A Business Cycle Model with Neuroeconomic Foundations

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Abstract

In standard business cycle models (Woodford, 2003; Galí, 2015), agents use sophisticated dynamic optimization techniques to decide how much to consume and how long to work. I present a new business cycle model in which decision-making follows a simpler mental process motivated by neuroeconomics (Fehr and Rangel, 2011). Agents compute the value of two different options and choose the option with the highest value, but with errors. The model is highly tractable and intuitive. Although most predictions are in line with standard models, a demand function replaces the Euler equation. As a result, consumption is not excessively smooth, forward guidance is not overly powerful, and government spending or supply shocks do not have surprising effects at the zero lower bound.

1 Introduction

In standard business cycle models (Woodford, 2003; Galí, 2015), agents decide how much to consume and how long to work by maximizing an intertemporal objective function under a resource constraint. The dynamic optimization techniques that they use to solve this problem seem much more sophisticated than the simple thinking that guides our everyday decisions. In this paper, I present a new business cycle model in which decision-making is instead constrained to follow a simple mental process motivated by neuroeconomics (Fehr and Rangel, 2011).

Decision makers first compute the value of two different options and then choose the option that offers the highest value, but with errors. For example, consumers decide

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whether to buy one unit of good or not. They like to consume but they dislike spending their money because of a thrift motive. Then, a lower price, a higher wealth, and a lower thrift increase demand. Similarly, producers decide whether to produce one unit or not. They like to sell their goods but dislike the effort required for production. A higher price and a lower cost of effort increase supply.

The model yields standard predictions, suggesting that the restrictions on the decision-making process are relatively innocuous. For example, monetary and fiscal policy can affect output in the short run but not in the long run. This is because producers are not able to immediately adjust their prices to unexpected demand shocks (Keynesian equilibrium). In the long run, however, prices adjust until producers reach their desired level of production (neoclassical equilibrium).

Furthermore, the model is highly tractable and intuitive. The results are easily derived in closed form. The equilibrium can be represented in an ordinary supply-demand diagram.

The main difference with standard models is that a demand function replaces the Euler equation. This first implies that consumers do not excessively smooth their consumption (Jappelli and Pistaferri, 2010) and policies that increase their income (e.g. a helicopter drop of money) can thus stimulate the economy. Even liquid consumers can have a high marginal propensity to consume, consistent with several empirical studies (Jappelli and Pistaferri, 2014; Fagereng et al., 2016; Olafsson and Pagel, 2017). By contrast, standard models typically resort to hand-to-mouth or illiquid consumers to increase the sensitivity of consumption to income shocks (Campbell and Mankiw, 1989; Kaplan and Violante, 2014).

Second, the interest rate does not affect consumption through the conventional intertemporal substitution motive.[1] Instead, it only affects consumer debt, through the cost of borrowing. Consistent with this implication, Gross and Souleles (2002) find a significant effect of the interest rate on consumer debt while Cloyne et al. (2016) find no

[1]Alternatively, consumers may not pay attention to the interest rate (Maćkowiak and Wiederholt, 2015; Gabaix, 2017a,b).

effect on the consumption of outright homeowners.[2]

Third, forward guidance only works to the extent that it affects the current interest rate and thus the cost of borrowing. By contrast, the Euler equation in standard models implies that consumers overreact to far-future interest rates, a prediction referred to as the *forward guidance puzzle* (Carlstrom et al., 2015; Del Negro et al., 2015; McKay et al., 2016).[3]

Fourth, the zero lower bound does not make negative supply shocks expansionary (Eggertsson, 2010, 2012; Eggertsson et al., 2014; Wieland, 2017) nor does it inflate government spending multipliers (Christiano et al., 2011; Woodford, 2011). These predictions arise in standard models because negative supply shocks or higher government spending increase expected inflation. At the zero lower bound, the resulting lower real interest rate stimulates consumption. These effects vanish in the present model because consumers do not respond to expected inflation.[4]

The agents are forward-looking, even though they do not behave according to the Euler equation. For example, they can perfectly anticipate a future tax increase and deduct it from their current wealth. I show that the Ricardian equivalence then holds. Furthermore, I present an extension in which agents explicitly compute how their decisions today impact their future utility. Like the Euler equation, their demand function then depends on expected inflation and the interest rate. The model is flexible and could easily be extended in many other directions.

2 Decision-Making

This section introduces the simple mental process that agents will follow when making decisions. The process integrates several insights from neuroeconomics and has been

[2]Mortgagors and renters, however, do adjust their spending to changes in the interest rate, presumably because they are liquidity constrained and not because of intertemporal substitution. See Cloyne et al. (2016) for more details.

[3]The puzzle can also be solved by extending standard models with bounded rationality (García-Schmidt and Woodford, 2015; Farhi and Werning, 2017; Gabaix, 2017b), or imperfect information (Angeletos and Lian, 2017; Wiederholt, 2017; Andrade et al., 2018).

[4]There is yet no consensus on the sign of the relationship between inflation expectations and consumer spending (Burke and Ozdagli, 2013; Bachmann et al., 2015; Crump et al., 2015; Ichiue and Nishiguchi, 2015; DAcunto et al., 2018).

applied to a wide range of economic decisions (Fehr and Rangel, 2011). The brain of the decision maker computes a value for each option available. This value integrates information about the attributes of each option and their attractiveness. Finally, the brain makes errors when comparing the values of the different options. As a result, decisions are noisy, that is, the decision maker does not always make the same decision even if his preferences and the environment remain unchanged.

Decision makers choose between different options that differ along several dimensions indexed by i. The value v of option x is then equal to the weighted average of the value of each dimension $d_i(x)$, that is:

$$v(x) = \sum_i \alpha_i d_i(x),$$

where α_i is the weight attached to dimension i.

The agent then chooses the option with the highest value but with some error. If there are two options, x and y, the individual then compares $v(x)$ to $v(y)$. He chooses x if:

$$v(x) - v(y) > \epsilon,$$

where ϵ is a random variable drawn from the cumulative distribution function F, that has a mean of 0 and is identically and independently distributed. Thus, choice is stochastic. The probability of choosing x is $F[v(x) - v(y)]$. The more attractive x is relative to y, the higher the probability of choosing x.

Note that this decision-making process abstracts from several dimensions relevant to neuroeconomics, such as the dynamic process of evidence accumulation that leads to stochastic choice (Woodford, 2016; Fudenberg et al., 2017), the distinction between experienced and predicted utility (Caplin and Leahy, 2001; Caplin and Dean, 2008), or time-inconsistent preferences in consumption-saving decisions (Laibson, 1997; Gul and Pesendorfer, 2004; Loewenstein and O'Donoghue, 2004; Benhabib and Bisin, 2005; Amador et al., 2006; Krusell et al., 2010).

3 Demand

Demand is captured by individual consumption-saving decisions. The model aims to capture the following simple tradeoff. Consumers like consuming but dislike spending because of a thrift motive.

Within a period, a continuum 1 of consumers receives a continuum 1 of consumption opportunities. For each consumption opportunity, a consumer decides whether to consume 1 unit or not. Consuming yields utility u while not consuming yields utility 0. Consuming also decreases the monetary wealth w (measured at the beginning of each period) by the price p while not consuming leaves the wealth intact. The ratio $-p/w$ measures the extent to which wealth is reduced. The disutility attached to a reduction in wealth is $-\sigma p/w$, where σ measures thrift. Consuming hurts thriftier consumers more. A higher price and a lower wealth make consuming less attractive. When wealth approaches 0, the disutility of consumption becomes infinite.

The value attached to consuming is $u-\sigma p/w$ while the value attached to not consuming is 0. Consumers choose the option that yields the highest value but they make errors in the process. They decide to consume if $u - \sigma p/w > \epsilon$. As a result, the probability of consumption is $F(u - \sigma p/w)$.

Since there is a continuum 1 of consumers, the aggregate demand is equal to the probability of consumption

$$D = F(u - \sigma p/w).$$

Since F is increasing, the aggregate demand D increases with wealth w and utility u, and decreases with the price p and thrift σ.

Comparison with standard models Overall, this demand function has standard properties. It replaces the Euler equation in standard models, that relates consumption growth to the discount rate, the interest rate, and expected inflation. This difference arises because consumers have a different objective function. First, they do not explicitly consider the implications of the consumption decisions on their future consumption. Instead, thrift implicitly captures the concerns about future consumption. Second, consumers face a discrete choice and not a continuum. This implies that the utility of consumption is simply captured by a utility parameter instead of the traditional concave utility function.

Link with Euler equation It is possible to extend the model with explicit intertemporal concerns to generate a demand function that looks more like an Euler equation. Consumers may realize that when they decide not to consume, they save the price p and could potentially derive the additional utility $\alpha p(1+r)u'/p'$ in the next period, where α is a parameter governing the strength of the intertemporal concerns, r is the interest rate, p' is the future price, and u' is the discounted utility of future consumption. Thus, they decide to consume if $u - \alpha p(1+r)u'/p' - \sigma p/w > \epsilon$. The decision to consume now depends on future prices, the interest rate and the discount factor, in a way similar to the Euler equation. For simplicity, I abstract from these explicit intertemporal concerns in the rest of the paper.

Marginal propensity to consume (MPC) Compared to standard models, consumers have a weaker consumption smoothing motive and thus can have a high MPC. The MPC tells us how much consumer spending increases following an increase in wealth of one monetary unit. It is given by $MPC = \partial pD/\partial w = f(u - \sigma p/w)\sigma p^2/w^2$, where f is the probability density function associated with F. For simplicity, assume that f is constant (uniform distribution).[5] The model can predict a wide range of MPCs depending on parameter values. In particular, the MPC increases with the level of thrift σ and decreases with wealth w. The intuition is that not so thrifty or wealthy consumers already have exhausted most of their consumption opportunities and a higher wealth can thus only have a minimal impact. Abstracting for now from general equilibrium considerations, this implies that policies that increase the wealth of consumers (e.g. a fiscal transfer or a helicopter drop of money) can effectively stimulate the economy. The main difference with standard models is that the MPC can be large, even when consumers are liquid. Several empirical studies support this prediction (Jappelli and Pistaferri, 2014;

[5]More generally, the results are unchanged if we assume a hump-shaped density function centered in 0 and focus on the case of a desirable consumption opportunity, that is, $u > \sigma p/w$.

Olafsson and Pagel, 2017; Fagereng et al., 2016). By contrast, the strong smoothing motive in standard models forces the MPC to stay close to 0, unless consumers are illiquid or hand-to-mouth (Campbell and Mankiw, 1989; Kaplan and Violante, 2014).

Forward-looking So far, consumers do not need to think explicitly about the future. In a richer environment, however, they may need to be more forward-looking. A simple way to do this is to broaden the concept of wealth, which is so far just the stock of money. For example, consumers may subtract higher future taxes from their current wealth (see section 8). More generally, wealth could also depend on asset prices, expected career path, bequests, retirement, etc. Each of these components of wealth could affect consumption-saving decisions. I leave these extensions to future research.

4 Supply

The production decisions determine the supply side of the economy. Each period, a continuum 1 of producers (who are the same individuals as the consumers) face a continuum 1 of production decisions. Producers tradeoff the cost of providing effort e against the benefit pu/P of selling their product at price p, where P is the average price in the economy. Producers then decide to produce if $pu/P - e > \epsilon$, that is, with probability $F(pu/P - e)$. The probability of production increases with the individual price p and with the utility of consumption u, and decreases with the average price P and with the cost of effort e. This individual supply decision is similar in spirit to the optimality condition related to labor supply in standard business cycle models.

Since there is a continuum 1 of producers and since all producers and goods are symmetric, we have $p = P$ and the aggregate supply is given by:

$$S = F(u - e).$$

The aggregate supply is increasing in the utility u and decreasing in the cost of effort e. It is independent of the level of prices P.

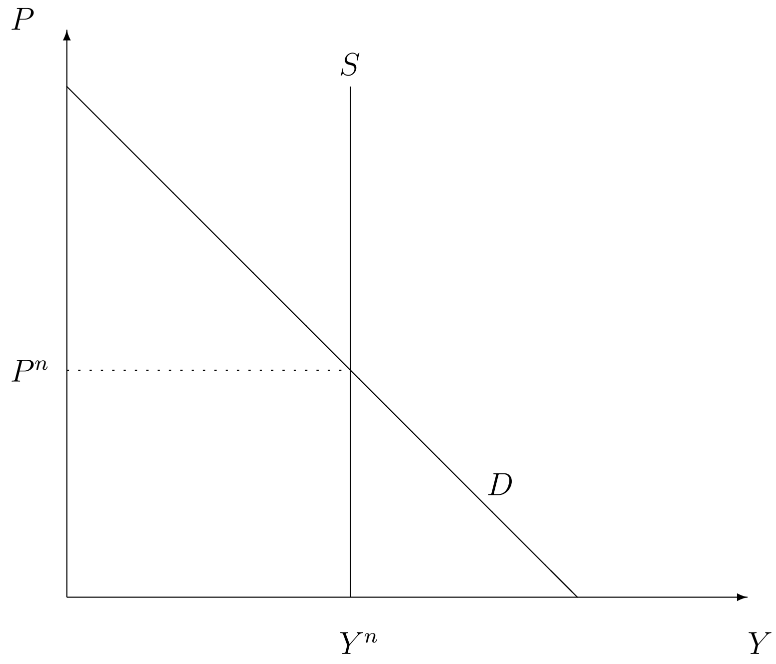

Figure 1: Equilibrium

5 Neoclassical Equilibrium

The neoclassical equilibrium is defined by a price P^n and output Y^n such that supply is equal to demand $S = D$. Since the supply S is independent of prices, the equilibrium output is:

$$Y^n = F(u - e).$$

The equilibrium condition $S = D$ implies $F(u - \sigma P^n/w)c = F(u - e)$ and yields the equilibrium price:

$$P^n = ew/\sigma.$$

It is increasing in wealth w and in the cost of effort e, and it decreasing in thrift σ.

Figure 1 graphically represents the supply and demand functions. The equilibrium is represented by the intersection of these two lines.

In equilibrium, consumers spend P^nY^n and earn P^nY^n as producers within the same period. As a result, their wealth w stays constant.

An increase in the wealth w of consumers (e.g. helicopter drop of money) increases demand. This effect is represented in Figure 2 by a switch from D_1 to D_2. Equilibrium

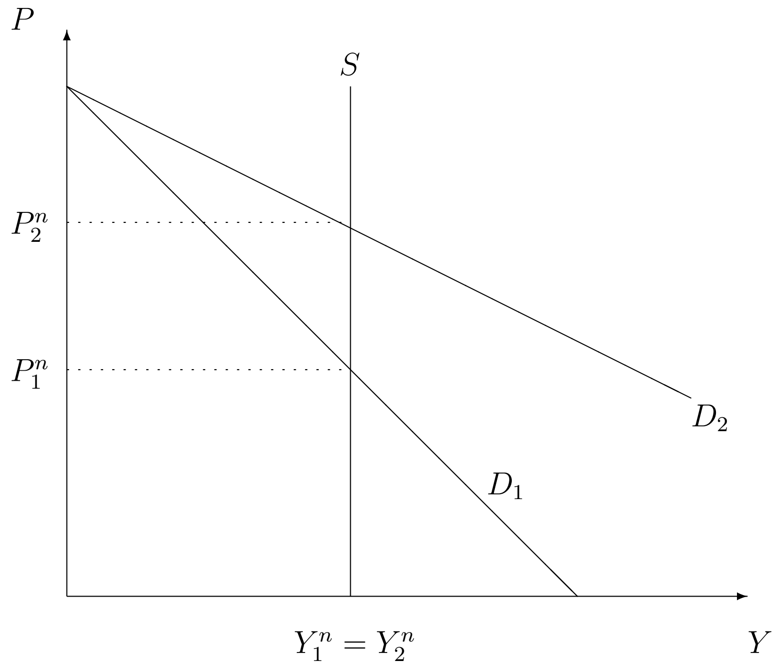

Figure 2: New equilibrium when demand increases from D_1 to D_2 (lower thrift or higher wealth)

prices increase. The higher price motivates producers to increase supply. However, since all prices increase at the same time, producers do not receive additional benefit from selling their products and are thus not willing to provide more effort. As a result, the equilibrium production stays constant.

A lower thrift σ also increases demand. This effect can also be represented in Figure 2 by a switch from D_1 to D_2. Equilibrium prices increase while production stays constant. This experiment has a similar interpretation as the paradox of thrift (Keynes, 1936; Eggertsson and Krugman, 2012). Consumers become thriftier and thus want to save more. Since all consumers spend less at the same time, their earnings decrease. Thus, they do not save more even though they spend less.

A higher productivity (a lower e) increases supply. This effect is represented in Figure 3 by a switch from S_1 to S_2. Producers are willing to provide more effort given the price they receive for their output. Output thus increases. Since demand does not change, equilibrium prices have to decrease.

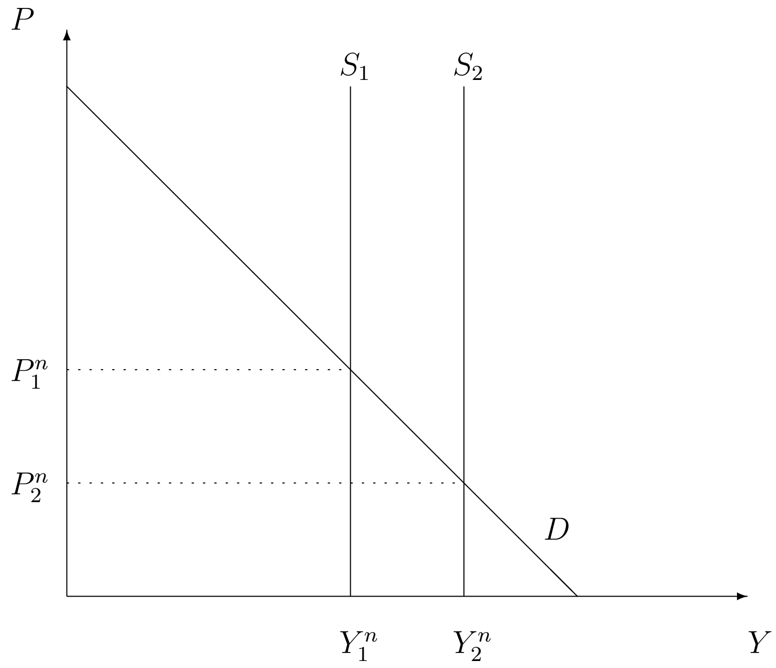

Figure 3: New equilibrium when supply increases from S_1 to S_2 (higher productivity)

6 Keynesian Equilibrium

I now study a Keynesian equilibrium that is useful to study how the economy responds in the short run to an unexpected shock.

Like in standard New Keynesian business cycle models, the main difference with the neoclassical world is that prices are rigid in the short run and that producers may not be able to adjust their prices to match their desired level of production. Producers first post a price p such that the expected demand for their product at this price $D(p)$ corresponds to their desired level of production $S(p)$. An unexpected demand shock may hit the economy after prices have been posted, resulting in a realized demand $\tilde{D}(p)$. (An unexpected supply shock does not affect the Keynesian equilibrium.) To ensure that markets clear, producers have to satisfy this realized demand even if it does not correspond to their desired level of production.

Because goods and producers are identical, all goods trade at the same price $p = P$. This implies that the desired level of production is $F(u - e)$.

The Keynesian equilibrium is defined by a price P^k and output Y^k such that expected demand is equal to the desired supply $D(P^k) = F(u - e)$ and such that the realized demand at this price is satisfied, that is, $Y^k = \tilde{D}(P^k)$. The first condition is the same condition as in the neoclassical equilibrium, so the equilibrium price is the same:

$$P^k = P^n = ew/\sigma.$$

The equilibrium level of output is then

$$Y^k = \tilde{D}(ew/\sigma).$$

If the realized demand is equal to the expected demand $\tilde{D} = D$, the Keynesian and the neoclassical equilibria coincide.[6] This case is represented in Figure 4.

An unexpected demand shock $\tilde{D} \neq D$ (e.g. a surprise change in thrift or wealth) introduces a difference between the Keynesian and the neoclassical equilibrium output. An unexpected positive demand shock increases output in the Keynesian equilibrium while a negative unexpected shock decreases it. The case of surprise drop in demand is illustrated in Figure 5.

7 Monetary Policy

I now introduce a simple credit market to introduce a more realistic form of monetary policy that shifts the interest rate. With probability γ, consumers are illiquid. They do not have enough liquidity to finance their consumption opportunity. The illiquidity may arise, for example, because of an unspecified timing mismatch between income and spending. To solve this liquidity problem, the consumer can borrow at the interest rate r. To keep things simple, I assume that there is no default.

The consumer then has to pay the price p with probability $1 - \gamma$ and $p(1 + r)$ with

[6] Unlike standard New Keynesian models, the price-making assumption does not enable producers to charge a markup over the marginal cost and thus does not distort output. The reason is that all the goods are similar and thus trade at the same price.

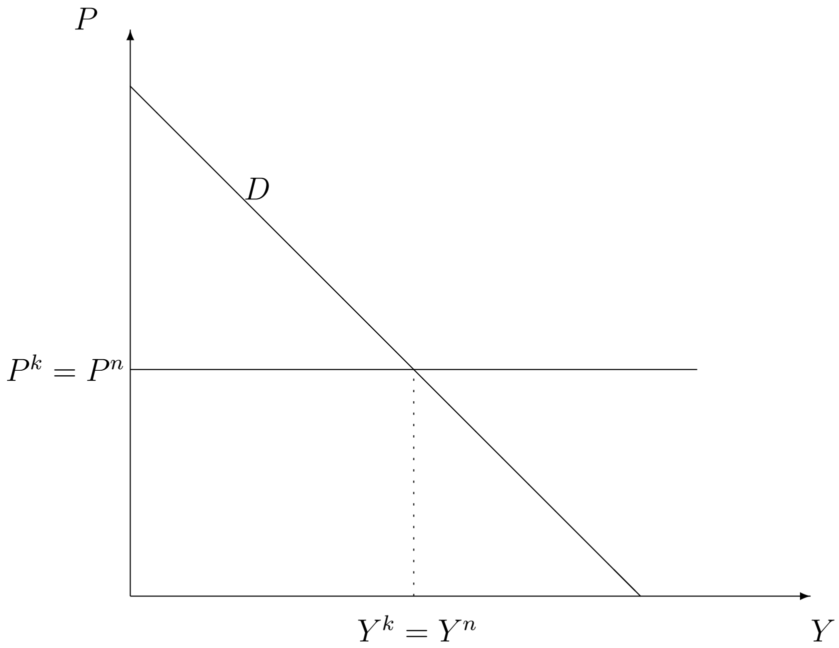

Figure 4: Keynesian equilibrium

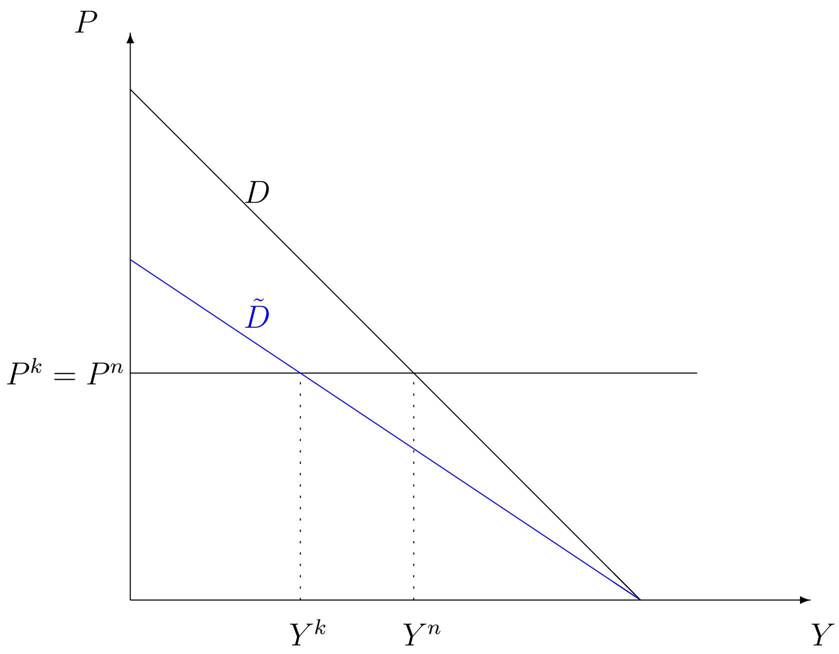

Figure 5: Keynesian equilibrium with unexpected demand shock

probability γ. Aggregate demand becomes

$$D = \gamma F(u - \sigma p(1+r)/w) + (1-\gamma)F(u - \sigma p/w).$$

It depends negatively on the price p, the interest rate r and illiquidity γ.

Since consumers suffer from illiquidity equally from all goods, we still have in equilibrium that all goods trade at the same price, that is, $p = P$. This implies that the equilibrium output is unaffected by the presence of a credit market and is still equal to

$$Y^n = F(u - e).$$

To find the equilibrium price, we again use the neoclassical equilibrium condition $S = D$, which implies $\gamma F(u - \sigma p(1+r)/w) + (1-\gamma)F(u - \sigma p/w) = F(u - e)$. To find a closed form solution, we assume that F is uniform and that the solution is interior. This yields:

$$P^n = \frac{ew}{\sigma(1+\gamma r)}.$$

The equilibrium price depends negatively on illiquidity γ and on the interest rate r. A higher interest rate makes it more expensive to buy the good and thus decreases its demand. The equilibrium price then decreases. For a given interest rate r, a higher degree of illiquidity means that consumers will more often have to finance their consumption with credit. Since credit increases the cost of buying the good, it also decreases demand and thus the equilibrium price. If consumers are never illiquid ($\gamma = 0$) or if the interest rate is equal to 0, the equilibrium price is the same as in the benchmark model.

We can also study the Keynesian equilibrium. The central bank unexpectedly changes the interest rate from r to $\tilde{r}$. As before, the equilibrium price is unaffected, that is, we have

$$P^k = P^n = \frac{ew}{\sigma(1+\gamma r)}.$$

The Keynesian equilibrium level of production is now equal to the realized demand

$\tilde{D}$ at the posted price P^k:

$$Y^k = F(u - \frac{1+\gamma r}{1+\gamma \tilde{r}} e).$$

If the central bank implements the expected level of interest rate $\tilde{r} = r$, then the equilibrium output is equal to its neoclassical level. If the central bank unexpectedly increases (decreases) the interest rate, the Keynesian equilibrium level of output is higher (lower) than the neoclassical level.

Note that everybody lends and borrows the same amount, so the introduction of a financial market does not affect wealth accumulation. It still stays constant and the same for everyone.

Comparison with standard models Although monetary policy has the same consequences as in standard models, it works differently. In standard models, the interest rate affects consumption through the Euler equation. Consumers realize that if they spend less today, they can save more, receive interests on these additional savings, and thus consume more tomorrow. A lower interest rate then makes it less profitable to postpone consumption and thus increases consumption today. By contrast, a lower interest rate in this model works through a more straightforward cost of borrowing motive and only has an effect on consumption when consumers have to borrow to finance their consumption. Consistent with this implication, Gross and Souleles (2002) find a significant effect of changes in the interest rate on consumer debt. By contrast, Cloyne et al. (2016) find that outright homeowners do not adjust their spending following an interest rate shock. Mortgagors and renters do adjust their spending, presumably because they are more liquidity-constrained and not because of intertemporal substitution.

Forward guidance Finally, the model solves the forward guidance puzzle (Del Negro et al., 2015; McKay et al., 2016). In standard models, the Euler equation implies that the consumption response to a future change in the interest rate does not depend on how far in the future this change will occur. This puzzling implication is absent in the present model simply because there is no Euler equation. Naturally, forward guidance works to the extent that it decreases the interest rate and thus the cost of borrowing.

Zero lower bound The presence of a zero lower bound for the interest rate naturally restricts the effectiveness of conventional monetary policy. In standard models, policy makers can alternatively resort to policies that increase expected inflation and thus decrease the real interest rate. Such policies include restrictive supply-side policies (Eggertsson, 2010, 2012; Eggertsson et al., 2014; Wieland, 2017) or higher government spending (Christiano et al., 2011; Woodford, 2011). In the present model, these policies do not work because consumer debt does not respond to expected inflation. This is because consumers care about the ratio of their interest expenses to their monetary wealth, which is a real object and is thus unaffected by prices.

8 Fiscal Policy

I now introduce a government. The government buys G goods from all producers and levies lump-sum taxes $T = PG$.

To find the neoclassical equilibrium, we use the new market clearing condition $S = D + G$. Government spending does not affect the supply decisions of producers:

$$Y^n = F(u - e).$$

The equilibrium price is then given by $F(u-e) = F(u - \sigma p/w) + G$. To find a closed form solution, I assume that F is uniform with support $[-a, a]$ and that the solution is interior. This yields:

$$P^n = (e + g)w/\sigma,$$

with $g = G/2a$.

Government spending does not affect the neoclassical level equilibrium output in this model. The additional demand, however, naturally increases equilibrium prices. The government spending multiplier $\partial Y^n/\partial G$ is thus equal to 0. Government spending perfectly crowds out private consumption. The reason is that producers are providing the level of effort they desire and respond to a higher demand by increasing prices. Since all prices increase at the same time, the producers are not willing to provide more effort.

In the Keynesian equilibrium, however, government spending can have real consequences. Producers now post the price $P^k = P^n$. If the government implements a surprise change in government spending, then producers will have to adjust their production to the new demand without being able to immediately adjust their price. Let $\tilde{G}$ be the realized level of government spending. Then, the Keynesian equilibrium level of production is given by.

$$Y^k = Y^n + \tilde{G} - G.$$

A surprise change in government spending moves output one for one. Output is now equal to its neoclassical level plus the difference between the realized level of government spending and its expected level. The spending multiplier is 1.

Government spending is financed by raising lump sum taxes equal to government spending. Agents now earn additional income from the government but have to pay the same amount in taxes, so their wealth still stays constant.

Comparison with standard models The results on the government spending multiplier are in line with the literature. For example, Woodford (2011) also obtains a multiplier equal to 1 in an analytically simple New Keynesian model. In the neoclassical case, he finds a multiplier that is between 0 and 1 while I find it to be 0. However, his multiplier converges to 0 as his utility function becomes more linear, which would be the case the most similar to the present environment.

Ricardian equivalence Alternatively, the government may finance its additional spending by borrowing on the credit market. Assume the government spends G and issues debt $D = PG$ to finance this spending. At some future period, the government raises taxes $T' = D(1+r)$ to repay its debt. If consumers include these future additional taxes in the measurement of their wealth and discount them at the interest rate r, then the wealth of consumers and thus their demand remain the same whether the government uses taxes or debt to finance its spending. That is, the Ricardian equivalence holds. Of course, if consumers are myopic and fail to anticipate these future higher taxes, then the increase in government spending temporarily increases their wealth and thus their demand.

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