsuccessful in finding a solution to all the anomalies simultaneously.[32]

With IES preferences and monopolistic competition, all cross-correlations are positive, and output displays the largest comovements. Similar results hold for the normalized model with unitary intertemporal elasticity (not shown in Table 6).[33] Positive spillovers emerge because a productivity rise in one country increases the profitability of sales toward that country, boosting output also in the less productive trading partner. Indeed, a similar (weaker) effect emerges also in the specification with monopolistic competition and CES preferences, though the cross-correlation is low for output and remains negative for investments. Under perfect competition, instead, profit spillovers are absent and the

[30] The differences in moments between the original BKK model and the CES model with perfect competition are essentially due to the assumption of financial autarky as opposed to complete financial markets of BKK.

[31] Ambler *et al.* (2004) document a decline in the degree of these comovements in recent times. In addition, they find no significant differences in the cross-correlation of consumption, employment and investments. Only output is significantly more correlated than the other variables.

[32] A non-exhaustive list of candidates includes non-tradable goods, durable goods, consumption habits, distribution services, capital market frictions, cointegrated TFP shocks, and firm entry. See Obstfeld and Rogoff (2000).

[33] Simulations using the baseline calibration and the posterior means for the normalized model, $\gamma = 1.21$ and $\theta = 1.14$, yield cross-correlations equal to 0.10 for consumption, 0.38 for output, 0.03 for investment, and 0.32 for employment.

comovements of output are mainly driven by consumption. In both the IES and CES models with perfect competition, consumption is highly correlated across countries as in the BKK model, and for similar reasons. The model with increasing elasticity performs slightly better compared to constant elasticity, though the effect is small.

Table 6: Moments, open economy under financial autarky

A: Correlations between home and foreign variables

	IES Mon. Comp.	**CES** Mon. Comp.	**IES** Perf. Comp.	**CES** Perf. Comp.	**BKK** IRBC	**US-EU data**
Y	0.40	0.30	0.19	0.14	-0.21	0.28 (0.66)
C	0.07	0.33	0.75	0.85	0.88	0.15 (0.51)
I	0.03	-0.15	-0.12	-0.22	-0.31	0.22 (0.53)
L	0.38	0.01	-0.16	-0.37	-0.31	0.22 (0.33)
p	0.07	0	0	0	0	n.a.

B: Home business cycle

	IES Mon. Comp.		**CES** Mon. Comp.		**IES** Perf. Comp.		**CES** Perf. Comp.	
	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)
Y	1.58	1	1.47	1	1.64	1	1.57	1
C	0.82	0.86	0.73	0.86	0.64	0.86	0.63	0.86
I	5.25	0.98	4.81	0.98	5.29	0.98	5.01	0.98
L	0.73	0.96	0.72	0.95	0.80	0.97	0.72	0.95
p	0.32	-0.86	0	0	0	0	0	0

Notes: Empirical moments are from Ambler *et al.* (2004) and BKK (1992). Standard deviations are reported in percentage points. The theoretical moments of each model are computed as the median based on 1000 simulations of the corresponding model. All specifications consider financial autarky in the baseline calibration.

For a better understanding of the role of market structure and preferences, consider a productivity rise in the Home country. The shock generates a positive wealth effect that pushes for an increase in consumption in both countries. In our baseline model, an additional substitution effect works in the opposite direction: final goods' prices are lower in the country where the shock originates, implying a real exchange rate depreciation and an increase in relative home consumption. The real exchange rate is negatively correlated with consumption (the contemporaneous correlation is -0.75) and fairly volatile (the standard deviation is 1.12 in absolute terms and 0.71 relative to output). This behavior is consistent with the negative relation between the real exchange rate and relative consumption observed in the data (Backus and Smith, 1993), while falling short of the high volatility seen in the great moderation period (Rabanal *et al.*, 2015).[34] The outcome is that the correlation of consumption between countries is still positive, but much lower than in BKK and well below the correlation of output and labor. Monopolistic competition *per se* contributes to reduce the correlation of consumption between countries (this can be verified looking at the model with CES preferences, where the correlation is 0.33 under monopolistic competition against 0.75 with perfect competition), but it is markup variability (with IES preferences) that makes the difference and allows to reach a correlation of 0.07. Notice that the baseline model provides plausible moments also for domestic variables in line with the performance of our single country model.

Table 7: Moments, open economy under financial autarky and persistent shocks

A: Correlations between home and foreign variables

	IES Mon. Comp.	**CES** Mon. Comp.	**IES** Perf. Comp.	**CES** Perf. Comp.
Y	0.96	0.95	0.30	0.31
C	-0.78	-0.66	0.28	0.29
I	0.92	0.89	0.30	0.30
L	-0.18	-0.47	0.30	0.30
p	-0.78	0	0	0

B: Home business cycle

	IES Mon. Comp.		**CES** Mon. Comp.		**IES** Perf. Comp.		**CES** Perf. Comp.	
	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)
Y	1.34	1	1.20	1	1.56	1	1.47	1
C	1.76	0.42	1.39	0.51	0.72	0.96	0.71	0.97
I	3.92	0.99	3.37	0.99	4.47	0.99	4.03	0.99
L	0.96	0.53	0.86	0.38	0.66	0.98	0.53	0.98
p	0.18	-0.42	0	0	0	0	0	0

Notes: Standard deviations are reported in percentage points. The theoretical moments of each model are computed as the median based on 1000 simulations of the corresponding model. All specifications consider financial autarky in the calibration with persistent shocks.

An important insight from international business cycle studies is that highly persistent shocks, by attenuating consumption smoothing, can help generate a lower correlation of consumption compared to output correlation as seen in the data. In models with only one good, persistence increases the impact response of consumption because of a larger wealth effect (see Backus *et al.* 1992, Baxter and Crucini, 1993). A similar mechanism - based on profit spillovers - is at work in our setup. To gauge the role of these two mechanisms we replace the

[34] In our setup, real exchange rate fluctuations are entirely and only driven by markups (the RER is constant under perfect competition or constant elasticity). Previous studies have emphasized the role of a variety of other features and frictions, like home bias, non-durables and nominal rigidity, for explaining international prices.

assumption that the productivity process (14) is trend-stationary and characterized by spillovers with the assumption that it follows a unit root without spillovers, using the parameterization proposed by Baxter and Crucini (1995):

$$\mathbf{\Lambda} = \begin{bmatrix} 0.999 & 0 \\ 0 & 0.999 \end{bmatrix}$$

All other parameters, including the contemporaneous correlations of the shocks and the innovation variances, are the same as in Table 6. The results of simulations with persistent shocks are in Table 7.

Persistent shocks have the effect of generating positive comovements under perfect competition, in line with similar findings in extant studies. In addition, they imply a real exchange rate far more volatile than output as observed in the data. It is by now well understood that relative prices become more volatile when shocks are near unit root (because of a large wealth effect, see Rabanal *et al.*, 2015) and our model makes no exception. The comovements are almost indistinguishable with constant or increasing elasticity, suggesting a minor role of our mechanism based on intertemporal substitution when wealth effects are large. The combination of persistence and monopolistic competition, on the contrary, yields near perfect comovements of output and investments while the correlations of consumption and labor supply turn negative, and particularly so when the elasticity is increasing. These outcomes are consistent with an even larger wealth effect and a very small incentive to smooth consumption in the presence of international profit spillovers. Both persistence and procyclical profits, in fact, increase the impact response of consumption and labor supply.

4.3 Macro dynamics with bond trade

To shed further light on our mechanism of intertemporal substitution, consider an economy where bonds can be traded in international financial markets. Herein we discuss the main alterations this implies relative to the assumption of financial autarky with the understanding that all other relations remain as in the earlier setup.

Consumers in the world economy hold domestic and foreign risk-free bonds, which are denominated in the local numeraire, and provide risk-free, gross real returns in units of the domestic numeraire. The home and foreign consumers face similar constraints, in units of the local numeraire with:

$$K_{t+1}^h - K_t^h(1-\delta) + B_{t+1}^h(1+\frac{\xi}{2}B_{t+1}^h) + \varepsilon_t B_{*t+1}^f(1+\frac{\xi}{2}B_{*t+1}^f) =$$

$$B_t^h(1+i_t^h) + \varepsilon_t B_{*t}^f(1+i_t^f) + w_t^h L_t^h + r_t^h K_t^h + T_t^h + \Pi_t^h - \int_0^1 p_{jt}^h C_{jt}^h dj \qquad (20)$$

for the home consumers, where a star subscript denotes the holdings of foreign bonds, $\xi \in (0,1)$ represents the costs of adjusting the portfolio and T_t^i is a transfer that rebates these costs on households. Without loss of generality and in line with the symmetry of the model, we assume identical adjustment costs for holdings of domestic and foreign bonds. As is well known, these costs allow to pin down a unique steady state where bond holdings are zero for any initial condition. This ensures that the steady state coincides with the one under financial autarky.

Four FOCs govern the optimal choice of domestic and foreign bond holdings in each country. With $\xi = 0$, Euler equations for bond holdings at home and abroad would imply the familiar *uncovered interest rate parity* condition $(1 + i^h_{t+1})/(1 + i^f_{t+1}) = \mathbb{E}[\varepsilon_{t+1}/\varepsilon_t]$: the interest rate differential must be equal to the expected exchange rate depreciation for agents to be indifferent between home and foreign bonds. With $\xi > 0$, the no-arbitrage condition reads as:

$$\frac{(1 + i^h_{t+1})}{(1 + i^f_{t+1})} = \mathbb{E}\left[\frac{\varepsilon_{t+1}}{\varepsilon_t}\right] \frac{(1 + \xi B^h_{t+1})}{(1 + \xi B^f_{*t+1})} = \mathbb{E}\left[\frac{\varepsilon_{t+1}}{\varepsilon_t}\right] \frac{(1 + \xi B^f_{t+1})}{(1 + \xi B^h_{*t+1})} \tag{21}$$

Equilibrium in the bond market requires the home and foreign bonds are in zero net supply worldwide, $B^f_{t+1} + B^f_{*t+1} = B^h_{t+1} + B^h_{*t+1} = 0$. The holdings of home and foreign bonds must add up to zero in the world economy because home and foreign agents make identical portfolio choices in equilibrium and the home (foreign) bonds are issued only in the home (foreign) country. Using this in conjunction with the no-arbitrage condition, it is easy to show that agents spread the adjustment costs equally among home and foreign bonds and $B^i_{*t} = B^i_t$ for $i = h, f$. The aggregate resource constraint in the home country is given by:

$$B^h_{t+1} + \varepsilon_t B^f_{*t+1} + K^h_{t+1} - K^h_t(1 - \delta) =$$

$$B^h_t(1 + R^h_t) + \varepsilon_t B^f_{*t}(1 + R^f_t) + Y^h_t - \frac{(\varepsilon_t p^f_t C^f_t - p^h_t C^h_t)}{2} - \frac{(C^h_t + C^f_t)}{2}$$

where the last two terms are profits net of expenditure. An analogous constraint holds abroad. Compared to the resource constraint under financial autarky (18), international borrowing and lending allow to finance a country's absorption in excess of domestic output. As it will be apparent soon, the country hit by a positive shock will borrow resources from abroad to finance an increase in the volume of imports well above the increase in the volume of exports. Finally, the current accounts of the two countries are by definition equal to the change in their net foreign assets position between any two periods. The home current account is:[35]

$$CA^h_t \equiv B^h_{t+1} - B^h_t + \varepsilon_t \left(B^f_{*t+1} - B^f_{*t}\right)$$

The simulations are based on the same parameterization of the model with financial autarky. The additional parameter representing the portfolio adjustment costs is set at $\xi = 0.0025$ as in Ghironi and Mélitz (2005). This value is sufficient to ensure stationarity, yet small enough to have a negligible impact on the dynamics. Table 8 reports the comovements for the bond economy.

[35] The bond market-clearing conditions imply that borrowing must equal lending in the world economy, namely $CA^h_t + \varepsilon_t CA^f_t = 0$, and world output equals world spending, $\sum_{i=h,f} Y^i_t = \sum_{i=h,f} \left[C^i_t + K^i_{t+1} - K^i_t(1 - \delta)\right]$.

Table 8: Moments, open economy under bond trade
Correlations between home and foreign variables

	IES Mon. Comp.	**CES** Mon. Comp.	**IES** Perf. Comp.
Y	0.39	0.30	0.36
C	0.12	0.37	0.21
I	0.03	-0.14	-0.03
L	0.36	0.02	0.26
p	-0.18	0	0

Notes: The theoretical moments of each model are computed as the median based on 1000 simulations of the corresponding model. All specifications consider bond trade in the baseline calibration.

Trade in bonds is largely inconsequential for the performance of the baseline model: cross-correlations and domestic moments (not reported in Table 8) are similar to those emerging under financial autarky. The only remarkable difference is a higher correlation of consumption, which reflects enhanced capacity to smooth consumption compared to autarky.

This constitutes a substantial departure from the familiar finding that the behavior of traditional IRBC models under financial autarky is close to the data while the complete markets and the bond economies have a similar (poorer) performance (Heathcote and Perri, 2002). In standard models, international trade of financial activities provides a powerful tool for pooling idiosyncratic risk, and typically implies an almost perfect correlation of consumption across countries. In our setup, consumption smoothing is attenuated by intertemporal substitution and wealth effects that increase the impact response of consumption.

In order to see why, consider a positive shock to Home productivity. The Home terms of trade appreciate because of the decline in home markups, increasing relative consumption at home (positive wealth effect). In addition, temporarily low (high) prices induce home (foreign) households to anticipate (postpone) consumption in current (future) periods (intertemporal substitution). These effects work in the direction of increasing the impact response of consumption, attenuating consumption smoothing. Bond trade is exploited to increase current consumption in the Home economy, and the home country runs a current account deficit. Remarkably, the model can replicate countercyclical net exports as found in the data (the correlation of net exports with output is -0.25).

In traditional models, on the contrary, the terms of trade of the country hit by the shock deteriorate, reflecting the relative abundance of the good exported by this country in the world economy. The deterioration is particularly large under financial autarky, because countries cannot run current account deficits and households must export more and import less compared to the model with asset trade. This in turn has the effect of increasing the cross-correlation of output and its components, and explains the better performance under financial autarky stressed by Heathcote and Perri (2002).

Shutting off the appreciation of the terms of trade, by considering constant elasticity or perfect competition, results in a deterioration of performance compared to the baseline model: investments are negatively correlated, while the correlation of consumption is higher than output correlation with CES preferences. The bond economy behaves similarly to autarky also in these cases, albeit with two important caveats. First, the CES model becomes invariant to market structure as in closed economy. Second, the IES model under perfect competition displays far less correlation of consumption and positive comovements of labor supply (like in the baseline model). These outcomes reflect the ability of bond trade to pool idiosyncratic risks, which implies offsetting cross-country profit spillovers in the CES model while hedging households against income fluctuations in the IES model under perfect competition.

5 Conclusion

We have developed a DSGE model with endogenous markups due to preferences with a variable elasticity of substitution between differentiated goods. The main lesson is that demand matters for the business cycle because it affects pricing: the impact of supply shocks on consumption and labor supply is magnified through new intertemporal substitution mechanisms due to markup fluctuations, and the second moments show that the estimated model outperforms the standard RBC model (based on CES preferences and either perfect or monopolistic competition). The impact is even more radical in an open economy framework, where monopolistic competition and pricing to market contribute to amplify the propagation of shocks abroad while reducing the correlation of consumption across countries.

While our quantitative analysis is based on a specification of preferences that nests and generalizes the CES, our theoretical results are general, therefore further investigations based on other specifications for the demand structure would be fruitful. Future research should also try to discriminate empirically between the sources of markup variability emphasized in different theoretical models, such as sticky price models, endogenous entry models and models with a general microfoundation of the demand side. Our framework could be used to measure the social costs of business cycle fluctuations, which in the closed economy is entirely due to the fluctuations associated with markup variability. A natural extension of such a model concerns entry of firms in the spirit of Bilbiie *et al.* (2012) in closed economy and Ghironi and Melitz (2005) in an open economy with price frictions. Finally, the open economy model could be extended to allow for different substitutability between goods from the same country and goods from different countries, which has been shown to be important for the international propagation of shocks.

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Appendix

The data set comprises the following series: real gross domestic product per capita (A939RX0Q048SBEA), real personal consumption expenditure per capita (A794RX0Q048SBEA), real gross private investment (GDPIC96), weekly hours worked, manufacturing sector (HOHWMN02USQ065S), civilian employment, all persons (USAEMPTOTQPSMEI), population (B230RCOQ17). All series are seasonally adjusted. Raw data are logged and filtered with a band pass filter *à la* Christiano and Fitzgerald (2003).