

The Macroeconomics of Subsistence Points

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Abstract

This paper explores the macroeconomic consequences of preferences displaying a subsistence point. It departs from the existing related literature by assuming that subsistence points are specific to each variety of goods rather than to the composite consumption good. We show that this simple feature makes the price elasticity of demand for individual goods procyclical. As a result, markups behave countercyclically in equilibrium. This implication is in line with the available empirical evidence. *JEL Classification:* D10, D12, D42, E30.

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1 Introduction

There is a long literature in microeconomics, going back to the seminal work of Stone (1950) and Geary (1954), studying the role of non-homothetic preferences for the specification of demand functions. The existence of subsistence points also has macroeconomic implications. In particular, subsistence points affect the intertemporal elasticity of substitution of consumption and therefore aggregate savings. For this reason, in macroeconomic theory Stone-Geary preferences have been studied mostly for understanding the process of economic development and transitional dynamics (for recent studies, see Matsuyama 2002; and Steger, 2000). Comparatively little work has been devoted to exploring the consequences of Stone-Geary preferences for business-cycle fluctuations.

The contribution of this paper is to show that Stone-Geary preferences can have important consequences for the propagation of aggregate shocks. The novel element of our analysis is to introduce subsistence points at the level of individual varieties of goods, as opposed to at the level of aggregate consumption goods. We embed the assumption of good-specific subsistence points into an economy with imperfectly competitive product markets a la Dixit-Stiglitz.¹ Modeling subsistence points in consumption of individual goods varieties implies that the demand for individual varieties features a time-varying price elasticity. Specifically, the price elasticity of demand is procyclical. We assume that goods are supplied by monopolistically competitive firms. In setting prices, producers of individual varieties take into account the procyclicality of the price-elasticity of demand and as a result charge countercyclical markups.

The intuition behind the countercyclicality of markups in a model with good-specific subsistence points is straightforward. Under the standard Dixit-Stiglitz aggregation assumption, the demand for individual varieties is of the form $q_{it} = p_{it}^{-\eta} q_t$, where q_{it} denotes the demand for good i , p_{it} denotes the (relative) price of good i , and q_t is a measure of aggregate demand. This formulation of demand obtains either in the absence of subsistence points or when subsistence points are modeled at the level of aggregate consumption. The above demand function features a constant price elasticity equal to η . As a result, monopolistically competitive producers charge a constant markup of prices over marginal costs. When subsistence points are good specific, the demand function for good i becomes $q_{it} = p_{it}^{-\eta} (q_t - q^*) + q_i^*$. Here, q_i^* denotes the subsistence level of consumption of good i , and q^* is a constant. This demand function is the sum of an isoelastic term, $p_{it}^{-\eta} (q_t - q^*)$, with price elasticity η , and a

¹Atkeson and Ogaki (1996) also allow for goods specific subsistence points but concentrate on the implications of this assumption for the intertemporal elasticity of substitution. In particular, these authors do not consider the supply-side ramifications of good-specific subsistence points, which are at the center of our analysis.

price inelastic term, q_i^* . Thus, the price elasticity of demand is a weighted average of η and 0. The weight on the price-elastic term is determined by the importance of the price-elastic component of demand in total demand. It follows that an expansion in aggregate demand (i.e., an increase in q_t), is associated with a rise in the price elasticity of demand. Because markups are inversely related to the price elasticity, implies that Stone-Geary preferences at the level of individual goods give rise to a theory of countercyclical markups. The countercyclical behavior of markups is in line with the available empirical evidence. For a survey of this evidence, see Rotemberg and Woodford, 1999.

Countercyclical markups are potentially important for understanding the propagation of aggregate shocks. In particular, countercyclical movements in markups have important consequences for the way in which the economy is affected by aggregate demand shocks. To see this, note that the reciprocal of the markup acts as a shifter of the aggregate labor demand schedule. Hence, models with countercyclical markups have the potential to account for the empirical facts that wages and consumption rise in response to positive demand shocks. In this respect, the model with good-specific Stone-Geary preferences brings data and theory a step closer.

One may question the relevance of studying the role of subsistence points for the propagation of business cycles in developed countries on the grounds that as an economy grows, the relative importance of subsistence absorption in aggregate demand may be expected to vanish. This view is correct if subsistence points are understood in a narrow sense. That is, as referring to the minimum amount of food, clothing, and shelter necessary to sustain life. However, a broader interpretation of necessities would include those dictated by social norms. A luxury in a poor society, such as tap water, inside plumbing, and health care are considered necessities in developed countries. Thus, it is conceivable that subsistence points might be appropriately modeled as an increasing function of long-run measures of output. In this case, non-homotheticities in preferences may remain relevant for understanding business cycle fluctuations even for economies traveling along a stable development path.

The remainder of the paper is organized in 3 sections. Section 2 presents the model. Section 3 discusses the business-cycle implications of the model. Section 4 concludes.

2 The Model

The basic structure of the model is the standard real-business-cycle model augmented with a monopolistically competitive structure of product markets a la Dixit-Stiglitz. The innovation of the model is to assume the existence of subsistence consumption at the level of individual varieties as opposed to at the level of the composite good and the combination of this aspect

with monopolistic competition.

2.1 Households

Consider an economy populated by a continuum of identical households with preferences described by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(x_t^c - v_t, h_t), \quad (1)$$

where x_t^c denotes consumption of a composite good, h_t denotes labor effort, and v_t denotes an exogenous and stochastic preference shock following a univariate autoregressive process of the form

$$v_t = \rho_v v_{t-1} + \epsilon_t^v,$$

with $\rho_v \in [0, 1)$ and ϵ_t^v distributed i.i.d. with mean zero and standard deviation σ_v . This shock is meant to capture innovations to the level of private non-business absorption.

The composite consumption good x_t^c is composed of a continuum of differentiated goods indexed by $i \in [0, 1]$. Specifically, x_t^c is assumed to be given by

$$x_t^c = \left[\int_0^1 (c_{it} - c_i^*)^{1-1/\eta} di \right]^{1/(1-1/\eta)}, \quad (2)$$

where c_i^* denotes the subsistence level of consumption of good i . The demands for individual varieties are the solution to the dual problem of minimizing consumption expenditure, given by $\int_0^1 P_{it} c_{it} di$, where P_{it} denotes the nominal price of good i , subject to the aggregation constraint (2) given x_t^c . The resulting demand for any variety i is of the form

$$c_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\eta} x_t^c + c_i^*, \quad (3)$$

where $P_t \equiv \left[\int_0^1 P_{it}^{1-\eta} di \right]^{\frac{1}{1-\eta}}$, is a nominal price index. The presence of a good-specific subsistence point alters the demand function implied by the Dixit-Stiglitz aggregator in a fundamental way. For in the presence of good-specific subsistence points, the price elasticity of demand is no longer constant. Now the demand function is the sum of an isoelastic term, $(P_{it}/P_t)^{-\eta} x_t^c$, and a price inelastic term, c_i^* . The price elasticity of demand is therefore a weighted average of the elasticity of the isoelastic term, η , and the elasticity of the inelastic term, 0. Thus, the price elasticity of demand is no larger than η . This implies that the presence of good-specific subsistence points increases the market power of the monopolistically

competitive producers of good i . More importantly, the price elasticity of demand is time varying and increasing in aggregate demand. This is because the weight on the isoelastic component increases with x_t^c , which is a measure of aggregate demand. In other words, in expansions subsistence points affect aggregate demand relatively less than in recessions. The procyclicality of the price elasticity of demand is the basic element driving the result that in equilibrium markups are countercyclical.

Households are assumed to own physical capital. The capital stock held by the household, denoted k_t , is assumed to evolve over time according to the following law of motion

$$k_{t+1} = (1 - \delta)k_t + x_t^i, \quad (4)$$

where x_t^i denotes investment in period t . Investment is a composite good produced using a continuum of differentiated goods via the following technology:

$$x_t^i = \left[\int_0^1 (i_{it} - i_i^*)^{1-1/\eta} di \right]^{1/(1-1/\eta)}. \quad (5)$$

Here, $i_i^* > 0$ denotes a minimum level of good-specific investment required to produce new capital goods. We introduce this feature to maintain symmetry across the various components of aggregate absorption. In this way, we isolate the effects of good specific price-inelastic demands on the dynamic behavior of markups. Assuming alternatively that $i_i^* = 0$ implies that shocks to the economy not only changes the price elasticity of consumption demand but also the weight of the components of aggregate demand that are subject to time-varying price elasticity. Here we choose to focus of the former of these effects, i.e. $i_i^* > 0$.

For any given levels of x_t^i , purchases of each variety $i \in [0, 1]$ in period t must solve the dual problems of minimizing total investment expenditure, $\int_0^1 P_{it} i_{it} di$, subject to the aggregation constraint (5). The optimal level of i_{it} for $i \in [0, 1]$ is then given by

$$i_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\eta} x_t^i + i_i^*. \quad (6)$$

At the optimum, we have that $P_t x_t^i = \int_0^1 P_{it} (i_{it} - i_i^*) di$.

At the beginning of each period $t \geq 0$, households rent their stock of capital to firms at the rate u_t . Households are assumed to have access to complete contingent claims markets. Let $r_{t,t+j}$ denote the stochastic discount factor such that $E_t r_{t,t+j} z_{t+j}$ is the period- t price of a random payment z_{t+j} in period $t + j$. In addition, households are assumed to be entitled to the receipt of pure profits from the ownership of firms, Φ_t . Then, the representative

household's period-by-period budget constraint can be written as

$$x_t^c + x_t^i + \psi_t + E_t r_{t,t+1} d_{t+1} = d_t + w_t h_t + \Phi_t + u_t k_t, \quad (7)$$

where $\psi_t \equiv \int_0^1 P_{it}/P_t(c_i^* + i_i^*) di$. The variable w_t denotes the real wage rate. In addition, households are assumed to be subject to a borrowing constraint that prevents them from engaging in Ponzi games. The household's problem can then be stated as consisting of choosing processes x_t^c , h_t , x_t^i , d_{t+1} , and k_t , so as to maximize the lifetime utility function (1) subject to (4), (7), and a borrowing constraint that prevents it from engaging in Ponzi-type schemes, given processes v_t , ω_t , w_t , $r_{t,t+1}$, u_t , and Φ_t . The optimality conditions associated with this problem are (4), (7), a transversality condition, and

$$\begin{aligned} -\frac{U_h(x_t^c - v_t, h_t)}{U_x(x_t^c - v_t, h_t)} &= w_t \\ U_x(x_t^c - v_t, h_t) &= \beta E_t U_x(x_{t+1}^c - v_{t+1}, h_{t+1}) [1 - \delta + u_{t+1}] \\ U_x(x_t^c - v_t, h_t) r_{t,t+1} &= \beta U_x(x_{t+1}^c - v_{t+1}, h_{t+1}) \end{aligned}$$

The above 3 optimality conditions are identical to those arising from the standard neoclassical model. Note, however, that the presence of subsistence points also affects the intertemporal elasticity of substitution in consumption as well as the intratemporal elasticity of substitution between consumption and leisure. These effects are the same in our model as in models that assume subsistence points at the level of aggregate consumption.

2.2 The Government

Each period $t \geq 0$, nominal government spending is given by $P_t g_t$. We assume that real government expenditures, denoted by g_t , are exogenous, stochastic, and follow a univariate first-order autoregressive process of the form

$$\ln(g_t/\bar{g}) = \rho_g \ln(g_{t-1}/\bar{g}) + \epsilon_t^g,$$

where the innovation ϵ_t^g is assumed to be distributed as an i.i.d. process with mean zero and standard deviation σ_g . The government allocates spending over individual varieties of goods, g_{it} , so as to maximize the quantity of a composite good produced with differentiated varieties of goods according to the relationship

$$x_t^g = \left[\int_0^1 (g_{it} - g_i^*)^{1-1/\eta} di \right]^{1/(1-1/\eta)}.$$

The parameters g_i^* denote good-specific levels of subsistence consumption of public goods. As in the case of investment demand, good-specific subsistence levels of government consumption is introduced to preserve symmetry in the specification of aggregate demand. Later, we will also consider the case $g_i^* = 0$ for all i . The government's problem consists in choosing g_{it} , $i \in [0, 1]$, so as to maximize x_t^g subject to the budget constraint $\int_0^1 P_{it}g_{it} \leq P_t g_t$. The resulting government demand for each differentiated goods $i \in [0, 1]$ is

$$g_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\eta} x_t^g + g_i^*, \quad (8)$$

where

$$x_t^g = g_t - \int_0^1 \frac{P_{it}}{P_t} g_i^* di.$$

Public spending is assumed to be fully financed by lump-sum taxation.

2.3 Firms

Each good $i \in [0, 1]$ is manufactured by a monopolist using labor and capital as inputs via the following production technology:

$$y_{it} = A_t F(k_{it}, h_{it}) - \phi, \quad (9)$$

where y_{it} denotes output of good i , k_{it} and h_{it} denote services of capital and labor, and ϕ denotes fixed costs of production. While we assume that F is homogeneous of degree one, the presence of fixed costs introduces increasing returns to scale in the production technology. We include fixed costs to ensure that profits are relatively small on average as is the case for the U.S. economy in spite of equilibrium markups of price over marginal cost significantly above zero. The variable A_t denotes an aggregate technology shock. We assume that the logarithm of A_t follows a first-order autoregressive process

$$\ln A_t = \rho_a \ln A_{t-1} + \epsilon_t^a, \quad (10)$$

where ϵ_t^a is a white noise disturbance with standard deviation σ_a .

Firms are price setters. In exchange, they must stand ready to satisfy demand at the announced prices. Formally, firm i must satisfy

$$A_t F(k_{it}, h_{it}) - \phi \geq c_{it} + i_{it} + g_{it}, \quad (11)$$

where c_{it} , i_{it} , and g_{it} are given by equations (3), (6), and (8), respectively.

Firm i 's problem consists of choosing processes $p_{it} \equiv P_{it}/P_t$, c_{it} , g_{it} , i_{it} , h_{it} , and k_{it} , so as to maximize the present discounted value of profits, which is given by

$$E_0 \sum_{t=0}^{\infty} r_{0,t} [p_{it}(c_{it} + i_{it} + g_{it}) - w_t h_{it} - u_t k_{it}], \quad (12)$$

subject to (3), (6), (8), and (11), given processes $r_{0,t}$, w_t , u_t , A_t , x_t^c , x_t^g , and x_t^i . Letting $x_t = x_t^c + x_t^g + x_t^i$, $x_t^* = c_t^* + c_t^g + c_t^i$, and mc_{it} denote the Lagrange multiplier on constraint (11), the first-order conditions associated with the firm's problem are equations (3), (6), (8), (11), and

$$\begin{aligned} mc_{it} &= \frac{w_t}{A_t F_h(k_{it}, h_{it})} \\ mc_{it} &= \frac{u_t}{A_t F_k(k_{it}, h_{it})} \\ \frac{p_{it}}{mc_{it}} &= \left[1 - \frac{1}{\eta(1 - x_t^*/y_{it})} \right]^{-1} \end{aligned}$$

The first two of these optimality conditions simply state that the marginal cost of producing good i equals the factor price divided by its marginal product.

The third optimality condition contains the essence for why the model with good-specific subsistence points provides a theory of countercyclical markups. It relates the markup of prices over marginal costs, p_{it}/mc_{it} , to the price elasticity of demand, $\eta(1 - x_t^*/y_{it})$. In the absence of subsistence points, $x_t^* = 0$, the price elasticity of demand is constant and equal to η . As a result, in this case the markup is also time invariant and equal to $\eta/(\eta - 1)$. In the economy with subsistence points, $x_t^* > 0$, the price elasticity is increasing in sales, y_{it} , and therefore the markup is decreasing in this variable.²

2.4 Symmetric Equilibrium

For simplicity we assume that the level of subsistence of each component of absorption is invariant across varieties. That is, $c_i^* = c^*$, $g_i^* = g^*$, and $i_i^* = i^*$, for all varieties $i \in [0, 1]$. As in much of the related literature, we restrict attention to symmetric equilibria in which all firms charge the same price. It follows that in equilibrium the relative price of each variety, p_{it} , equals unity. It also follows that we can drop the subscript i from all variables. Moreover, in equilibrium $x_t^c = c_t - c^*$, $x_t^i = i_t - i^*$, and $x_t^g = g_t - g^*$. A stationary symmetric equilibrium is then given by stationary stochastic processes k_{t+1} , h_t , w_t , u_t , y_t , c_t , i_t , and μ_t satisfying equations (13)-(19) given in the appendix, given the stochastic processes describing v_t , A_t ,

²Had we assumed the absence of subsistence points in investment or in government spending, the composition of aggregate demand would enter this expression.

g_t , and the initial condition k_0 .

3 The Cyclical Behavior of Markups

From the optimality conditions of the firm, it is straightforward to see that the equilibrium markup, which we denote by μ_t , is given by

$$\mu_t = \left[1 - \frac{1}{\eta(1 - x^*/y_t)} \right]^{-1}.$$

Clearly, because the subsistence level of absorption, x^* , is necessarily less than total absorption, y_t , it follows immediately that for a given value of η , the equilibrium markup is larger than the markup that would obtain in the absence of subsistence absorption, given by $\eta/(\eta - 1)$.³ Furthermore, it is clear that, given x^* , the larger is the level of aggregate activity, y_t , the smaller is the markup. In other words, the markup is countercyclical. Intuitively, this effect is brought about by the fact that an increase in aggregate demand makes subsistence points less important and therefore increases the price elasticity faced by producers. The issue is then how important this effect is. Letting ϵ_t^μ denote the elasticity of the equilibrium markup with respect to aggregate demand, we have that

$$\epsilon_t^\mu = - \frac{x^*/y_t}{(1 - x^*/y_t) [\eta(1 - x^*/y_t) - 1]} < 0.$$

Under the maintained assumption that the price elasticity of demand exceeds unity, the output elasticity of the markup is negative. Table 1 illustrates how the size of the markup and the elasticity of the markup change as the share of subsistence absorption in total output increases from 0 to 0.8. In the table we assume that η takes a value of 6. The table shows that for low values of the markup the income elasticity of the markup is quite small. For example, in the extreme case when subsistence demand accounts for 50 percent of total absorption, the equilibrium markup is 50 percent, a high value given the available empirical evidence. Nevertheless, the output elasticity of the markup is only 0.5, which means that a 1 percent increase in output lowers the markup by less than 1 percentage point, from 50 to 49.25 percent. Thus, it appears that although this model has the potential of generating countercyclical markups, the elasticity of the markup to output is moderate for realistic values of the steady-state markup.

³For the individual firm's problem to be well defined, it must be the case that the price elasticity is greater than one, that is, it must be the case that $\eta(1 - x^*/y_t) > 1$. In what follows we will assume that this condition is satisfied.

Table 1: The Markup and the Output Elasticity of the Markup as Functions of the Share of Subsistence Absorption

x^*/y_t	μ_t	ϵ_t^μ
0	1.2	0
0.1	1.23	-0.03
0.2	1.26	-0.07
0.3	1.31	-0.13
0.4	1.38	-0.26
0.5	1.5	-0.5
0.6	1.71	-1.07
0.7	2.25	-2.91
0.8	6.0	-20.0

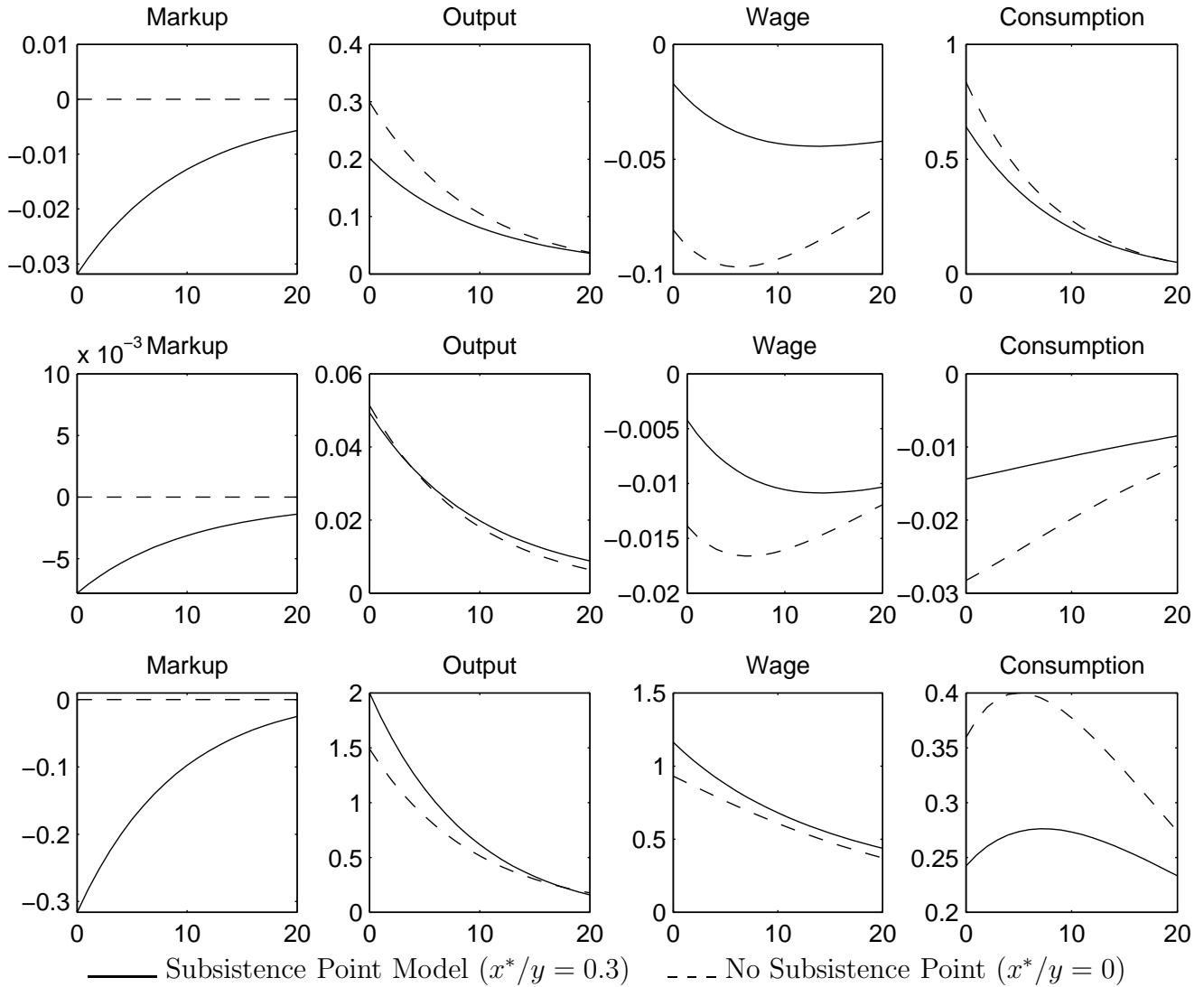
Note: x^* denotes subsistence absorption, y_t denotes aggregate demand, μ_t denotes the gross markup, and ϵ_t^μ denotes the elasticity of the markup with respect to aggregate demand. The parameter η is assumed to be 6.

Figure 1 displays impulse responses to preference, government spending, and productivity shocks. The calibration of the model follows Ravn, Schmitt-Grohé, and Uribe (2004). We set the share of subsistence absorption in total absorption to 30 percent ($x^*/y = 0.3$). In this case the average markup equals 37 percent. Table 2 displays the values assigned to the remaining deep structural parameters of the benchmark economy. This economy is shown with solid lines in the figure. For comparison, we include with broken lines, the response of an economy without subsistence absorption ($x^*/y = 0$).

The model economy without subsistence absorption exhibits no movements in markups. We note that in an economy with subsistence points at the level of aggregate absorption (as opposed to at the level of each variety of goods) markups are also constant along the business cycle. This is because in this case the demand functions faced by the monopolistic producers of each variety are price isoelastic.

By contrast, in the economy with good-specific subsistence points the markup responds countercyclically to all 3 shocks. However, quantitatively the predicted markup movements are small. In particular, the decline in markups in response to demand shocks is not strong enough to overturn the negative response of wages. The reason why wages decline less in the model with good-specific subsistence points than in the model without this feature is that changes in the markup affect the aggregate labor demand curve. Specifically, the demand for labor takes the form $w_t = A_t F_h(k_t, h_t)/\mu_t$. So a decline in the markup shifts the demand schedule out. Thus, when the markup is countercyclical its effect on the demand for labor

Figure 1: Impulse Responses to Positive Preference, Government Spending, and Productivity Shocks



Row 1: Preference Shock. Row 2: Government Spending Shock. Row 3: Technology shock. Impulse responses are measured in percent deviations from steady state. Horizontal axes display the number of quarters after the shock.

Table 2: Calibration

Symbol	Value	Description
β	0.9902	Subjective discount factor
σ	2	Inverse of intertemporal elasticity of substitution
c^*	0.064	subsistence level of consumption
g^*	0.011	subsistence level of public consumption
i^*	0.016	subsistence level of investment
α	0.25	capital elasticity of output
δ	0.01	Quarterly depreciation rate
η	5.3	Elasticity of substitution across varieties
ϵ_{hw}	1.3	Frisch elasticity of labor supply
h	0.2	Steady-State fraction of time devoted to work
\bar{g}	0.0367	Steady-state level of government purchases
ϕ	0.1129	Fixed cost
ρ_v, ρ_g, ρ_a	0.9	Persistence of exogenous shocks

is similar to the effect of positive productivity shocks. Rotemberg and Woodford (1992) show that in U.S. postwar data wages increase in response to demand shocks in the form of innovations in public consumption. They use this feature of the data to judge the empirical plausibility of various models of the business cycle.

In the model without good-specific subsistence points, an increase in government purchases is associated with a decline in private consumption. This effect is a consequence of a negative wealth effect caused by the increase in unproductive government spending. In the economy with good-specific subsistence points, consumption also falls in response to the increase in public absorption, but by less than in the economy with homothetic preferences. The reason is that in the economy with good-specific absorption the decline in markups leads to a smaller fall in wages which causes a substitution effect toward consumption and away from leisure. This substitution effect is not sufficiently strong to offset the negative wealth effect. As a result, consumption falls. This prediction of the model brings theory and data a step closer. For available evidence suggests that positive government purchases shocks are associated with expansions in private consumption (see, e.g., Galí et al., 2003; and Blanchard and Perotti, 2002).

4 Conclusion

This paper demonstrates that the simple introduction of subsistence points at the level of individual goods in the context of an otherwise quite standard dynamic general equilibrium

model gives rise to a theory countercyclical markups. The resulting theory contributes to understanding two important aspects of the data, namely, the cyclical behavior of real wages and private consumption in response to government spending shocks. In effect, the standard neoclassical model implies a strong negative correlation between wages and aggregate spending, originating in negative wealth effects associated with unproductive public spending. The countercyclicality of markups induces expansions in the demand for labor during booms and the reverse during contractions, thereby reducing the tendency for wages and government spending to move in opposite directions.

While the model with Stone-Geary preferences at the level of individual varieties represents a step in the right direction, it leaves much ground to be covered. In particular, like other theories of endogenous markups, the good-specific subsistence point model faces a steep tradeoff between the level of the markup and the elasticity of the markup with respect to output. The higher the markup, the higher the output elasticity of the markup. For realistic markup levels the subsistence point model implies a relatively small elasticity, which limits the model's ability to explain the observed wage and consumption dynamics in response to demand shocks. Alleviating the level-elasticity tradeoff of markups is an important challenge for future research.

Appendix

Stationary Competitive Equilibrium: A stationary symmetric equilibrium is a set of stationary stochastic processes k_{t+1} , h_t , w_t , u_t , y_t , c_t , i_t , and μ_t satisfying

$$-\frac{U_h(c_t - c^* - v_t, h_t)}{U_x(c_t - c^* - v_t, h_t)} = w_t \quad (13)$$

$$U_x(c_t - c^* - v_t, h_t) = \beta E_t U_x(c_{t+1} - c^* - v_{t+1}, h_{t+1}) [1 - \delta + u_{t+1}] \quad (14)$$

$$A_t F(k_t, h_t) - \phi = c_t + i_t + g_t \quad (15)$$

$$k_{t+1} = (1 - \delta)k_t + i_t - i^* \quad (16)$$

$$\frac{F_h(k_t, h_t)}{F_k(k_t, h_t)} = \frac{w_t}{u_t} \quad (17)$$

$$\mu_t = \left[1 - \frac{1}{\eta(1 - x^*/y_t)} \right]^{-1} \quad (18)$$

$$y_t = c_t + g_t + i_t \quad (19)$$

given stochastic processes v_t , A_t , g_t , and the initial condition k_0 .

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