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 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.

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

JEL Codes: E1, E2, E3.

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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 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. 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. In particular, when substitutability increases in consumption an expansionary technology shock reduces the markups under monopolistic competition 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), Murphy *et al.* (1989), Rotemberg and Woodford (1999) and Chevalier *et al.*

[2] Non-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, Bertoletti *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, Ravn *et al.* (2008), Etro (2016) and Boucekkine *et al.* (2017). As well known non-homotheticity precludes studying heterogenous 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.

(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 directly additive preferences. These deliver simple markup rules under monopolistic competition that depend on aggregate consumption and therefore change over the business cycle. We also show that our results apply to more general preferences of the GAS type, due to Pollak (1972) and Gorman (1970, 1987), which nest also direct and indirect additivity, generate demand systems depending on a unique aggregator and have been recently applied to the study of monopolistic competition when each firm sets prices taking the same aggregator as given (Bertoletti and Etro, 2017a,b).

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 specification of directly additive 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 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 support non-homothetic preferences and, if so, what are their implications for markups:[4] the results support an elasticity of substitution among varieties that is increasing in consumption, which leads to countercyclical markups under monopolistic competition. 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, 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 trade by Krugman, 1979). 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) 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.

[3] The specification is borrowed from Bertoletti *et al.* (2008), forthcoming in the Special Issue in honor of 40 years of the Dixit-Stiglitz model of *Research in Economics*.

[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.

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 well known, New-Keynesian models generate countercyclical markups due to price stickiness, because expansionary shocks tend to increase nominal costs while some prices remain unchanged, while our focus on flexible price models abstracts from the impact of inflation.[5] Rotemberg and Woodford (1992, 1999) have obtained countercyclical markups under collusive behavior of firms, but the average markets in the economy are not price-fixing cartels, therefore we consider more relevant to analyze imperfect competition with flexible prices. A recent literature has shown that endogenous entry of firms can generate countercyclical markups under general homothetic preferences (Bilbiie *et al.*, 2012) or oligopolistic competition (Etro and Colciago, 2010),[6] but these mechanisms originate on the supply side 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. Compared to these works, we introduce capital accumulation on the supply side and we generalize the demand side to a wide type of non-homothetic preferences. On the open economy front, Ghironi and Melitz (2005) have generated variable average prices (but not variable markups) through endogenous entry of heterogeneous firms retaining CES preferences, 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. We are not aware of international RBC models featuring endogenously variable markups due to non-homothetic preferences, but this appear to be extremely relevant to reproduce realistic co-movements of aggregate variables and relative prices across countries.

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

[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.

[6] On the aggregate consequences of endogenous entry and markups see also, among others, Campbell (1998), Jaimovich and Floetotto (2008) and Cavallari (2013a,b).

second moments. Section 4 extends the model to two countries to analyze international business cycles. Section 5 is the conclusion.

1 RBC with non-homothetic preferences

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 or to produce a variety of downstream final goods with a linear technology.

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

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

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 $\mathbb{U}_t$ is a utility functional of the consumption of final goods, which is assumed symmetric on a given unitary mass of goods. We will mainly interpret this intratemporal utility as directly additive:

$$\mathbb{U}_t = \int_0^1 u(C_{jt}) dj$$

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 $u(C) = \frac{\theta}{\theta-1} C^{\frac{\theta-1}{\theta}}$ 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). Here we are interested in exploring the more general class of directly additive aggregators which deliver non-homotheticity.

However, our results apply to more general symmetric preferences. In particular, we can use the GAS (Generalized Additive Separability) preferences, originally introduced by Pollak (1972) and Gorman (1970, 1987), which deliver a demand system depending on a common aggregator, and have been recently exploited to analyze monopolistic competition when each firm sets prices taking as given the same aggregator (see Bertoletti and Etro, 2017a,b). The GAS preferences can be expressed as:

$$\mathbb{U}_t = \int_0^1 \left[u(\xi C_{jt}) - \phi(\xi) \right] dj$$

When ξ is a constant we obtain the directly additive preferences, and the demand system depends on an aggregator given by the marginal utility of income (Dixit and Stiglitz, 1977). We obtain the Gorman-Pollak preferences when ξ is an aggregator implicitly defined by $\phi'(\xi) = \int_0^1 u'(\xi C_j) C_j dj$, as if ξ was a shopping cost that enhances the utility from the consumption of each good and that is chosen to maximize overall utility.[7] Finally, we can also nest indirectly additive preferences, which require an indirect utility $\mathbb{U} = \int_0^1 v(s_j)dj$ additive in the price-expenditure ratios s_j, with decreasing and convex functions $v(s)$: we can recover its direct utility by setting $u(z) = v(v'^{-1}(z))$ and $\phi = 0$ when ξ is an aggregator implicitly defined by $\xi = \int_0^1 v'(v'^{-1}(\xi C_j))v'^{-1}(\xi C_j)dj$.[8] If and only if preferences are of the GAS type, the associated demand system features a unique symmetric aggregator either of consumption levels or prices (Gorman, 1970), which allows a natural implementation of monopolistic competition.

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:

$$K_{t+1} = K_t(1-\delta) + w_t l_t + r_t K_t + \Pi_t - \int_0^1 p_{jt} C_{jt} dj \tag{2}$$

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:

$$\frac{\partial \mathbb{U}_t / \partial C_{it}}{\mathbb{U}_t} = \lambda_t p_{it} \tag{3}$$

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

$$\upsilon l_t^{\frac{1}{\varphi}} = \lambda_t w_t \quad \text{and} \quad \lambda_t = \beta \mathbb{E}[R_{t+1}\lambda_{t+1}] \tag{4}$$

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

[7] These preferences are not additive and contain a homothetic family: indeed, whenever $\phi(\xi) = \ln \xi$ the definition of the aggregator above implies $1 = \int_0^1 \tilde{u}'(\xi C_j)\xi C_j dj$, therefore ξ is homogeneous of degree -1. This implies that the demand system is homothetic and actually that the direct demand of each good depends on the ratio between the price of that good and a homogeneous price aggregator (see Matsuyama and Ushchev, 2017). We are thankful to Paolo Bertoletti for discussions on this point.

[8] By applying the Roy's identity one can derive the direct demand $C_i = v'(p_i/E)/\xi$ where E is expenditure, the adding up constraint $\int p_j C_j = E$ provides the definition of ξ, and the demand system depends on it. See Bertoletti and Etro (2017a) for details.

1.1 Pricing

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

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

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 $\mathbb{U}_t$ are taken as given. The FOCs for each firm i provide the symmetric equilibrium monopolistic price as:

$$p(C_t) = \frac{1}{1 - \epsilon(C_t)} \tag{5}$$

where we defined the elasticity of the marginal subutility $\epsilon(C) \equiv -\frac{(\partial^2 \mathbb{U}/\partial C_i^2)C_i}{\partial \mathbb{U}/\partial C_i}$ evaluated under symmetry, and we assumed that this is smaller than unity. In the case of directly additive preferences we have $\mathbb{U}(C) = u(C)$ and $\partial \mathbb{U}/\partial C = u'(C)$, and this elasticity is the familiar index of relative risk aversion $\epsilon(C) \equiv \frac{-u''(C)C}{u'(C)}$.[9] As shown in Bertoletti 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 ($C_i = C_j = C$).[10] Notice that we need $\epsilon(C) < 1$ to insure a positive markup, which requires a positive marginal revenue. Moreover, the SOCs require the marginal revenue to be locally decreasing as well. Both these conditions are satisfied if $(\partial \mathbb{U}/\partial C)C$ is increasing and concave in consumption, as we will assume. Nevertheless, the elasticity $\epsilon(C)$ can be either increasing or decreasing in consumption, with $p'(C) \gtreqless 0$ if and only if $\epsilon'(C) \gtreqless 0$. 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.[11] This will be the relevant case in our

[9] Under Gorman-Pollak preferences the relevant elasticity is $\epsilon(C) = \frac{-u''(\xi C)\xi C}{u'(\xi C)}$ with ξ evaluated under symmetry. Under indirectly additive preferences the maximization of profits with respect to the price, taking as given the expenditure E and the aggregator ξ, delivers the relevant elasticity $\epsilon(C) = \frac{-v'(1/C)C}{v''(1/C)}$ under the symmetry condition $pC = E$. See Bertoletti and Etro (2017a,b) for more details.

[10] These are indeed the Morishima elasticities, that are the relevant elasticities of perceived demand under monopolistic competition for any symmetric preferences (Bertoletti and Etro, 2016).

[11] An old conjecture by Marshall suggests that 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,

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.[12]

The symmetric equilibrium allows us to solve for the Lagrange multiplier $\lambda_t = (\partial \mathbb{U}/\partial C)/\mathbb{U}p_t$ and to rewrite the FOCs as follows:

$$l_t = \left[\frac{w_t(\partial \mathbb{U}/\partial C_t)}{\upsilon \mathbb{U}(C_t)p_t}\right]^{\varphi}$$

$$\frac{\partial \mathbb{U}/\partial C_t}{\mathbb{U}(C_t)p_t} = \beta \mathbb{E}\left\{R_{t+1}\frac{\partial \mathbb{U}/\partial C_{t+1}}{\mathbb{U}(C_{t+1})p_{t+1}}\right\}$$

Taking the logs of the Euler equation and differentiating provides an expression for the *intertemporal elasticity of substitution*:[13]

$$\chi(C_t) \equiv -\frac{\partial \ln C_t}{\partial \ln p_t} = \frac{1}{\psi(C_t) + \epsilon(C_t)} \tag{6}$$

where we defined the elasticity of the subutility as $\psi(C) \equiv (\partial \mathbb{U}/\partial C)C/\mathbb{U}(C)$. In case of CES preferences we have $\psi(C) = 1 - 1/\theta$, and the intertemporal elasticity is unitary. With general directly additive preferences, however, $\psi'(C) \propto 1 - \psi(C) - \epsilon(C)$ implies $\chi(C) \gtrless 1$ if and only if $\psi'(C) \gtrless 0$. 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 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:

$$K_{t+1} = K_t(1-\delta) + A_t K_t^{\alpha} L_t^{1-\alpha} - C_t \tag{7}$$

delivering countercyclical markups, emerges if consumers that become richer also become less risk averse and less lovers of differentiation. See Bertoletti *et al.* (2008) for further discussion on the second law of demand of Marshall.

[12] Bilbiie *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 and a constant number of firms.

[13] We are grateful to Paolo Bertoletti for pointing out this definition.

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:

$$L_t = \left[\frac{(1-\alpha) A_t K_t^{\alpha} \psi(C_t)}{\upsilon C_t p(C_t)} \right]^{\frac{\varphi}{1+\alpha\varphi}} \tag{8}$$

$$\frac{\psi(C_t)}{C_t p(C_t)} = \beta \mathbb{E} \left\{ \frac{\left[1 - \delta + \alpha A_{t+1} K_{t+1}^{\alpha-1} L_{t+1}^{1-\alpha}\right] \psi(C_{t+1})}{C_{t+1} p(C_{t+1})} \right\} \tag{9}$$

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.

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 (8) and in the Euler equation (9).[14]

1.3 Preference specification

To perform the quantitative analysis we need to adopt a specific functional form for the preferences. We have experimented a variety of directly additive and indirectly additive specifications, but to clarify the relation between the traditional CES assumption and our more general environment, we have selected the simplest specification that nests CES preferences.

We adopt directly additive preferences with a polynomial specification of the subutility which combines a linear and a power function:

$$u(C) = \gamma C + \frac{\theta}{\theta - 1} C^{\frac{\theta-1}{\theta}} \quad \text{with } \theta > 1 \tag{10}$$

[14] 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 (1) under the resource constraint (7) 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 (8) - and the other is an intertemporal distortion of the savings decision - $p(C_{t+1}) \neq p(C_t)$ in (9). 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.

Of course this "bi-power" subutility reduces to the CES case for $\gamma = 0$. 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 of $\gamma > 0$. This was originally introduced by Bertoletti *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 $\vartheta'(C) > 0$).[15]

The specification (10) generates the following pricing rule:

$$p(C_t) = \frac{\theta(1 + \gamma C^{\frac{1}{\theta}})}{\theta(1 + \gamma C^{\frac{1}{\theta}}) - 1} \tag{11}$$

and the assumption $\theta > 1$ is enough to satisfy the SOCs for profit maximization. The markups are indeed countercyclical (procyclical) if $\gamma > (<)\ 0$. Moreover, the elasticity of the subutility is $\psi(C) = (1+\gamma C^{\frac{1}{\theta}})/(\frac{\theta}{\theta-1}+\gamma C^{\frac{1}{\theta}})$ 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:

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

together with the resource constraint (7). 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.[16]

2 Calibration

The calibration is on a quarterly basis to match the frequency of business cycle data. The main structural parameters and those governing the stochastic

[15] Of course, this is only one possible directly additive specification featuring increasing elasticity of substitution. We have experimented others, as the Stone-Geary preferences, but the quantitative results are modest as already shown by 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.

[16] It 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.

process are calibrated in a standard fashion. The capital share is $\alpha = 0.33$. The depreciation rate is $\delta = 0.025$ to match the 10% rate of capital depletion per year found in US data. The discount factor is $\beta = 0.99$, corresponding to a real interest rate of 4% per annum. We normalize the steady state value of total factor productivity to $A = 1$.[17] The scale parameter for the disutility of labor υ 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 productivity shock follows an AR(1) process in logs:

$$\ln A_t = \rho \ln A_{t-1} + \epsilon_t \tag{12}$$

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 $\rho = 0.979$ and the magnitude of innovations is $\sigma = 0.0072$.

Given our focus on non-homothetic preferences, the parameterization of the utility function deserves particular attention. It is amply recognized that matching the utility function and the dynamics of consumption and leisure is very challenging. We estimate the preference parameters γ, θ and φ with a Bayesian approach along the lines of Schorfheide (2000) and Fernandez-Villaverde and Rubio-Ramirez (2004). The exercise is meant to provide a reasonable calibration of utility for the scope of illustrating the potential of our mechanism.

The model is estimated with quarterly US data over the period 1980q1-2008q2.[18] In the baseline specification, the observable variable is real personal consumption expenditure. We also consider output and hours for robustness purposes. The data source is the FRED database of the Federal Reserve Bank of St. Louis. Consumption and output are expressed in per capita terms, while hours worked are expressed per person employed. All variables 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 υ 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 Smets and Wouters (2007).

The estimated parameters have 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 1.6 and 3, and standard deviation 0.75 and 1, respectively. Our choices reflect a desire to elicit priors that are easy to understand and consistent with evidence. For instance, a prior mean of φ

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

[18] We overlook the great recession period to avoid excessive volatility.

above unity is appropriate in models that do not distinguish the intensive and the extensive margin of employment. The prior density, running from 0.82 to 7.05, reveals the extent of uncertainty that surrounds estimates of the Frisch elasticity.[19]

The prior mean of γ reflects our preference for an increasing elasticity of substitution, though the guess is highly uncertain (the density lies between -0.29 and 2.49). The prior mean of θ is above unity for consistence of the model and the density 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 $\vartheta(C) = \theta(1 + \gamma C^{\frac{1}{\theta}})$, and depends not only on θ but also on γ and the consumption level. Our priors together with steady-state consumption imply a mean elasticity of 4.56 and average markups of 28%.

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	0.25	**1.03**	0.53-1.76
φ	Gamma	3	1	4.20	0.83	**3.51**	1.64-5.44
Log marginal density 267.744							

Table 1 reports two sets of results. The first set contains the estimated posterior mode of the parameters, which is obtained by maximizing the log of the posterior distribution, and an approximate standard error based on the corresponding Hessian (in parenthesis). The second set reports the mean, and the 5th, and 95th percentile of the posterior distribution based on 10.000 draws of the two-block Random Walk Metropolis Hastings algorithm. The generated Markov chain of parameters passes all the requirements of convergence.[20]

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. A positive γ implies that the elasticity of substitution is increasing in the level of consumption and markups are countercyclical.

The posterior means of θ and γ imply a steady-state elasticity of substitution $\vartheta(2.3) \approx 3.8$, exactly matching the assumption of Bilbiie *et al.* (2012) and

[19] Microeconomic evidence points to lower values of the Frisch elasticity relative to macroeconomic studies. The wage elasticity exhibits ample variability across workers, and estimates range from from zero to more than one (see Keane, 2011). The range in macro studies is between 2 and 8.

[20] 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.

similar models with variable markups.[21] The steady-state markup is around 35%, well in the range 15-45% found for the average price markup in US data.[22] 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 like financial constraints that may contribute to increase markups. We view the ability to reproduce plausible markups as an important advantage of our model.

Next, we consider changes in the priors, the market structure and the observable variables for robustness purposes. Once again, we are particularly interested in the coefficient of the linear term. Table 2 contains the outcomes of the sensitivity analysis.

Table 2: Sensitivity analysis

	CES Preferences		*Perfect Competition*	
	post. mean	95-5 %ile	post. mean	95-5 %ile
θ	1.32	1.03-2.33	1.69	0.86-2.91
γ	0.23	0.05-0.52	1.05	0.21-1.85
φ	2.77	1.51-5.50	4.23	2.45-6.30
	Output		*Hours*	
	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

In the first exercise, we consider a prior of $\gamma = 0$ to reflect the assumption of CES preferences: see the column entitled *CES preferences*. The prior distribution is normal with standard error 0.2. Remarkably, the posterior mean of γ remains significantly positive, although it is lower than in the baseline model. The Bayes factor, measuring the odds the data prefer IES compared to CES preferences, is 6.2.[23] According to Jeffreys (1998), a Bayes factor of this size provides "substantial" evidence in favor of the IES model.

Second, we estimate a version of the model under perfect competition (see the column entitled *Perfect Competition)* to assess the role of market structure for the model fit. Under perfect competition, a positive γ captures changes in the curvature of the utility function over the cycle that strengthen intertemporal substitution effects. The posterior mean of $\gamma = 1.05$ suggests that these mechanisms are not rejected by the data. Notice that the posterior mean of θ is larger compared to the model under monopolistic competition, implying a

[21] Notice that the intertemporal elasticity of substitution in steady state is $\chi(2.3) = 1.3$, slightly higher than the usual unitary elasticity associated with log preferences.

[22] See, among others, Rotemberg and Woodford (1999) and Basu and Fernald (1997).

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

much higher demand elasticity. More competition turns out to increase wage elasticity as well.[24]

Finally, we consider output or hours as the observable variable. The motivation is that these variables may be more closely linked to the structural innovations in the model. The estimation is done with 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 hours worked are used, although it is less precise. The posterior means of θ and φ show ample variability across samples.

Overall, the exercise suggests that our specification of preferences, characterized by an increasing elasticity of substitution is well supported by the data. Most important adopting 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

The quantitative analysis starts 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 major business cycle facts with an analysis of second 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).[25] 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 monopolistic and perfect competition, respectively. In each figure, the y-axis indicates the 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.

[24] 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 the latter is not sufficient for an econometrician to ignore the model under perfect competition.

[25] Simulations are made with Dynare. The algorithm used to compute a quadratic approx-

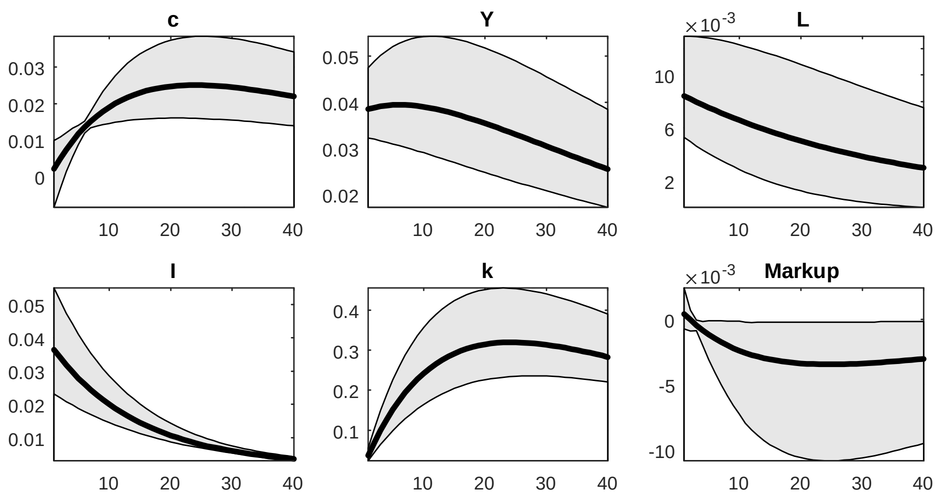

Figure 1: Bayesian IRFs and 95% confidence interval. IES model under monopolistic competition

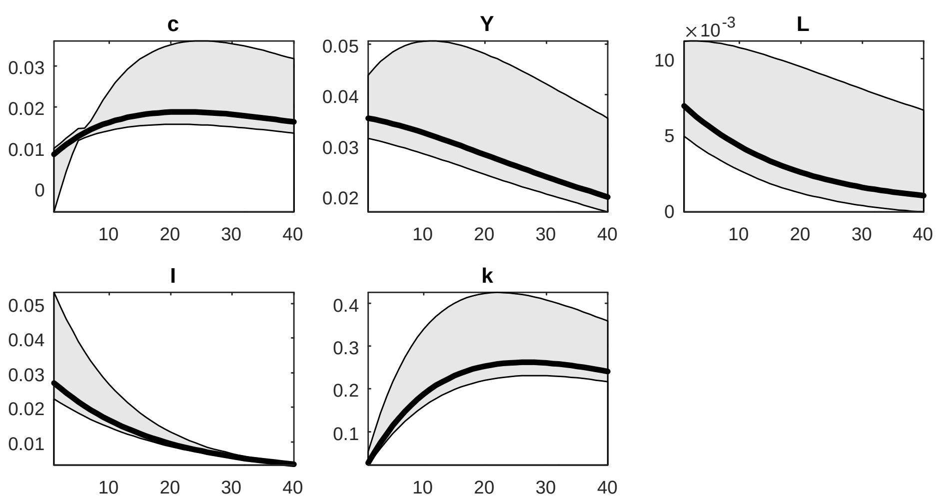

Figure 2: Bayesian IRFs and 95% confidence interval. IES model under perfect competition

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 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 substitution effects due to the variability of markups generate an inverse U-shape of the output response, which is absent in the case of perfect competition.

3.2 Second moments

Table 3 reports selected moments derived from the simulation of alternative models, together with US data from King and Rebelo (1999). The baseline specification considers the IES model under monopolistic competition. We then consider a version of the model under perfect competition, where the parameterization is the same but prices are unitary (namely equal to the marginal cost). Finally, we consider CES preferences (by setting $\gamma = 0$), for which the behavior of the model becomes independent of the parameter θ and 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 helps increase the variability of output and labor (with a Kydland-Prescott ratio 0.85) due to the higher intertemporal substitutability associated with our preferences. It

imation of the decision rules is described in Collard and Juillard (2001).

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.[26]

Table 3: Second moments for the closed 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

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* Backus *et al.* (1992, BKK).[27]

We develop the simplest extension of our framework to a symmetric two-country economy. 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*

[26] Similar results hold for indirect additivity. We have experimented the indirect subutility $v(s) = (s - \bar{s})^{1-\vartheta}$ where $\bar{s}$ can be positive or negative and $\vartheta > 1$. In this case the elasticity $\epsilon(C) = (1 - \bar{s}C)/\vartheta$ is decreasing in consumption if and only if $\bar{s} > 0$ (of course, $\bar{s} = 0$ leads to CES preferences). Also in this case monopolistic competition indeed amplifies macro dynamics compared to perfect competition whenever markups are countercyclical. For instance, setting $\bar{s} = 0.13$ and $\vartheta = 3.8$ to obtain steady state markups of 22%, the standard deviation of output is 1.81 under monopolistic competition and 1.67 under perfect competition, it is 6.34 against 5.65 for investments, and 1.23 against 1.09 for employment. This confirms that our qualitative results extend beyond direct additivity and do not depend on our favorite specification.

[27] 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.

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 consumption smoothing, and 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 as 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 without frictions in both 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 that the elasticity of substitution between varieties is independent of the country of origin and destination of the variety.[28] Home and foreign markets, however, are segmented, therefore under monopolistic competition each firm can sell its own variety at different prices in the two markets.[29]

The Cobb-Douglas production functions in each country $i = h, f$ are $Y^i_t = A^i_t (K^i_t)^\alpha (L^i_t)^{1-\alpha}$. 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.[30]

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

$$\mathbf{A}_{t+1} = \mathbf{\Lambda} \mathbf{A}_t + \boldsymbol{\epsilon}_{t+1} \tag{13}$$

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,

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

[29] Instead perfect competition implies that each variety is sold at the marginal cost of the producer in both countries.

[30] 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.

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 conservative choice of stationary shocks reflects the desire to focus on preferences as the main departure from an otherwise standard international RBC 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). As it will be apparent soon, in our setup the volatility of international prices is entirely driven by endogenus changes in markups.

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:

$$K_{t+1}^i + B_{t+1}^i = K_t^i(1-\delta) + B_t^i(1+i_t^i) + w_t^i l_t^i + r_t^i K_t^i + \Pi_t^i - \int_0^1 p_{jt}^i C_{jt}^i dj \quad (14)$$

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:

$$\upsilon \left(l_t^i\right)^{\frac{1}{\varphi}} = \lambda_t^i w_t^i, \quad \lambda_t^i = \beta\mathbb{E}[(1+r_{t+1}^i-\delta)\lambda_{t+1}^i] \quad \text{and} \quad \lambda_t^i = \beta(1+i_{t+1}^i)\mathbb{E}[\lambda_{t+1}^i] \quad (15)$$

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_{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. 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 $p^f_{jt} = 1/[1-\epsilon(C^f_t)]$ 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:

$$p^i(C^i_t) = \frac{1}{1-\epsilon(C^i_t)} \tag{16}$$

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.[31]

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:

$$L^i_t = \left[\frac{w^i_t \psi(C^i_t)}{\upsilon C^i_t p^i(C^i_t)}\right]^{\varphi} \text{ and } \frac{\psi(C^i_t)}{C^i_t p(C^i_t)} = \beta \mathbb{E}\left\{\frac{\left[1-\delta+\alpha A^i_{t+1}\left(\frac{K^i_{t+1}}{L^i_{t+1}}\right)^{\alpha-1}\right]\psi(C^i_{t+1})}{C^i_{t+1}p^i(C^i_{t+1})}\right\}$$

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

$$\Pi^h_t = \frac{\left(p^h_t - 1\right)C^h_t + (\varepsilon_t p^f_t - 1)C^f_t}{2}$$

Using this and the market clearing condition in the financial market, $B^h_t = 0$ for any t, and recognizing that trade is balanced under financial autarky, $\varepsilon_t p^f_t C^f_t = p^h_t C^h_t$, the resource constraint in the home country reads as:

[31] 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*.

$$K_{t+1}^h = K_t^h(1-\delta) + Y_t^h - \frac{C_t^h + C_t^f}{2} \tag{17}$$

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 $K_{t+1}^f = K_t^f(1-\delta) + Y_t^f - \left(C_t^h + C_t^f\right)/2$. Notice that international profit flows under monopolistic competition 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).

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:

$$TOT_t = \frac{\varepsilon_t p_t^f}{p_t^h} = \frac{1-\epsilon(C_t^h)}{1-\epsilon(C_t^f)} \tag{18}$$

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. The appreciation has the effect of further stimulating home consumption and reducing the correlation with foreign consumption. Notice that the terms of trade would be constant with CES preferences.

Finally, the consumption-based real exchange rate RER_t, defined as the ratio of home to foreign consumer prices, 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 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.

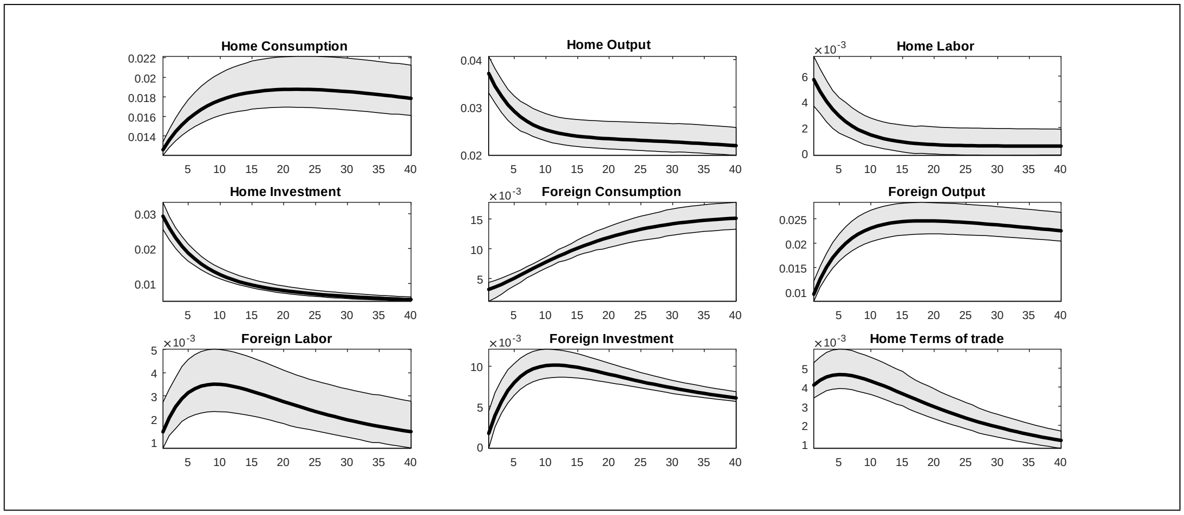

Figure 3: Bayesian impulse responses to a positive shock to Home productivity. Shaded areas are 95% confidence intervals. IES model under monopolistic competition.

4.2 Quantitative evaluation

The simulations are based on the same functional form used in the one country model (10), 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. 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 $\varphi = 3.4$.[32]

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

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

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 to increase the correlation of output across countries.

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 a relative abundance of the exported goods. The improvement in the Home terms of trade, in turn, contributes 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 4 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 cross-border profit flows, but as in the closed economy model the behavior of the CES model is independent of the parameter θ). For ease of comparison, it also reports the moments in the model with perfect competition of BKK,[33] 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 the largest.[34] 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.[35]

[33] 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.

[34] 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.

[35] A non-exhaustive list of successful candidates includes non-tradable goods, durable goods,

In our baseline model (IES preferences with monopolistic competition), the cross-correlations are all positive, and output displays the largest comovements. 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 lower for output and remains negative for investments and labor. This suggests that the variability of markups over time and across countries is key to solve the comovement and quantity puzzles.

Table 4: Second moments for the open economy (financial autarky)

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	0.78	0.88	0.15 (0.51)
I	0.10	-0.17	-0.13	-0.24	-0.31	0.22 (0.53)
L	0.39	-0.05	-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

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, therefore consumption is temporarily higher than abroad. 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 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 terms of 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 volatile than in the single country model because of the technology spillovers.

consumption habits, distribution services, capital market frictions, cointegrated TFP shocks, and firm entry. See Obstfeld and Rogoff (2000).

4.3 Intertemporal trade with non-contingent bonds

To shed further light on the propagation mechanism at work in the model, we now 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 with:

$$K^h_{t+1} - K^h_t(1-\delta) + B^h_{t+1}(1+\frac{\xi}{2}B^h_{t+1}) + \varepsilon_t B^f_{*t+1}(1+\frac{\xi}{2}B^f_{*t+1}) =$$

$$B^h_t(1+i^h_t) + \varepsilon_t B^f_{*t}(1+i^f_t) + w^h_t L^h_t + r^h_t K^h_t + T^h_t + \Pi^h_t - \int_0^1 p^h_{jt} C^h_{jt} dj \qquad (19)$$

for the home consumers, where a star subscript denotes the holdings of foreign bonds, $\xi \in (0,1)$ parametrizes the costs of adjusting the portfolio and T^i_t 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:

$$\frac{(1+i^h_{t+1})}{(1+i^f_{t+1})} = \mathbb{E}\left[\frac{\varepsilon_{t+1}}{\varepsilon_t}\right]\frac{(1+\xi B^h_{t+1})}{(1+\xi B^f_{*t+1})} = \mathbb{E}\left[\frac{\varepsilon_{t+1}}{\varepsilon_t}\right]\frac{(1+\xi B^f_{t+1})}{(1+\xi B^h_{*t+1})} \qquad (20)$$

Equilibrium in the bond market requires that home and foreign bonds be 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 constraints 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 (17), 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. For instance, in the home country this implies:[36]

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

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 5 reports the comovements for the bond economy.

Table 5: Second moments for the open economy (bond trade)
Correlations between home and foreign variables

	IES-MC	**CES-MC**	**IES-PC**	**CES-PC**
Y	0.41	0.10	-0.94	-0.92
C	0.09	0.78	0.87	0.88
I	0.09	-0.24	-0.71	-0.93
L	0.40	-0.38	0.27	0.60
p	-0.20	0	0	0

Trade in bonds is inconsequential for the performance of the baseline model: the cross-correlations and the domestic second moments (not reported in Table 5) are very similar to those under financial autarky. The bond *per se* does not seem to provide relevant means for smoothing consumption in addition to what can be achieved under financial autarky. This constitutes a substantial departure from the familiar finding that the financial autarky and the bond-trade economy behave very differently.[37] The reason is a small incentive to smooth consumption in our model because of the wealth effect brought about by the appreciation of the terms of trade. The terms of trade of the country hit by a positive shock improve (because of the decline in home markups), increasing wealth and relative consumption at home. Temporarily low (high) prices induce home (foreign) households to anticipate (postpone) consumption, therefore bond trade is exploited to anticipate consumption in the Home economy (rather than

[36] The bond market-clearing conditions 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, $\sum_{i=h,f} Y_t^i = \sum_{i=h,f} \left[C_t^i + K_{t+1}^i - K_t^i(1-\delta) \right]$.

[37] Heathcote 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.

smoothing it) and the home country runs a current account deficit. Net exports - which coincide with the change in net foreign assets - move countercyclically (the correlation with output is -0.55) as in the data.

Notice that the wealth effect works in the opposite direction in alternative models with a constant elasticity of substitution between home and foreign goods different from that between goods produced in the same country (and with constant or zero markups). In these traditional models the terms of trade of the country hit by a positive shock deteriorate, reflecting the relative abundance of the good exported by this country in the world economy. The deterioration (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 (and this explains the better performance under financial autarky stressed by Heathcote and Perri, 2002) while providing a strong incentive to smooth consumption (and this explains the difference between financial autarky and international asset trade).

The behavior of the bond economy is indeed poorer than the one under financial autarky when we shut down the wealth channel (the appreciation of the terms of trade). In our setup, this happens whenever the terms of trade are constant, namely with CES preferences or under perfect competition. The IES model with perfect competition and 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). The performance of the models with CES preferences is similar. In all these cases, international bond trade does provide a useful means for smoothing out consumption. This in turn has the usual (poor) consequences for the performance of the bond economy.

5 Conclusion

We have developed a DSGE model with endogenous markups due to preferences with a variable elasticity of substitution between differentiated goods. This implies that demand matters for the business cycle: 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.

Future research should 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 the closed economy and Ghironi and Mélitz (2005) and Cavallari (2013b) in the open economy. Finally, the open economy model could be fruitfully extended with different substitutability between goods from the same country and from different countries, which has been shown to be important for the international propagation of shocks.

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