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**Demand, Markups and the
Business Cycle.
Bayesian Estimation and
Quantitative Analysis in Closed
and Open Economies**

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Keywords

RBC, variable markups, non-homothetic preferences, international macroeconomics

JEL Codes

E1, E2, E3

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Demand, Markups and the Business Cycle

Bayesian Estimation and Quantitative Analysis in Closed and Open Economies

Lilia Cavallari and Federico Etro¹

University of Rome III and University of Venice

June 2017

Abstract

We generalize the demand side of a Real Business Cycle model introducing non-homothetic preferences over differentiated final goods. Under monopolistic competition this generates variable markups that depend on the level of consumption. We estimate a flexible preference specification through Bayesian methods and obtain countercyclical markups. The associated closed-economy model magnifies the propagation of shocks (compared to perfect competition or fixed markups) 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 reduces its markups and improves its terms of trade, which promotes consumption in the Home country but also production in the Foreign country to exploit the increased profitability of exports.

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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 labor supply to technology shocks (while the evolution of capital generates a volatility of investment comparable with the data), and they generate too much consumption smoothing. Open economy models (Backus *et al.*, 1992, BKK) 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 naturally solve the above inconsistencies if we adopt a more general microfoundation of the demand side that delivers variable markups and additional intertemporal substitution mechanisms. 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 (a result already noticed in 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. In particular, when substitutability increases in consumption, an expansionary technology shock reduces the markups and increases even more the real wages, thereby promoting both consumption and labor supply. 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.² Of course, 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, but important studies, such as Bils (1987, 2016),

²Non-homothetic preferences are typically used in models of structural change (e.g. Herrendorf, Rogerson and Valentinyi, 2014; Matsuyama, 2017) and are gaining rapid adoption in general equilibrium trade theory with monopolistic competition (see for instance Arkolakis *et al.*, 2015, Etro, 2017, Bertolotti *et al.*, 2017) for their ability to generate incomplete pass-through and pricing to market. Non-homothetic preferences have been introduced also in standard macroeconomic models: see, for instance, Etro (2016) on dynamic entry and Boucekine, Latzer and Parenti (2017) on growth. As well known this precludes studying heterogeneous agents in a simple way. The analysis of the role of heterogeneous agents for the business cycle falls beyond the scope of our work.

Murphy *et al.* (1989), Rotemberg and Woodford (1999) and Chevalier *et al.* (2003) support the view that markups are broadly countercyclical.

We start our theoretical analysis by studying a closed economy model which departs from a standard RBC framework by replacing CES preferences over the final goods with symmetric and directly additive preferences, already used in the original work of Dixit and Stiglitz (1977), and in trade theory (Krugman, 1979; Bertolotti and Epifani, 2014; Simonovska, 2015; Arkolakis *et al.*, 2015), but rarely employed in dynamic models. Their impact on monopolistic pricing delivers 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 specification of preferences that exhibits a variable elasticity of substitution and nests CES preferences as a special case.³ We provide an empirical model validation exercise which uses Bayesian techniques (in the spirit of Schorfheide, 2000, Fernandez-Villaverde and Rubio-Ramirez, 2004, and Smets and Wouters, 2007) to estimate the role of non-homothetic preferences in an otherwise standard RBC model. The estimation is based on U.S. data and its aim is to verify if these data support non-homothetic preferences and, if so, what are their implications for markups. 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. Our estimation results strongly support an elasticity of substitution among varieties that is increasing in consumption, which leads to countercyclical markups.

Adopting the estimated preference parameters and other standard calibrated parameters, our next aim is to gauge the role of markup variation for the transmission of technology shocks in a closed economy. To this end, 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 a radical increase in the reactivity of labor supply, and also consumption becomes 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 move to an international RBC framework with two identical countries and directly additive preferences over the differentiated goods (as in the static model of Krugman, 1979). Countries can trade goods but not inputs and are subject to correlated shocks as in BKK. 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) maintaining our baseline calibration for each country. The model generates positive comovements of output, labor and investment and reduces drastically the correlation of consumption between countries. These outcomes are due to endogenous pricing to market under monopolistic competition. A positive tem-

³The specification is borrowed from Bertolotti *et al.* (2008)

porary technology shock in the Home country reduces markups in this country below those in the Foreign country, thereby improving the Home terms of trade and depreciating 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 the consumption of cheaper imports more than expensive exports.

Endogenous markup variation has been extensively studied in macroeconomic theory. As well known, the New-Keynesian literature generates variable markups on average, but this is only due to price stickiness, because expansionary shocks tend to increase nominal costs while some prices remain unchanged.⁴ Rotemberg and Woodford (1992, 1999) have emphasized countercyclical markups in flexible price models with imperfect collusion among firms, yet collusion can hardly apply to the average markets in the economy. Ravn *et al.* (2006, 2008) have considered monopolistic competition with deep habits or subsistence consumption at the good level, where intertemporal links in consumption imply countercyclical markups; in particular, the work of Ravn *et al.* (2008) is closely related to ours, though their preference specification is unable to generate a strong amplification of the business cycle. Etro and Colciago (2010) have studied Cournot and Bertrand competition with CES preferences and Bilbiie *et al.* (2012) have used monopolistic competition with translog preferences, and both models generate countercyclical markups due to procyclical entry (studies on the aggregate consequences of endogenous entry and markups include, among others, Campbell 1998, Cavallari 2013a, and Jaimovich and Floetotto 2008). On the open economy front, Ghironi and Melitz (2005) is among the first studies emphasizing the role of heterogeneous firms for the international business cycle. Their model assumes CES preferences, neglects capital accumulation and generates variable average prices through endogenous entry. Following this direction and retaining the CES assumption, 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. As we will show, price rigidities, strategic interactions, habits, entry and trade costs are not necessary to generate variable markups with aggregate consequences.

The work is organized as follows. Section 1 presents the baseline model for a closed economy. Section 2 discusses the calibration and estimates the preference parameters. Section 3 evaluates the propagation of technology shocks and the second moments. Section 4 extends the model to two countries to analyze international business cycles. Section 5 is the conclusion.

⁴This applies not only in the canonical model based on CES preferences, but also in models *à la* Kimball (1995) which are based on a symmetric and homothetic aggregator. Notice that such an aggregator is unable to generate variable markups when prices are flexible and the number of firms is exogenous because non-homotheticity is key to markup variability in this case.

1 RBC with monopolistic competition

In this section we analyze the flexible price DSGE model in a closed economy. 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:

$$Y_t = A_t K_t^\alpha L_t^{1-\alpha} \quad (1)$$

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 a standard process of capital accumulation with depreciation rate $\delta \in [0, 1]$, or to produce a variety of downstream final goods with a linear technology.⁵

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

$$U = \mathbb{E} \sum_{t=1}^{\infty} \beta^{t-1} \left[\log \left[\int_0^1 u(C_{jt}) dj \right] - \frac{v l_t^{1+\frac{1}{\varphi}}}{1 + \frac{1}{\varphi}} \right] \quad (2)$$

where $\mathbb{E}[\cdot]$ is the expectations operator, $\beta \in (0, 1)$ is the discount factor, the mass of final goods is fixed and assumed unitary and C_{jt} is private consumption of good j with subutility $u(C)$, l_t is labor supply, $\varphi \geq 0$ is the Frisch elasticity and $v \geq 0$ is a scale parameter for the disutility of labor.

The preference aggregator is directly additive and symmetric across varieties as in the general static model of Dixit and Stiglitz (1977) and we assume $u(0) = 0$, $u'(C) > 0$ and $u''(C) < 0$.⁶ The case of a power subutility as $u(C) = \frac{\theta}{\theta-1} C^{\frac{\theta-1}{\theta}}$ with $\theta > 1$ is commonly adopted in the macroeconomic literature based on “log-CES” 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). Departing from this ubiquitous assumption, we will consider the entire class of directly additive preference aggregators.⁷

Under monopolistic competition in the market for final goods each variety i is sold at price p_{it} chosen in each period by firm i to maximize profits $\pi_{it} = (p_{it} - 1) C_{it}$, since 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.

⁵A two-sector structure is essential to distinguish the price of capital and consumption. See Boldrin, Christiano and Fisher (2001).

⁶Symmetry of preferences simplifies the analysis by identifying individual and aggregate consumption in equilibrium, but is not essential. Adopting asymmetric preferences over the differentiated goods (see Bertolotti and Etro, 2017 for a static analysis) would require a dynamic analysis in terms of the marginal utility of income instead of aggregate consumption.

⁷It is worth reminding the reader that CES preferences are the only homothetic specification within the class of directly additive preferences.

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:

$$K_{t+1} = K_t(1 - \delta) + w_t l_t + r_t K_t + \Pi_t - \int_0^1 p_{jt} C_{jt} dj \quad (3)$$

where total profits and all the prices are taken as given. The FOCs for each C_{it} is:

$$\frac{u'(C_{it})}{\int_0^1 u(C_{jt}) dj} = \lambda_t p_{it} \quad (4)$$

the FOC for l_t is:

$$v l_t^{\frac{1}{\varphi}} = \lambda_t w_t \quad (5)$$

and the FOC for K_{t+1} is:

$$\lambda_t = \beta \mathbb{E}[R_{t+1} \lambda_{t+1}] \quad (6)$$

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

1.1 Pricing

Under monopolistic competition, each firm producing a variety i maximizes profits:

$$\pi_{it} = (p_{it} - 1) C_{it} = \frac{u'(C_{it}) C_{it}}{\lambda_t \int_0^1 u(C_{jt}) dj} - C_{it}$$

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 are taken as given. The FOCs for each firm i are:

$$\frac{u'(C_{it})}{\lambda_t \int_0^1 u(C_{jt}) dj} + \frac{u''(C_{it}) C_{it}}{\lambda_t \int_0^1 u(C_{jt}) dj} = 1$$

and provide the symmetric equilibrium monopolistic price or (equivalently) markup as:

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

where we defined the elasticity of the marginal subutility $\epsilon(C) \equiv \frac{-u''(C)C}{u'(C)}$ and assumed that it is smaller than unity. As shown in Bertolotti and Etro (2016), this elasticity is also 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 Notice that we need $\epsilon(C) < 1$ to insure a positive markup, which requires a positive marginal revenue. Moreover, the SOC's 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:

$$p'(C) \geq 0 \quad \text{iff} \quad \epsilon'(C) \geq 0$$

In the mentioned case of CES preferences, the elasticity is constant, namely $\epsilon(C) = 1/\theta$, and the markups are constant as well. Instead, when the subutility $u(C)$ is characterized by a decreasing index of relative risk aversion, markups are decreasing in consumption. 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.⁹

The symmetric equilibrium allows us to solve for the Lagrange multiplier $\lambda_t = u'(C_t)/u(C_t)p_t$ and to rewrite the FOCs as follows:

$$l_t = \left[\frac{w_t u'(C_t)}{v u(C_t) p_t} \right]^\varphi$$

$$\frac{u'(C_t)}{u(C_t) p_t} = \beta \mathbb{E} \left\{ R_{t+1} \frac{u'(C_{t+1})}{u(C_{t+1}) p_{t+1}} \right\}$$

Taking the logs of the Euler equation and differentiating provides an expression for the *intertemporal elasticity of substitution*:¹⁰

$$\chi(C_t) \equiv - \frac{\partial \ln C_t}{\partial \ln p_t} = \frac{1}{\psi(C_t) + \epsilon(C_t)} \quad (8)$$

where we defined the elasticity of the subutility as $\psi(C) \equiv u'(C)C/u(C)$. In case of CES preferences we have $\psi(C) = 1 - 1/\theta$, and the intertemporal elasticity is unitary. In general, however, $\psi'(C) \propto 1 - \psi(C) - \epsilon(C)$ implies:

$$\chi(C) \geq 1 \quad \text{if} \quad \psi'(C) \geq 0$$

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. Notice that, since there is no direct relation between the signs of the derivatives of $\psi(C)$ and $\epsilon(C)$, there is

⁸These are indeed the Morishima elasticities, that are the relevant elasticities of perceived demand under monopolistic competition for any symmetric preferences (Bertoletti and Etro, 2016). In principle we could generalize the analysis beyond the assumption of additive intratemporal preferences, retaining all our qualitative results.

⁹Bilbiie *et al.* (2012) argue that an increase in the number of varieties makes them more substitutable, which is what happens with their homothetic translog preferences. This effect is absent under directly additive preferences.

¹⁰We are grateful to Paolo Bertoletti for suggesting this definition.

no direct relation between the markup cyclicality and the extent of intertemporal substitutability (neither we can say whether $\chi(C)$ increases or decreases in consumption). However, the intertemporal elasticity is always lower than the intratemporal elasticity since $\chi(C) < 1/\epsilon(C)$.

1.2 Equilibrium

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 with price $p_t = p(C_t)$ and total profits $\Pi_t = [p(C_t) - 1]C_t$ allows us to solve for the resource constraint as:

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

which is the same as with perfect competition because all profits are rebated to the consumer. Using these conditions we can rewrite the modified labor supply and Euler conditions as follows:

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

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

which emphasizes the role of variable markups in affecting the business cycle. 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 in our model.

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 should be 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 would simply replace $p(C) = 1$ in the labor supply equation (10) and in the Euler equation (11).

It is standard to verify that the perfectly competitive equilibrium corresponds to the efficient allocation that would be chosen by a social planner maximizing utility (2) under the resource constraint (9) with $C_t = \int_j C_{jt} dj$. 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). The

additional business cycle propagation due to markup fluctuations is therefore costly to consumers. In principle, one can avoid this cost of the business cycle by introducing a labor income subsidy and a capital income tax that neutralize all the differences in relative prices between goods and leisure and between goods in different periods. Notice that variable markups require time-varying optimal taxes: in particular countercyclical markups require a labor income subsidy which decreases with consumption and a positive capital income tax which reaches zero only in steady state.¹¹

1.3 IES preferences

To perform the 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, we select the simplest subutility $u(C)$ that nests the power subutility and satisfies the properties $u(0) = 0$, $u'(C) > 0$, $u''(C) < 0$ and $u'(C)C$ increasing and concave. We adopt the a polynomial specification which combines a linear and a power function:

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

Of course this “bi-power” subutility reduces to the CES case for $\gamma = 0$. The elasticity of the marginal disutility is $\epsilon(C) = 1/\theta(1 + \gamma C^{\frac{1}{\theta}})$ and is decreasing (increasing) in consumption if $\gamma > (<) 0$. 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 with $\gamma > 0$. This was originally introduced by Bertolotti *et al.* (2008) in the static analysis of monopolistic competition under the label of *IES preferences* due to the increasing elasticity of substitution ($\epsilon'(C) < 0$ and $\vartheta'(C) > 0$).¹²

The specification (12) generates the following pricing rule:

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

¹¹In the traditional case of CES preferences markups are constant and the familiar Euler equation with perfect competition holds also under monopolistic competition, with $C_t^{-1} = \beta \mathbb{E} [R_{t+1} C_{t+1}^{-1}]$, while labor supply under monopolistic competition is a constant fraction of labor supply under perfect competition: that is why a constant labor income subsidy is sufficient to restore efficiency in standard models based on CES preferences. See Etro (2016) for further details on optimal taxation in a model with non-additive preferences.

¹²Of course, this is only one possible specification featuring increasing elasticity of substitution. We have experimented others, as the Stone-Geary preferences, but the quantitative results are modest (see also Ravn *et al.*, 2008). A more general functional form nesting a power function with another concave function of consumption would allow a more flexible calibration of parameters, but our parsimonious specification is sufficient for our purposes.

and the assumption $\theta > 1$ is enough to satisfy the SOC's for profit maximization. The markups are indeed countercyclical (procyclical) if $\gamma > (<) 0$. Moreover, 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 intertemporal elasticity of substitution $\chi(C)$ is greater (smaller) than one if $\gamma > (<) 0$.

The equilibrium conditions under monopolistic competition read as follows:

$$\begin{aligned} L_t &= \left[\frac{(1-\alpha) A_t K_t^\alpha [\theta(\gamma C_t^{\frac{1}{\theta}} + 1) - 1]}{v\theta(\gamma C_t^{\frac{1}{\theta}} + \frac{\theta}{\theta-1})C_t} \right]^{\frac{\varphi}{1+\alpha\varphi}} \\ \frac{\theta(\gamma C_t^{\frac{1}{\theta}} + 1) - 1}{(\gamma C_t^{\frac{1}{\theta}} + \frac{\theta}{\theta-1})C_t} &= \beta \mathbb{E} \left\{ \frac{[1 - \delta + \alpha A_{t+1} K_{t+1}^{\alpha-1} L_{t+1}^{1-\alpha}] [\theta(\gamma C_{t+1}^{\frac{1}{\theta}} + 1) - 1]}{(\gamma C_{t+1}^{\frac{1}{\theta}} + \frac{\theta}{\theta-1})C_{t+1}} \right\} \end{aligned}$$

together with the resource constraint (9). Given the initial capital stock K_1 , this equilibrium system for $\{K_t, L_t, C_t\}$ will be at the basis of our quantitative assessment. One can easily verify that $\gamma = 0$ leads back to the traditional CES case. Instead, as long as $\gamma > 0$, the model will amplify the propagation mechanism through changes in labor supply and savings compared to the perfectly competitive equilibrium. The magnitude of this effect is the focus of the rest of the work.¹³

2 Calibration and Bayesian estimation

In this section we calibrate the model and estimate the new preference parameters which provide the key differentiation from the traditional RBC framework.

The main structural parameters and those governing the stochastic process for technology are calibrated in a standard fashion. Periods are interpreted as quarters to match the frequency of business cycle data. The capital share is $\alpha = 0.33$. The discount factor is set at $\beta = 0.99$, and corresponds to a real interest rate of 4% per annum. We normalize the steady state value of total factor productivity to $A = 1$. The scale parameter for the disutility of labor v is set to normalize the steady-state value of employment to $L = 1$ under any experiment: this insures that the steady state is identical for all specifications with either perfect or monopolistic competition. The capital depreciation rate

¹³It would be interesting to investigate also the role of public spending and aggregate demand shocks in our model. For instance, as long as public spending does not affect the marginal utility of consumption, but is spent in the final goods, its temporary increase would tend to make demand more rigid and increase markups: this would temporarily depress consumption and labor supply.

is $\delta = 0.025$, matching the 10% rate of capital depletion per year commonly found in US data.¹⁴ The productivity shock 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 . For comparison with the basic RBC model of King and Rebelo (1999), the persistence parameter is set at $\rho = 0.979$ and the magnitude of innovations is $\sigma = 0.0072$.

To obtain the parameters of the intratemporal preferences γ , θ and φ , we apply Bayesian estimation methods as in Schorfheide (2000) and Fernandez-Villaverde and Rubio-Ramirez (2004). As is well known, this approach combines the Bayesian prior information with the data to obtain posterior distributions of the parameters. The model is estimated with quarterly US data over the period 1980q1-2008q2.¹⁵ In the baseline specification, the observable variable is real personal consumption expenditure. We then consider output, investments and hours for robustness purposes. The data source is the FRED database of the Federal Reserve Bank of St. Louis. All variables are expressed in per capita terms, except hours worked which are expressed per person employed, and all of them are measured as percentage changes from the preceding period, are seasonally adjusted and demeaned by subtracting the respective sample average.

We impose dogmatic priors on the structural parameters α , β , δ and v as well as on the parameters of the stochastic process according to the calibration mentioned above. This restriction plays two roles. First, it reduces the dimensionality of the estimation problem and alleviates the computational burden. Second, it favors the comparability with previous studies, which impose analogous restrictions on parameters set at commonly used values, for instance in Smets and Wouters (2007).

The estimated parameters have quite diffuse priors. Specifically, we assume that γ follows a normal distribution with mean 1.1 and standard deviation 0.45, while θ and φ have a gamma distribution with mean, respectively, 1.6 and 3, and standard deviation 0.75 and 1. Our choices reflect a desire to elicit priors that are, on one side, easy to understand and, on the other side, are consistent with previous estimation outcomes. In this vein, the gamma distribution is applied to the parameters that require priors that rule out non-negative draws or impose a lower bound. For instance, a prior mean of φ above unity is appropriate in models that do not distinguish between an intensive and an extensive margin of employment. Moreover, the prior mean is three times its standard deviation, which gives a 95 percent probability interval running from 0.82 to 7.05. Hence, the prior reveals the extent of uncertainty that surrounds the Frisch elasticity.¹⁶

¹⁴The steady state capital is $K \approx 13.5$ and the steady state consumption is $C \approx 2.3$ for any preference specification.

¹⁵We overlook the great recession period to avoid excessive volatility.

¹⁶Estimates of the Frisch elasticity obtained from micro data are typically lower than those in macro studies. The wage elasticity exhibits ample variability across workers, and estimates

Table 1: Prior and posterior distribution, baseline model

	Prior distribution			Posterior distribution			
	type	mean	St. Err.	mode	St. Err.	mean	95% int.
θ	Gamma	1.6	0.75	1.67	0.26	1.29	1.04-2.29
γ	Normal	1.1	0.45	1.12	0.45	1.03	0.53-1.76
φ	Gamma	3	1	4.20	1.03	3.51	1.64-5.44
Log marginal density 267.744							

The prior of θ reflects the assumption of a positive lower bound, even if we look for a value above unity for the consistency of the model. The probability interval, which lies between 0.21 and 4.93, includes the lower range of values that are entertained in macro studies. However, it is worth repeating that the elasticity of substitution between goods in our model is $\vartheta(C) = \theta(1 + \gamma C^{\frac{1}{\theta}})$, which depends not only on θ but also on γ as well as on the consumption level. Given the steady-state consumption for our calibration, our priors of θ and γ imply a probability interval of the demand elasticity in the range 0.19 – 4.63. By the same token, the prior means give a steady-state markup of 28%, which lies in the middle of the range 15-45% found for the average price markup in the US.¹⁷

Table 1 reports two sets of results regarding the parameter estimates. The first set contains the estimated posterior mode of the parameters, which is obtained by directly maximizing the log of the posterior distribution, and an approximate standard error based on the corresponding Hessian. The second set reports the mean, and the 5th, and 95th percentile of the posterior distribution of the parameter obtained through the two-block Random Walk Metropolis Hastings algorithm. The latter is based on 10.000 draws and generates a Markov chain of parameter values that passes all the requirements of convergence.¹⁸

Notice that a low variance of the posterior distributions indicates that the data are quite informative. All parameters are estimated with precision. Our main parameter of interest is the coefficient of the linear term in the utility function, which implies non-homothetic preferences for $\gamma \neq 0$ and affects the strength of the amplification effect. The posterior mean $\gamma = 1.03$ is significantly different from zero, and close to the prior mean. A positive γ suggests that the elasticity of substitution is increasing in the level of consumption and markups are countercyclical. This is in line with empirical studies that emphasize countercyclical markups as Bils (1987, 2016), Rotemberg and Woodford (1999) and

range from from zero to more than one (see Keane, 2011). The range in macro studies is between 2 and 8.

¹⁷See, among others, Rotemberg and Woodford (1999) and Basu and Fernald (1997).

¹⁸The 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.

Chevalier *et al.* (2003).

The posterior mean for the other parameter of the subutility function, $\theta = 1.29$, is smaller than the mean assumed in its prior distribution, indicating a lower elasticity of substitution, which in steady state is $\vartheta(2.3) \approx 3.8$, exactly matching the assumption of Bilbiie *et al.* (2012) and similar models.¹⁹ The posterior distributions imply a steady-state markup around 35%, while the 95% confidence interval lies between 14% and 70%. These values are in line with the results reported in many micro and macro studies of markups. Compared to large DSGE models, our estimate of the average markup is lower - for instance, Smets and Wouters (2007) find a markup of 60%. A reason is that we focus on monopoly distortions, and overlook price and wage rigidity, as well as other distortions that may contribute to increase the average markup. We view the ability to reproduce plausible markups as an important advantage of our model. Finally, the posterior mean for the Frisch elasticity $\varphi = 3.51$ lies in the middle of the range considered in macroeconomic studies, which provides an additional confirmation of the ability of this estimate to reproduce results in line with the literature.

To gauge the relevance of non-homotheticity for the model fit, we also estimate a version of the model under CES preferences. Table 2 contains summary statistics on the prior and posterior distribution. Compared to the baseline model, the prior mean of γ is modified to reflect the assumption of CES preferences, while allowing for a similar degree of uncertainty about the initial guess. In an analogous way, we have modified the prior distribution of θ to reflect the range of values commonly considered in macro studies. The prior mean implies a steady-state markup of 40%.

Table 2: Prior and posterior distribution, CES model

	Prior distribution			Posterior distribution			
	type	mean	St. Err.	mode	St. Err.	mean	95% int.
θ	Gamma	3.5	1.6	2.48	1.76	3.60	0.83-6.41
γ	Normal	0	0.2	0.1	0.19	0.1	-0.27-0.40
φ	Gamma	3	1	3.83	1.01	4.21	2.29-6.55
Log marginal density 265.969							

The posterior mean of the Frisch elasticity is close to that in the baseline model, although it is a bit less precisely estimated. The posterior mean of θ is instead higher, in line with the assumption of CES preferences embedded in the priors and the zero mean of γ , whose posterior mean, however, is again positive, though barely so. The marginal likelihood for the baseline model and the CES model gives evidence about which model better matches the data. The Bayes factor is employed to gauge the relative merits of the estimated models. We adopt the Laplace approximation as described in Geweke (1999, 2005) to

¹⁹Notice also that the intertemporal elasticity of substitution in steady state is $\chi(2.3) = 1.3$, therefore marginally different from the usual unitary elasticity associated with log preferences.

marginalize or integrate the estimated data out of the likelihoods. The Bayes factor, measuring the odds the data prefer the baseline model compared to the CES model, is 5.9. According to Jeffreys (1998), a Bayes factor of this size provides “substantial” evidence in favor of the baseline model.²⁰

Next, we investigate the robustness of our outcomes to changing the priors, the market structure and the observable variables. Once again, we are particularly interested in the coefficient of the linear term. Table 3 contains the outcomes of the sensitivity analysis.

In the first exercise, we base the choice of the prior means on trials with very weak priors, the results are displayed in the column entitled *Trial-based priors*. Consider for example the prior of θ : we start with a mean of 3.5 and standard error of 2, obtaining a posterior mean of 2.8. We then revise the initial guess using the posterior mean as a new, more informative prior. We proceed in this way until the domain of the prior covers a reasonable range of values. A similar procedure is applied for selecting the priors of the other parameters. The posterior means of all parameters are close to those under the baseline prior distributions.

Table 3: Sensitivity analysis

	<i>Trial-based priors</i>			<i>Perfect Competition</i>	
	priors	post. mean	95-5 %ile	post. mean	95-5 %ile
θ	G(1.8;0.6)	1.47	1.04-2.43	1.69	0.86-2.91
γ	N(1.4;0.4)	1.36	0.79-2.10	1.05	0.21-1.85
φ	G(4;1.3)	4.46	2.65-7.39	4.23	2.45-6.30
	<i>Output</i>		<i>Hours</i>		
	post. mean	95-5 %ile	post. mean	95-5 %ile	
θ	0.76	0.51-0.86	2.37	1.17-4.41	
γ	1.24	0.59-1.86	1.09	0.04-1.98	
φ	1.55	1.14-1.86	0.60	0.46-0.85	

Second, we estimate a version of the model under perfect competition: see the column entitled *Perfect Competition*. The motivation is to assess the role of the market structure in affecting the estimation outcomes and the model fit. Remarkably, the posterior mean of γ remains significantly positive, and its value is almost identical to the one in the baseline model. This strengthens our confidence that non-homothetic preferences are supported by the data independently of the market structure. Notice that the posterior mean of θ is significantly larger compared to the model under monopolistic competition, suggesting a much higher demand elasticity. More competition turns out to

²⁰To focus on our main parameter of interest, we have estimated the model under the CES prior of γ reported in Table 2, while leaving the priors for the other parameters as in the baseline specification. The odds ratio turns out to be even more favorable to the baseline model.

increase also wage elasticity. The odds ratio of the perfectly competitive model is 0.93. This provides evidence that, although the data support the model under monopolistic competition, the evidence in favor of this specification is not sufficient for an econometrician to ignore the model under perfect competition.

Finally, we consider output or hours as the observable variable. The motivation is that supply-side variables may be more closely linked to the structural innovations in the model. The model is estimated under the baseline priors, after modifying the measurement equations in accord with the new observables. The results are in the columns entitled, respectively, *Output* and *Hours*. Once again, the posterior mean of γ is significantly positive. It is very close to that in the baseline specification when data for hours worked are used, although it is much less precisely estimated. The posterior means of θ and φ show ample variability across the two samples.²¹

Overall, the sensitivity analysis suggests that our specification of preferences, characterized by an increasing elasticity of substitution is well supported by the data. Most important adopting our IES preferences with a positive γ implies that monopolistic markups are countercyclical. The following sections illustrate the role of markups for the business cycle using the calibration $\alpha = 0.33$, $\beta = 0.99$, $\gamma = 1.03$, $\delta = 0.025$, $\theta = 1.29$, $\rho = 0.979$, $\sigma = 0.0072$ and $\varphi = 3.51$.

3 Supply shocks

Turning to the quantitative analysis of the model, we start illustrating the transmission mechanism at work in the model by means of Bayesian impulse responses. To stress the role of market structure, we contrast the dynamics under perfect and monopolistic competition. Then, we evaluate the performance at replicating major business cycle facts with an analysis of the moments.

For ease of comparison with previous studies, we simulate alternative models that feature increasing and constant elasticity of substitution, as well as perfect and monopolistic competition. The stochastic simulations are based on a second-order approximation around the deterministic steady state, as described in Schmitt-Grohe and Uribe (2004).²² Hence, the presence of uncertainty can affect the dynamics through the second-order terms. In all simulations, the theoretical variables are HP filtered with a quarterly smoothing parameter of 1600 for consistence with the data.

3.1 Impulse responses

Figures 1 and 2 display the impulse responses in the wake of a productivity shock in the IES model under, respectively, monopolistic and perfect competition. In

²¹We also tried investment data in the estimation but we obtained extremely imprecise estimates: the scarce precision in the investment sample reflects the high volatility of investment data.

²²Simulations are made with Dynare. The algorithm used to compute a quadratic approximation of the decision rules is described in Collard and Juillard (2001).

Figure 1: Bayesian IRFs and 95% confidence interval. IES model under monopolistic competition

each figure, the y-axis indicates the responses in percent deviation from the posterior mean, together with their 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.

As we have anticipated, our setup with monopolistic competition implies countercyclical markups that amplify the propagation of the productivity shock, and the impulse response functions show that the size of this amplification is substantial. Consumption and labor are significantly higher over the whole transition compared to perfect competition. These responses reflect the incentive for households to anticipate their consumption plans and their labor efforts in periods where 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 additional markup reductions for a long period before prices start reverting toward their initial level. Remarkably, the additional mechanisms of intertemporal substitution due to the markup variability generate an inverse-U shape of the impulse response function for output, which is instead absent in the case of perfect competition.

3.2 Second moments

Table 4 reports selected moments derived from the simulation of alternative models, together with US data from King and Rebelo (1999). The simulations use the calibration discussed above, where the preference parameters are set at the values of the corresponding posterior means, i.e. $\gamma = 1.03$, $\theta = 1.29$ and $\varphi = 3.51$. The baseline specification considers the IES model under monopolistic

Figure 2: Bayesian IRFs and 95% confidence interval. IES model under perfect competition

competition. We then consider a version of the model under perfect competition, where the parametrization is the same but prices are unitary (namely equal to the marginal cost). Finally, we also consider the benchmark with CES preferences (by setting $\gamma = 0$), for which the behavior of the model becomes independent of the parameter θ as well as of the form of competition (perfect or monopolistic) because markups are constant (and labor supply is normalized to one in steady state). The values in the table are the medians across 500 simulations, each 2100 periods long.

In our baseline model (IES preferences with monopolistic competition), the volatility of output and investment is close to the data both in absolute and relative terms. The Kydland-Prescott ratio is 0.93 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 consumption and labor, although these variables are still too smooth compared to the data. Like the standard RBC model, it implies excessively procyclical investments and labor. The first-order auto-correlation is slightly higher than the data for consumption and smaller for the other variables, demonstrating a fair capacity to capture the persistence in the data.

It is instructive to consider the performance of the model in the alternative specifications to gain further insights about the role of preferences and market structure. Our model based on 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 0.76. Introducing IES preferences while retaining perfect competition, the variability of output and labor increases a bit (with a Kydland-Prescott ratio 0.85) due to the higher intertemporal substitutability associated with our preferences. It

is however the introduction of monopolistic competition with IES preferences that delivers a radical change in the macroeconomic dynamics, suggesting the quantitative importance of our mechanism based on markup fluctuations.

Table 4: Second moments for the close economy

	Standard deviation			
	IES-MC	IES-PC	CES	Data
Y	1.72	1.57	1.40	1.84
L	1.14	0.93	0.69	1.79
C	0.62	0.60	0.56	1.35
I	5.82	4.98	4.24	5.30
	Correlation with output			
	IES-MC	IES-PC	CES	Data
L	0.98	0.98	0.86	0.88
C	0.81	0.90	0.95	0.88
I	0.99	0.99	0.89	0.80
	1 st auto-correlation			
	IES-MC	IES-PC	CES	Data
Y	0.74	0.74	0.73	0.84
L	0.72	0.72	0.72	0.88
C	0.87	0.82	0.79	0.80
I	0.73	0.73	0.73	0.87

4 International business cycle with incomplete markets

This section explores the role of monopolistic competition and endogenous pricing to market for the transmission of shocks across countries in an international RBC model *à la* BKK (1992).²³

We develop the simplest extension of our closed economy framework to a symmetric two-country economy with incomplete markets. We begin by analyzing the model under the assumption that there are no markets for international asset trade, namely the case of “financial autarky” in Cole and Obstfeld (1991). This means that all trade must be *quid pro quo*. Then, we introduce trade in a riskless bond in order to shed some light on the implications of our model for intertemporal trade. By allowing consumers to borrow and lend in international markets, the presence of the bond can help to smooth consumption over time, favoring the flow of savings toward higher returns on investment.

²³See 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.

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 is always (2) in country $i = h, f$ with consumption C_{jt}^i for good j and labor supply l_t^i in period t . There is always a unit mass of imperfectly substitutable varieties, all of which are traded without frictions in both markets, but goods $j \in [0, \frac{1}{2}]$ are produced at home and goods $j \in [\frac{1}{2}, 1]$ are produced in the foreign country. Markets are segmented, therefore under monopolistic competition each firm can sell its variety at different prices in the two markets.

The Cobb-Douglas production functions in each country $i = h, f$ are:

$$Y_t^i = A_t^i (K_t^i)^\alpha (L_t^i)^{1-\alpha} \quad (14)$$

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 that depreciates at the rate $\delta \in (0, 1)$. 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.²⁴

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

$$\mathbf{A}_{t+1} = \mathbf{\Lambda} \mathbf{A}_t + \boldsymbol{\epsilon}_{t+1} \quad (15)$$

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.

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 gross 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:

$$K_{t+1}^i + B_{t+1}^i = K_t^i(1 - \delta) + B_t^i(1 + i_t^i) + w_t^i l_t^i + r_t^i K_t^i + \Pi_t^i - \int_0^1 p_{jt}^i C_{jt}^i dj \quad (16)$$

²⁴Notice 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_{jt}^i is the price of good j in terms of country i 's numeraire. So p_{jt}^h , 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:

$$v(l_t^i)^{\frac{1}{\varphi}} = \lambda_t^i w_t^i \quad (17)$$

$$\lambda_t^i = \beta \mathbb{E}[(1 + r_{t+1}^i - \delta) \lambda_{t+1}^i] \quad (18)$$

$$\lambda_t^i = \beta(1 + i_{t+1}^i) \mathbb{E}[\lambda_{t+1}^i] \quad (19)$$

The returns on real and financial investment coincide under perfect foresight. With 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_{jt}^i , can be derived as $u'(C_{jt}^i) / \int u(C_{jt}^i) dj = \lambda_t^i p_{jt}^i$. 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:

$$\pi_{jt}^h = \left(\frac{u'(C_{jt}^h)}{\lambda_t^h \int_0^1 u(C_{jt}^h) dj} - 1 \right) C_{jt}^h + \left(\frac{\varepsilon_t u'(C_{jt}^f)}{\lambda_t^f \int_0^1 u(C_{jt}^f) dj} - 1 \right) C_{jt}^f$$

where the exchange rate ε_t is defined as units of home intermediate per unit of foreign intermediate. 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_{jt}^h and C_{jt}^f with FOCs, respectively:

$$\frac{u'(C_{jt}^h)}{\lambda_t^h \int_0^1 u(C_{jt}^h) dj} + \frac{u''(C_{jt}^h) C_{jt}^h}{\lambda_t^h \int_0^1 u(C_{jt}^h) dj} = \frac{\varepsilon_t u'(C_{jt}^f)}{\lambda_t^f \int_0^1 u(C_{jt}^f) dj} + \frac{\varepsilon_t u''(C_{jt}^f) C_{jt}^f}{\lambda_t^f \int_0^1 u(C_{jt}^f) dj} = 1$$

This gives the following expressions for the prices for home and foreign sales (in units of the home intermediate good):

$$p_{jt}^h = \frac{1}{1 - \epsilon(C_t^h)} \quad \text{and} \quad \varepsilon_t p_{jt}^f = \frac{1}{1 - \epsilon(C_t^f)}$$

A similar problem holds for the foreign firms and implies the prices $p_{jt}^f = 1/[1 - \epsilon(C_t^f)]$ and $p_{jt}^h/\varepsilon_t = 1/[1 - \epsilon(C_t^h)]$ 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:

$$p^i(C_t^i) = \frac{1}{1 - \epsilon(C_t^i)} \quad (20)$$

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. Firms therefore price-to-market in response to country-specific aggregate 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 substitution is temporarily higher at home, so that prices are temporarily reduced in the Home country compared to the Foreign country.²⁵

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

$$\frac{\psi(C_t^i)}{C_t^i p(C_t^i)} = \beta \mathbb{E} \left\{ \frac{[1 - \delta + \alpha A_{t+1}^i (K_{t+1}^i / L_{t+1}^i)^{\alpha-1}] \psi(C_{t+1}^i)}{C_{t+1}^i p^i(C_{t+1}^i)} \right\} \quad (21)$$

$$L_t^i = \left[\frac{w_t^i \psi(C_t^i)}{v C_t^i p^i(C_t^i)} \right]^\varphi \quad (22)$$

The model is closed with the resource constraints in the home and foreign country. Aggregate profits at home are:

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

Using this and the market clearing condition in the financial market,

$$B_t^h = 0 \quad \text{for any } t$$

the resource constraint becomes:

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

Recognizing that trade is balanced under financial autarky, $\varepsilon_t p_t^f C_t^f = p_t^h C_t^h$, we obtain:

$$K_{t+1}^h = K_t^h (1 - \delta) + Y_t^h - \frac{C_t^h + C_t^f}{2} \quad (23)$$

²⁵We 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*.

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:

$$K_{t+1}^f = K_t^f(1 - \delta) + Y_t^f - \frac{C_t^h + C_t^f}{2} \quad (24)$$

Notice that international profit flows under monopolistic competition and free trade generate an interdependence between economies that is absent under perfect competition, where profits are zero and each 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, and 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, relative 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). In a more general setting, where there is a market for international asset trade, they could even borrow resources from abroad and anticipate the rise in consumption: as well known, a non-contingent asset is largely sufficient for this purpose.²⁶

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. This in turn mitigates the incentive to shift resources toward the country where the return to investments is higher compared to standard international RBC models. In addition, variable markups induce movements in relative 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:

$$TOT_t = \frac{\varepsilon_t p_t^f}{p_t^h} = \frac{1 - \epsilon(C_t^h)}{1 - \epsilon(C_t^f)} \quad (25)$$

A boom in the home country increases the perceived substitutability between goods consumed in the home market and reduces their prices, including those of the imported goods. Therefore the relative price of exports from the home country increases and the home terms of trade appreciate. This appreciation further stimulates home consumption, while reducing the correlation with foreign consumption.²⁷ Notice that the terms of trade would be constant in this

²⁶The literature on incomplete markets has made clear that the opportunities for international risk sharing are small when shocks are common or when they are far from a unit root (Cole and Obstfeld, 1991; Baxter and Crucini, 1995; Heathcote and Perri, 2002).

²⁷We are not the first to stress the relevance of markups for explaining the tendency of output and its components to move in a synchronized way in the world economy. A contribution of our model is to clarify the conditions under which the decline in markups originates from

fully symmetric environment with CES preferences. Finally, it is worth stressing that the consumption-based real exchange rate RER_t , defined as the ratio of home to foreign consumer prices, is the reciprocal of the country's terms of trade:

$$RER_t = \frac{p_t^h}{\varepsilon_t p_t^f} = \frac{1}{TOT_t} \quad (26)$$

With countercyclical markups, the RER depreciates in response to a rise in home productivity, implying that the home consumption basket becomes cheaper. As first shown by Backus and Smith (1993), for most OECD countries the correlation between relative consumption and the RER is low or negative.

4.2 Quantitative evaluation

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. We follow BKK and set the following coefficients for the matrix Λ :

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

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. The preference parameters are re-estimated with the baseline priors in Table 1 and set at the value of the corresponding posterior means, which are now marginally changed to $\gamma = 1.1$, $\theta = 1.5$ and $\varphi = 3.4$.²⁸

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, albeit moderately. The shock spreads its effects abroad gradually through the technology spillover and the increased profitability of the foreign firms exporting to the home market. The latter is a new effect compared to perfectly competitive RBC models *à la* BKK, and is brought about by the decline of markups in the home country (recall that markups are countercyclical and profits are procyclical in our setup). As it will be apparent soon, this helps increase the correlation of output across countries.

the demand side and to show that a simple international business cycle model can generate realistic comovements by abandoning the assumption of homothetic preferences. An important advantage of this strategy is that it does not require to resort to implausible parameterizations of the shocks or low values of the trade elasticity as those required to generate strong effects when markups are absent or constant (Corsetti *et al.*, 2008).

²⁸The values of γ and θ together with steady state consumption yield a steady state markup of around 30%.

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

The positive shock in the Home country generates an appreciation of the home terms of trade, reflecting lower markups in the Home country. Notice that this is the opposite of what happens in traditional models where a positive shock at home depreciates the terms of trade, reflecting the relative abundance of the exported goods compared to the imported goods. Improving terms of trade, in turn, contribute to increase relative consumption in the Home country and to reduce the correlation of consumption across countries, again compared to perfectly competitive RBC models *à la* BKK.

We now turn to the ability of the model to replicate key facts of the international business cycle. Table 5 reports the simulated moments in the IES model under monopolistic competition and perfect competition, and in the specification with CES preferences under both monopolistic and perfect competition (notice that the market structure is important also with CES preferences because of profit flows across countries). For ease of comparison, it also reports the moments in the model with perfect competition of BKK,²⁹ and EU-US data from Ambler *et al.* (2004) and from BKK (in parenthesis). The data refer to the sample 1973-2001 in Ambler *et al.* (2004) and to the sample 1954-1989 in BKK. 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

²⁹The 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.

the largest.³⁰ 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, 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.³¹

Remarkably, monopolistic competition and variable markups can contribute to solve these inconsistencies: in our baseline model (IES preferences with monopolistic competition), the cross-correlations are all positive, and output displays the largest comovements. Positive output spillovers emerge thanks to the fact that a productivity rise in one country increases the profitability of sales toward that country, promoting production also in the trading partner in spite of a lower productivity. Indeed, a similar (weaker) effect emerges also in the specification with monopolistic competition and CES preferences, though the cross-correlation is lower for output and remains negative for investments and labor. This suggests that markup variability over the business cycle and between countries is key to solve the comovement and quantity puzzles.

A positive technology shock creates a positive wealth effect that pushes for an increase in consumption in both countries, but our baseline model delivers an additional substitution effect working in the opposite direction: final goods' prices are lower in the country where the shock originates compared to the other country, therefore consumption is temporarily higher in the former relative to the latter. 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. A comparison across the different specifications shows that monopolistic competition *per se* contributes to reduce the correlation of consumption between countries (this can be verified looking at the case with CES preferences), but it is markup variability (with IES preferences) that makes the difference and allows us to broadly match the correlation in the data.

Besides outperforming the standard international RBC framework in reproducing key comovements, the model with monopolistic competition and IES preferences provides plausible moments for domestic variables in line with the performance of our single country model. Notice that all variables are more

³⁰ 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.

³¹ A non-exhaustive list of successful candidates includes non-tradable goods, durable goods, consumption habits, distribution services, capital market frictions, and firm entry. See Obstfeld and Rogoff (2000).

volatile than in the single country model because of the technology spillovers.

Table 5: Second moments for the open economy

A: Correlations between home and foreign variables

	IES-MC	CES-MC	IES-PC	CES-PC	BKK	US-EU data
Y	0.41	0.26	0.16	0.09	-0.21	0.28 (0.66)
C	0.11	0.42	0.75	0.79	0.88	0.15 (0.51)
I	0.10	-0.17	-0.13	-0.24	-0.31	0.22 (0.53)
L	0.39	-0.08	-0.16	-0.38	-0.31	0.22 (0.33)
p	-0.17	0	0	0	-	-

B: Home business cycle

	IES-MC		CES-MC		IES-PC		CES-PC	
	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)	St.Dev.	Corr(X,Y)
Y	1.81	1	1.56	1	1.78	1	1.68	1
C	0.83	0.78	0.72	0.90	0.67	0.87	0.64	0.88
I	5.89	0.98	5.18	0.97	5.81	0.98	5.43	0.98
L	1.05	0.98	0.74	0.95	1.0	0.98	0.92	0.98
p	0.48	-0.78	0	0	0	0	0	0

4.3 Intertemporal trade with non-contingent bonds

To shed further light on the transmission mechanism at work in the model, we finally depart from the assumption of financial autarky and consider an economy where a single bond can be traded in international financial markets. Herein we discuss the main alterations 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:

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

$$B_t^h(1 + i_t^h) + \varepsilon_t B_{*t}^f(1 + i_t^f) + w_t^h L_t^h + r_t^h K_t^h + T_t^h + \Pi_t^h - \int_0^1 p_{jt}^h C_{jt}^h dj \quad (27)$$

and

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

$$B_t^f(1 + i_t^f) + \frac{B_{*t}^h}{\varepsilon_t}(1 + i_t^h) + w_t^f L_t^f + r_t^f K_t^f + T_t^f + \Pi_t^f - \int_0^1 p_{jt}^f C_{jt}^f dj \quad (28)$$

where a star subscript denotes the holdings of foreign bonds, $\xi \in (0, 1)$ measures 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.

Two additional FOCs govern the optimal choice of foreign bond holdings:

$$\lambda_t^h(1 + \xi B_{*t+1}^f) = \beta(1 + i_{t+1}^f) \mathbb{E}\left[\frac{\varepsilon_{t+1}}{\varepsilon_t} \lambda_{t+1}^h\right] \quad (29)$$

$$\lambda_t^f(1 + \xi B_{*t+1}^h) = \beta(1 + i_{t+1}^h) \mathbb{E}\left[\frac{\varepsilon_t}{\varepsilon_{t+1}} \lambda_{t+1}^f\right] \quad (30)$$

With $\xi = 0$, Euler equations for bond holdings at home and abroad would imply the familiar *uncovered interest rate parity* condition $(1 + i_{t+1}^h)/(1 + i_{t+1}^f) = \mathbb{E}[\varepsilon_{t+1}/\varepsilon_t]$: 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:

$$\frac{(1 + i_{t+1}^h)}{(1 + i_{t+1}^f)} = \mathbb{E}\left[\frac{\varepsilon_{t+1}}{\varepsilon_t}\right] \frac{(1 + \xi B_{t+1}^h)}{(1 + \xi B_{*t+1}^f)} = \mathbb{E}\left[\frac{\varepsilon_{t+1}}{\varepsilon_t}\right] \frac{(1 + \xi B_{t+1}^f)}{(1 + \xi B_{*t+1}^h)} \quad (31)$$

Equilibrium in the bond market requires that home and foreign bonds be in zero net supply worldwide:

$$B_{t+1}^f + B_{*t+1}^f = B_{t+1}^h + B_{*t+1}^h = 0 \quad (32)$$

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 (32) 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 $B_{*t}^i = B_t^i$ for $i = h, f$.

The aggregate resource constraints in the two countries are given by:

$$B_{t+1}^h + \varepsilon_t B_{*t+1}^f + K_{t+1}^h - K_t^h(1 - \delta) = B_t^h(1 + R_t^h) + \varepsilon_t B_{*t}^f(1 + R_t^f) + Y_t^h - \frac{(\varepsilon_t p_t^f C_t^f - p_t^h C_t^h)}{2} - \frac{(C_t^h + C_t^f)}{2}$$

and

$$B_{t+1}^f + \frac{B_{*t+1}^f}{\varepsilon_t} + K_{t+1}^f - K_t^f(1 - \delta) = B_t^f(1 + R_t^f) + \frac{B_{*t}^h}{\varepsilon_t}(1 + R_t^h) + Y_t^f - \frac{(C_t^h + C_t^f)}{2} - \frac{(p_t^h C_t^h / \varepsilon_t - p_t^f C_t^f)}{2}$$

where the last two terms are profits net of expenditure. Compared to the resource constraint under financial autarky (23), 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 (cheaper) imports well above the increase in the volume of exports.

Finally, the current accounts of the two countries are by definition equal to the changes in their net foreign assets between any two periods, i.e.:

$$CA_t^h \equiv B_{t+1}^h - B_t^h + \varepsilon_t (B_{*t+1}^f - B_{*t}^f) \quad (33)$$

$$CA_t^f \equiv B_{t+1}^f - B_t^f + \frac{(B_{*t+1}^h - B_{*t}^h)}{\varepsilon_t} \quad (34)$$

The bond market-clearing conditions (32) imply that borrowing must equal lending in the world economy, namely $CA_t^h + \varepsilon_t CA_t^f = 0$, and world output equals world spending, $\sum_{i=h,f} Y_t^i = \sum_{i=h,f} [C_t^i + K_{t+1}^i - K_t^i(1 - \delta)]$.

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

Trade in bonds is largely inconsequential for the performance of the baseline model, and moments are very similar to those under financial autarky.³² The bond *per se* does not seem to provide relevant means for smoothing consumption in addition to what is achieved in the financial autarky case. This constitutes a major departure from the familiar finding that the financial autarky economy behaves very differently from the one with international asset trade.³³ The reason is the inter-temporal substitution effect brought about by variable markups that limits the incentive to smooth consumption. This effect is clearly absent in traditional models with a constant elasticity of substitution and constant (or zero) markups. In these models the terms of trade of the country hit by a positive shock tend to deteriorate, reflecting the relative abundance of the good exported by this country in the world economy. Such a deterioration of the terms of trade (which is larger under financial autarky, because countries cannot run current account deficits and households must export more and import less relative to the model with asset trade) has the effect of increasing the cross-correlation of output and its components in traditional models (and this explains the better performance under financial autarky stressed by Heathcote and Perri, 2002) while providing a strong incentive to smooth consumption over time (and this is also consistent with the difference between financial autarky and international asset trade).

In our variable-markup model the terms of trade of the country hit by a positive shock improve (because of the decline in home markups), which increases

³²The cross correlations in the model with IES preferences under monopolistic competition are 0.09, 0.41, 0.09 and 0.40 for, respectively, consumption, output, investments and labor supply.

³³Heathcote and Perri (2002) show that the behavior of the financial autarky model is closest to the data for a large parameter space while the complete markets and the bond economies have a similar (poorer) performance.

the relative consumption of this country and reduces the cross-correlation of consumption, while profit spillovers lead to positive comovements of output, investments and labor supply. Temporarily low (high) prices induce home (foreign) households to anticipate (postpone) rather than smooth consumption, therefore bond trade is exploited to anticipate consumption rather than smoothing it.

Notice that the behavior of the bond economy is very different from the one under financial autarky and perfect competition. In this case the IES model with bond trade generates a near perfect negative correlation of output across countries (the cross correlation of output is -0.94 against 0.16 under financial autarky), and an even larger correlation of consumption (0.87 against 0.75). Similarly in the specification with CES preferences, the cross correlation of output is negative under perfect competition (-0.93) while that of consumption is higher relative to the autarky case (0.88). International bond trade indeed provides a useful means for smoothing consumption whenever the intertemporal substitution mechanisms are small (in the model with IES preferences under perfect competition) or altogether absent (in the model with CES preferences). Instead, when the intertemporal substitution mechanisms due to markup variability are important, bond trade does not provide a useful means for smoothing out consumption.

In all specifications, the country experiencing the productivity rise (the home country in the simulations) runs a current account deficit on impact due to the high convenience of increasing consumption as long as prices are temporarily low. Over time, the deficit gradually reduces and eventually turns into a surplus before returning to zero. Net exports - which coincide with the change in net foreign assets - are less volatile than output and countercyclical (the correlation with output is -0.55), in line with the properties observed in the data.

5 Conclusion

We have developed a DSGE model with endogenous markups due to preferences with a variable elasticity of substitution between differentiated goods. This supports the old idea that demand matters for the business cycle due to its impact on monopolistic pricing. The impact of supply shocks on consumption and labor supply is magnified through new intertemporal substitution mechanisms, and second moments show that the estimated model largely 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.

The model 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. The natural extension of such a model concerns endogenous entry of firms in the spirit of Bilbiie *et al.* (2012) in the closed economy and Ghironi and Melitz (2005) and Cavallari (2013b) in the open economy,

which can affect markups and aggregate variables. Moreover, one could consider imperfections in the labor and credit market to analyze complementarity with imperfect competition in driving business cycle propagation. Finally, nominal frictions could be introduced in the intermediate good sector to evaluate the interaction between endogenous markups and monetary policy.

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