Demand Shocks as Productivity Shocks*

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Abstract

We provide a macroeconomic model where *demand* for goods has a productive role. A search friction prevents perfect matching between potential customers and producers, and larger demand induces more search, which in turn increases output in the economy. Consequently, when viewed through the lens of a standard neoclassical aggregate production function, an increase in demand will appear as an increase in the Solow residual. We estimate the model using standard Bayesian techniques, allowing for business cycles being driven by both preference shocks – which we interpret as shocks to demand – and true technology shocks. Technology shocks account for less than 18% of the fluctuations in output and the measured Solow residual. Our model also provides a novel theory for important macroeconomic variables such as the relative price of consumption and investment, Tobin's Q, and capacity utilization.

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1 Introduction

In the standard neoclassical model, output is a function of inputs such as labor and capital. There is no explicit role for *demand* because (Walrasian) prices will adjust so that all produced goods will be utilized. In reality, customers and producers must meet in order for the produced good to be consumed, so value added depends on how well they are matched. As an example, consider a restaurant. According to neoclassical theory, the output of a restaurant should be a function of its employees, buildings, tables, and raw material, irrespective of market conditions. However, the restaurant's production takes place only when customers show up to buy meals. The more customers who demand the restaurant's meals, the more will be served and the larger the value added will be. Thus, the demand for goods plays a direct role. The spirit of this example extends to many forms of production: dentists need patients, car dealers need shoppers, all producers need buyers.

This paper provides a theory where search for goods – which we sometimes refer to as *demand* – has a productive role. The starting point is that potential customers search for producers, and a standard matching friction prevents standard market clearing, in the neoclassical sense that all potential productive capacity translates into actual value added. Clearly, for households and firms, the acquisition of goods is an active process that involves costs not measured in the National Income and Product Accounts (NIPA). Technically, we resolve the search friction by building on the competitive search model (Moen, 1997). Firms post prices and customers trade off good prices versus congestion when searching for the goods: prices are higher for goods that are easier to find.

Allowing such an explicit role for demand has direct implications for business cycle analysis, especially for our understanding of the driving factors of business cycles. A striking consequence of the type of demand-driven business cycle model we propose is that changes in demand will increase output even if inputs, and the intensity with which they are used, remain constant. If viewed through the lens of a standard neoclassical aggregate production function that ignores demand, an increase in demand would imply an increase in total factor productivity (TFP). Thus, a preference shock that boosts consumption will also show up as a shock to the Solow residual. This mechanism reverses the direction of causation relative to the neoclassical model: there, a true technology shock would increase TFP which, in turn, would increase consumption and investment. Interestingly, aggregate data for the US suggest that it is factors influencing consumption that drives TFP, rather than TFP driving consumption. In particular, aggregate consumption turns out to Granger cause TFP, while TFP does not Granger cause aggregate consumption.[1]

The purpose of this paper is to show how our notion of demands shocks works in terms of driving the Solow residual and to quantify how important this mechanism can be for aggregate fluctuations, compared to standard technology shocks. To clarify our main argument, we start by analyzing a simple Lucas-tree version of our economy with search for goods (henceforth, the "shopping economy"). We show that shocks to *preferences* – which is our notion of demand shocks – can generate fluctuations in measured TFP in this economy. We then embed the search friction in an otherwise standard stochastic neoclassical growth model, where there is shopping for both consumption goods and investment goods. In line with the example above, we assume that goods and productive capacity cannot be stored, so those that are not found are lost.[2]

We allow for the possibility that business cycles can be driven both by demand shocks that influence the search for goods and by true technology shocks. In particular, we consider shocks that affect consumption and investment demand (via shocks to the search cost for consumption and investment goods and in some cases the discount factor), and shocks to the marginal rate of substitution (MRS) between consumption and leisure. Technology shocks are included so as to foster comparisons between the standard RBC model and our more general shopping economy. The model is estimated using Bayesian estimation techniques targeting time series for output, consumption, hours, and the measured Solow residual to tease out the contribution of each of those shocks to the variance of aggregate variables.

The Bayesian estimation chooses shocks so as to maximize the probability of the observed aggregate time series. One of our main findings is that it is necessary to attribute a much larger role to demand shocks than to productivity shocks in order to match the data: demand shocks to consumption and investment account for 47% of the variance of output, the shock to the MRS for 38%, and the technology shock for a mere 15% of the variance of output. It follows that the technology shock accounts for only a negligible share of the fluctuations in the Solow residual, even though the Solow residual fluctuates as it does in the data. According to our estimated model, what appears as technology shocks from the perspective of a standard neoclassical growth model,

[1] The Granger test was done with HP-filtered quarterly U.S. data, Q1 1960 to Q4 2009, with the Solow residual calculated by assuming a Cobb-Douglas production function with a labor share of 2/3. The p-value of TFP causing consumption is 0.6, while the p-value for consumption causing TFP is 0.002.

[2] The model can be interpreted literally as a model for services. However, the model is also relevant for standard manufacturing goods. When searching for goods, households and investors trade off search efforts with a possibly less than perfect match (delivery delays, settling for an imperfect substitute for the desired variety, etc.). Efforts to obtain the best goods matches are arguably important.

are increases in resource utilization arising from more effective search on the part of consumers and investors.

Summing up, our paper proposes a model that implements the widely held notion that shocks to demand can give rise to business cycle fluctuations. This is done by extending a standard neoclassical framework with a search friction for goods. The role for demand is intrinsic to the process of production and is not arbitrarily imposed: markets clear and no agent has incentives to deviate. There is a long tradition of attributing a role for demand in business cycle analysis, starting with Keynes' theories. However, in none of the earlier approaches has demand had a directly productive role. One popular alternative business cycle framework where demand shocks have real effects is the New Keynesian model. To achieve a role for demand in that model, it is necessary to force agents to trade at prices that are not equilibrium prices, in the sense that agents would, ex post, prefer to change the prices and quantities in order to achieve better allocations. A virtue of our search-based model is that the equilibrium allocation is efficient and demand shocks can have real effects without imposing such involuntary trades.

Our paper has several additional contributions. First, we show how in models with production and competitive search, achieving optimality requires indexing markets, not only by price and market tightness but also by the quantity of the good traded. Second, we provide a theory of the cyclical changes of the relative prices of investment and consumption goods that is not based on exogenous technology shocks.[3]. Third, we provide a theory of endogenous capacity utilization, different from the early capacity utilization literature. Fourth, we provide a theory of stock market movements associated not with capital adjustment costs, shocks to productivity, or production costs, but rather with aggregate demand and with how well firms can match up with customers.

Our exercise of exploring endogenous sources of Solow residual fluctuations is related to the capacity utilization literature. For example, Greenwood, Hercowitz, and Huffman (1988), Kydland and Prescott (1988), Bils and Cho (1994), Basu (1996), and Licandro and Puch (2000) consider variable capital utilization, and Burnside, Eichenbaum, and Rebelo (1993) introduce variable worker utilization in the form of labor hoarding during periods of low aggregate activity. In periods during which productivity and/or profits are high, firms will use the input factors more intensively, so that the measured Solow residual response is much larger than the underlying true technology shock. Moreover, Wen (2004) argues that with variable capacity utilization, preference shocks that change the desired timing of consumption will cause changes in the utilization of input factors and, hence,

[3] See, for example, Krusell, Ohanian, Ríos-Rull, and Violante (2000) and Fisher (2006) for papers that use exogenous technical shocks as the source of changes in the relative price of investment.

changes in the measured Solow residual.[4]

The mechanism for generating endogenous fluctuations in TFP in the variable capacity utilization literature is quite different from the search-based theory we explore in this paper. The variable capacity utilization model and, more generally, the neoclassical model, have a stark common implication: Market clearing and flexible prices implies that there are no idle resources. As long as the marginal revenue of inputs is positive, all resources will be in use, albeit possibly at low intensity.[5] If not, prices would immediately adjust to restore market clearing for the inputs. However, in reality, every shop has workers idle part of the time, and in every restaurant some tables are empty for at least part of the night. Why would the owners not adjust prices so that all resources come in use? Our answer is that due to a search friction, some resources would, in equilibrium, be idle even if prices are fully flexible. The reason is that search is costly, so it would be inefficient to have so much search that all potential goods get matched with consumers.[6]

Our paper is also related to Petrosky-Nadeau and Wasmer (2011), which is developed independently from our paper. They also model costly search for goods in final goods markets and study how this search interacts with search in the labor market and influences the business cycle properties of the model. Rudanko and Gourio (2011) study a business cycle model with a search friction in the market for consumption goods. Firms form long-lasting relationships with customers, and the authors focus on the role of customers as capital. Our contribution is also related to several papers emphasizing the effects of search frictions in shaping TFP (Alessandria (2005), Faig and Jerez (2005), and Lagos (2006)), although none of these focus on business cycles.

Finally, some papers examine, as we do, how demand changes affect productivity and capacity utilization, although through very different mechanisms. In Fagnart, Licandro, and Portier (1999), monopolistic firms with putty-clay technology are subject to idiosyncratic demand shocks, which causes fluctuations in capacity utilization. In Floetotto and Jaimovich (2008), changes in the number of firms cause changes in markups and, hence, changes in the measured Solow residual. Swanson (2006) shows that government expenditure shocks can increase aggregate output, consumption, and investment in a model with heterogeneous sectors.

[4] Incidentally, when included explicitly in estimated DSGE models, the variable utilization of capital is attributed a quantitatively small role in terms of driving business cycles (cf. Smets and Wouter 2007).

[5] One exception is Cooley, Hansen, and Prescott (1995). They assume an indivisibility in labor supply at the plant level, combined with plant-specific technology shocks. Thus, plants which experience very negative technology shocks will be left idle.

[6] An alternative approach would be to assume that for some (ad-hoc) reason, prices are fixed, as in the New Keynesian models. As discussed above, markets do not necessarily clear in those models, so resources could be idle.

The paper is organized as follows. Section 2 lays out the main mechanism in a simple Lucas-tree version of the economy where we show how increases in demand are partially accommodated by an increase in productivity via more search and by an increase in prices, whereas in the original Lucas (1978) model, all the adjustment occurs in prices. The full business cycle model is analyzed in Section 3. We then map the model to data in Section 4. In Section 5 we analyze the properties of the model when restricting attention to univariate shock processes (one shock at a time) and when we have only demand shocks. In Section 6 we estimate the full model with various shocks simultaneously to gauge their relative contribution. In Section 7 we explore other implications of the model, such as the relative price of investment, asset prices, and capacity utilization. Section 8 concludes, and an Appendix provides the proofs, additional tables, and computational and data details.

2 Competitive search for goods in a Lucas-tree model

We start by illustrating the workings of the model in a simple search model where output is produced by trees instead of capital and labor. We show that the search process has an impact on aggregate output in a way that appears as a level effect on the Solow residual. In an example we show how shocks to preferences are accommodated partly by increases in prices and interest rates and partly by increases in quantities, and demonstrate that absent the search friction, the same shocks translate only to price increases.

2.1 Technology and preferences

There is a continuum of trees (i.e., suppliers) with measure $T = 1$. Each tree yields one piece of fruit every period. A standard search friction makes it difficult for consumers to find trees. To overcome this friction, the consumer sends out a number of shoppers to search for fruit. The aggregate number of fruits found, Y, is given by the Cobb-Douglas matching function:

$$Y = A\, D^{\varphi}\, T^{1-\varphi}, \tag{1}$$

where D is the aggregate measure of shoppers searching for fruit (we sometimes call it aggregate demand) and A and φ are parameters of the matching technology.

Following Moen (1997), we assume a competitive search protocol where agents can choose to search in specific locations indexed by both the price and market tightness, defined as the ratio of trees per shopper, $Q = T/D$. The probability that a tree is found (i.e., matched with a shopper) is $\Psi_T(Q) = A\ Q^{-\varphi} = A\ D^{\varphi}/T^{\varphi}$. Once a match is formed, then the fruit is traded at the posted price p. By the end of the period, all fruit that is not found is lost. The trees pay out sales revenues as dividends and the expected dividend is $\varsigma = p\Psi_T(Q)$.

The economy has a continuum of identical, infinitely lived households of measure one. Their preferences are given by

$$E\left\{\sum_t \beta^t\ u\left(c_t, d_t, \theta_t\right)\right\}, \tag{2}$$

where c_t is consumption, d_t is the measure of shopping units (search effort) by the household, and θ is a preference shock that follows a stochastic Markov process. The probability that an individual shopping unit is successful is given by the ratio of matches to the aggregate number of shoppers. Given the matching technology (1), this can be expressed in terms of market tightness as $\Psi_d(Q) = A\ Q^{1-\varphi}$, so c_t is given by

$$c = d\ \Psi_d(Q) = d\ A\ Q^{1-\varphi}. \tag{3}$$

Trees are owned by households and are traded every period. We normalize the price of the tree to unity and use it as the numéraire good. Let s denote the number of shares owned by the household. The aggregate number of shares is unity. Consequently, with identical households the aggregate state of the economy is just θ, whereas the individual state also includes individual wealth s.[7] The representative household problem can then be expressed recursively as

$$v(\theta, s) = \max_{c,d,s'} u\left(c, d, \theta\right) + \beta\ E\left\{v(\theta', s')|\theta\right\} \tag{4}$$

$$\text{s.t.} \quad c = d\ \Psi_d[Q(\theta)] \tag{5}$$

$$P(\theta)\ c + s' = s\ [1 + \varsigma(\theta)]. \tag{6}$$

It is easy to see that the original Lucas (1978) economy is a special case of our model where $\varphi = 0$ and $A = 1$.

[7]Throughout the paper, we take advantage of the perfect correlation between the idiosyncratic and aggregate shocks to preferences, and we write only one of them as a state variable.

2.2 Competitive search in the market for goods

There are differentiated markets indexed by the price and market tightness (number of trees or firms per shopper). Let ς denote the outside value for firms of going to the most attractive market, yet to be determined. Clearly a market can attract trees only if it offers them at least ς. This constrains the feasible combinations of prices and market tightness that shoppers can offer:

$$\varsigma \leq \; p\, \Psi_T(Q). \tag{7}$$

The expected contribution to household utility of a shopper that chooses the best price–tightness pair is[8]

$$\Phi = \max_{Q,p} \left\{ u_d\,(\theta, s) \; + \; \Psi_d(Q) \; \left(u_c\,(\theta, s) \; - \; p\; \widehat{m}\right)\right\} \qquad \text{s.t.}\;\; \varsigma \leq \; p\, \Psi_T(Q), \tag{8}$$

where $u_d\,(\theta, s)$ and $u_c\,(\theta, s)$ are the marginal utility of increases in d and c, respectively. Moreover, $\widehat{m} = m[\theta, s'(\theta, s)]$ is the expected discounted marginal utility of an additional unit of savings:

$$m\,(\theta, s') = \beta\; E \left\{ \frac{P(\theta)\;[1 + \varsigma(\theta')]}{P(\theta')} \; \frac{\partial v\,(\theta', s')}{\partial s'} \middle| \, \theta \right\}.$$

Solve (8) by substituting (7) at equality and take the first-order condition w.r.t. Q. This yields the unique equilibrium price p and value of the tree ς as functions of market tightness Q:

$$p \;=\; (1-\varphi)\; \frac{u_c\,(\theta, s)}{\widehat{m}}, \tag{9}$$

$$\varsigma \;=\; pA\; Q^{-\varphi}. \tag{10}$$

2.3 Equilibrium

A *competitive search equilibrium* is defined by a set of individual decision rules, $c(\theta, s)$, $d(\theta, s)$, and $s'(\theta, s)$, the aggregate allocations $D(\theta)$ and $C(\theta)$, good prices $P(\theta)$, and the rate of return on trees $\varsigma(\theta)$ so that

1. The individual decision rules, $c(\theta, s)$, $d(\theta, s)$, and $s'(\theta, s)$ solve the household problem (4).

[8] To derive this, take the first-order condition of (4) with respect to d and consider the price-tightness posting problem when the cost $\overline{u}_d$ of sending an additional shopper has been borne. The idea is that each shopper is equipped with a credit card and if no fruit is found, then utility is not affected over and above the sunk search cost.

2. The individual decision rules are consistent with the aggregate functions

$$C(\theta) = c(\theta, 1) \qquad D(\theta) = d(\theta, 1) \qquad s'(\theta, 1) = 1.$$

3. Shoppers and firms search optimally in the market for goods, i.e., $(p(\theta), Q(\theta), \varsigma(\theta))$ satisfy the search conditions (9) and (10), where market tightness is $Q(\theta) = 1/D(\theta)$.

4. The goods market clears:

$$C(\theta) = A\, D(\theta)^{\varphi}. \tag{11}$$

The competitive search equilibrium and its efficiency properties can then be characterized by the following proposition.

Proposition 1. *1. Aggregate search D is determined by the functional equation*

$$0 = \varphi\, A\, D(\theta)^{\varphi-1}\; u_c\left[A\, D(\theta)^{\varphi}, D(\theta), \theta\right] + u_d\left[A\, D(\theta)^{\varphi}, D(\theta), \theta\right]. \tag{12}$$

The functions C, Q, and ς then follow directly from the equilibrium conditions $C(\theta) = A\, D(\theta)^{\varphi}$, $Q(\theta) = 1/D(\theta)$, and $\varsigma(\theta) = p(\theta)\; A\, D(\theta)^{\varphi}$.

2. The equilibrium price is defined by the functional equation

$$u_c\left[C(\theta), D(\theta), \theta\right] = \;\beta\, E\left\{\frac{P(\theta)\,\left[1+\varsigma(\theta')\right]}{P(\theta')}\; u_c\left[C(\theta'), D(\theta'), \theta'\right] \mid \theta\right\}. \tag{13}$$

3. The competitive equilibrium is efficient.

The proof of the first two items is straightforward: simply derive the first-order conditions of households and combine them with the competitive search conditions (see the Appendix for details). For efficiency, we consider a planner solving $\max_{C,D}\{u(C, D, \theta)\}$ subject to the aggregate resource constraint $C = A\, D^{\varphi}$. The solution to equation (12) solves this planner problem, which establishes efficiency. Interestingly, the Euler equation (13) is the same as the one in the standard Lucas tree model.

We now turn to our focus, the measured total factor productivity Z, which is defined as $C = Z\; T$. The Solow residual Z is a function of the search effort and fluctuates in response to preference shocks. A direct application of the equilibrium formulation of aggregate consumption from Proposition 1 and $T = 1$ yields the following corollary:

Corollary 1. *In equilibrium, the Solow residual is a function of preference shocks and given by*

$$Z(\theta) = A \ (D(\theta))^{\varphi} . \tag{14}$$

2.4 An example

Consider now an example which can be solved analytically. The purpose is to illustrate how preference shocks that increase the desire to consume are accommodated in part by an increase in the price of consumption today relative to consumption later and in part by an increase in search effort that translates into squeezing more output out of the economy, thereby making it more productive.

Let preferences be given by

$$u\left(c, d, \theta\right) = \theta_c \ \log c \ - \ d,$$

where θ_c is independently and identically distributed with $E\left\{\theta_c\right\} = 1$ and $\theta_c > 0$. Given these preferences, the equilibrium conditions (12) and (11) yield the following equilibrium allocations:

$$D(\theta) = \varphi \ \theta_c, \qquad C\left(\theta_c\right) = A \ \varphi^{\varphi} \ \ \theta_c^{\varphi}.$$

It is straightforward to verify that the equilibrium price and interest rate (in terms of the consumption good) are

$$P(\theta) = \left(\frac{1}{\beta} - 1\right) \frac{1}{A\varphi^{\varphi}} \ \theta_c^{1-\varphi}, \qquad\qquad 1 + r(\theta) = \frac{\theta_c^{1-\varphi}}{\beta \ E\left\{(\theta_c')^{1-\varphi}\right\}}.$$

An increase in the desire to consume today translates into an increase in consumption proportional to the shock to the power of φ and an increase in the gross interest rate proportional to the shock to the power of $1 - \varphi$. As $\varphi \to 0$, the shopping economy converges to the standard Lucas tree model. In this case, aggregate consumption is invariant to the demand shock, and all the adjustment to the shock takes place through prices.

3 The stochastic growth model version of the economy

We now extend the search model to an otherwise standard growth model suitable for quantitative business cycle analysis. We add capital, which requires for its installation both investment goods and professionals to shop for those goods, and a disutility of working. We start with describing technology and preferences. We then analyze the problems faced by households and firms, and study price determination in the presence of competitive search for consumption and investment goods. Along the way, we prove a few results that guarantee that all firms make the same choices of labor and investment. We also establish that the equilibrium is Pareto optimal. Finally, we discuss how the labor share and the Solow residual can be estimated using NIPA data.

3.1 Technology

There is a unit measure of firms. Each firm has a "location," i.e., equivalent to the tree in Section 2. The firm has a certain amount of capital installed in that location. There is a technology that transforms capital and labor services into goods that is described by a standard (differentiable and strictly concave) production function $f(k, n)$. To install new capital for the following period, the firm, like the households, has to shop. The firm has a technology that transforms one unit of labor (that cannot be used for production) into ζ shopping units.

As in Section 2, we assume a competitive search protocol in specific locations. Markets are indexed by a triplet (Q, P, F) of market tightness, price, and the quantity of the good produced, which in turn is a function of the firm's pre-installed capital stock and labor. Recall that the quantity produced was not part of the variables indexing markets in the simple Lucas-tree model.

At the beginning of each period, there could potentially be a distribution of firms with different pre-installed capital, perhaps specializing in the consumption or investment good. We proceed by guessing and verifying below that if firms have the same capital today, they choose the same capital for tomorrow. This approach allows us to look only at a representative firm and thus drastically reduce the state space of the economy from a distribution of firms to an aggregate level of capital. To simplify our presentation of the problems of firms and households, we use (θ, K), the preference shock and aggregate capital, to denote the state of the economy. Choosing the same capital stock, firms may, however, choose to produce different goods – consumption or investment goods – and charge different prices and market tightness. In equilibrium, there are two markets, one for consumption with index (Q^c, P^c, F^c) and one for investment with index (Q^i, P^i, F^i). These goods are identical from the viewpoint of production but not from the viewpoint of search and prices.

The share of firms producing consumption goods is given by $T(\theta, K)$.

As in Section 2, the matching technology is Cobb-Douglas indexed by A and φ: $A\, D^{\varphi}\, T^{1-\varphi}$.

3.2 Households

There is a measure one of households who have preferences over consumption c, shopping d, and working n and who are affected by preference shocks θ perfectly correlated across households. This is summarized in the utility function $u(c, d, n, \theta)$.

The state variable for the household is the state of the economy (θ, K) and the individual wealth, i.e., the number of shares s. The households take a number of aggregate variables as given: market tightness Q^c, price P^c, and quantity F^c in the consumption good market, the rate of return, the wage, and the law of motion of capital denoted $G(\theta, K)$. These objects are equilibrium functions of the state variable (θ, K).

Household problem The representative household solves

$$v(\theta, K, s) = \max_{c,d,n,s'} u(c, d, n, \theta) + \beta\, E\left\{v(\theta', K', s')|\theta\right\} \tag{15}$$

$$\text{s.t.} \quad c = d\, \Psi_d[Q^c(\theta, K)]\, F^c(\theta, K), \tag{16}$$

$$P^c(\theta, K)\, c + s' = s\, [1 + R(\theta, K)] + n\, w(\theta, K), \tag{17}$$

$$K' = G(\theta, K). \tag{18}$$

Equation (16) shows that consumption requires the household's shopping effort, but it also depends on market tightness and the amount produced by consumption-producing firms. Equation (17) is the budget constraint in terms of shares.

The solution to this problem is a set of individual decision rules $d(\theta, K, s)$, $c(\theta, K, s)$, $n(\theta, K, s)$, and $s'(\theta, K, s)$. Anticipating equilibrium conditions, we introduce the aggregate counterparts of these functions:

$$C(\theta, K) = c(\theta, K, 1) \tag{19}$$

$$D^c(\theta, K) = d(\theta, K, 1) \tag{20}$$

$$N(\theta, K) = n(\theta, K, 1) \tag{21}$$

$$s'(\theta, K, 1) = 1. \tag{22}$$

The last condition stems from the fact that stock market shares are the only asset in positive net supply and the equilibrium condition that these shares add up to unity. Abusing notation, we use these aggregate conditions to write marginal utility as a function only of aggregate state variables yielding $u_c(\theta, K) = u_c\left[C(\theta, K), D(\theta, K), N(\theta, K), \theta\right]$. Using these aggregate conditions, the stochastic discount factor can be expressed as

$$\Pi(\theta, \theta', K) = \beta \frac{P^c(\theta, K)}{P^c(\theta', G(\theta, K))} \; \frac{u_c\left[\theta', G(\theta, K)\right] + \frac{u_d\left[\theta', G(\theta, K)\right]}{\Psi_d\left[Q^c(\theta', G(\theta, K))\right] \; F^c(\theta', G(\theta, K))}}{u_c(\theta, K) + \frac{u_d(\theta, K)}{\Psi_d\left[Q^c(\theta, K)\right] \; F^c(\theta, K)}}. \tag{23}$$

So the intertemporal Euler becomes

$$1 = E\left\{\left[1 + R(\theta', G(\theta, K))\right] \Pi(\theta, \theta', K) \;\mid \theta\right\}, \tag{24}$$

while the intratemporal first-order condition is

$$u_c(\theta, K) + \frac{u_d\left(\theta, K\right)}{\Psi_d\left[Q^c(\theta, K)\right] \; F^c(\theta, K)} = u_n\left(\theta, K\right) \; \frac{P^c(\theta, K)}{w(\theta, K)}. \tag{25}$$

To further simplify notation, let $m(\theta, K, \theta, s)$ denote the value in terms of marginal utility of an additional unit of savings and let $M(\theta, K)$ be its aggregate counterpart,

$$M(\theta, K) = \beta \; E\left\{\frac{\left[1 + R(\theta', G(\theta, K))\right]}{P^c(\theta', G(\theta, K))} \; \left(u_c\left[\theta', G(\theta, K)\right] + \frac{u_d\left[\theta', G(\theta, K)\right]}{\Psi_d\left[Q^c(\theta', G(\theta, K))\right] \; F^c(\theta', G(\theta, K))}\right) |\theta\right\}. \tag{26}$$

3.3 Firms

Given the state of the economy (θ, K) and its individual state k, each firm has to choose three things in a particular order: first, whether to produce for investment or consumption, second, the specific submarket to go to, and third, how much to invest. Firms choose to produce whichever good that gives higher value, i.e.,

$$\Omega(\theta, K, k) = \max\{\Omega^c(\theta, K, k), \Omega^i(\theta, K, k)\}, \tag{27}$$

where $\Omega^j(\theta, K, k)$ is the best value for producing consumption goods, $j = c$, or investment goods, $j = i$; that is, they choose (Q^j, P^j, F^j) among those available (a still to be determined set):

$$\Omega^j(\theta, K, k) = \max \ \widetilde{\Omega}^j(\theta, K, k, Q^j, P^j, F^j) \qquad \text{for all available } (Q^j, P^j, F^j).$$

A firm in a (Q^c, P^c, F^c) consumption goods submarket chooses labor for shopping n^k, investment i, and next period's capital stock k' to solve the following problem:

$$\begin{aligned} \widetilde{\Omega}^c(\theta, K, k, Q^c, P^c, F^c) \ &= \ \max_{n^k, k', i} \ P^c \Psi_T(Q^c) F^c - w(\theta, K)\, [n(k, F^c) + n^k] \\ &\qquad -P^i(\theta, K)\ i + E\left\{\Omega(\theta', K', k')\ \Pi(\theta, \theta', K)|\ \theta\right\} \end{aligned} \tag{28}$$

$$\text{s.t.} \qquad i = n^k \ \zeta \ \ \Psi_d[Q^i(\theta, K)] \ \ F^i(\theta, K) \tag{29}$$

$$k' = i + (1-\delta)k \tag{30}$$

$$K' = G(\theta, K), \tag{31}$$

where $n(k, y)$ is the inverse function of the production function $y = f(k, n)$ for a given k, and ζ is a technological requirement specifying how many shopping workers are needed to provide one unit of shopping service. Finally, $F^i(\theta, K)$ is the amount of investment good produced by investment-producing firms.

As for investment good producers, a firm delivering to an investment good market (Q^i, P^i, F^i) chooses labor for shopping n^k, investment i, and next period's capital stock k' to solve the following problem:

$$\begin{aligned} \widetilde{\Omega}^i(\theta, K, k, Q^i, P^i, F^i) \ &= \ \max_{n^k, k', i} \ P^i \ \Psi_T(Q^i)\ F^i - w(\theta, K)\, [n(k, F^i) + n^k] \\ &\qquad -P^i(\theta, K)\ i + E\left\{\Omega(\theta', K', k')\ \Pi(\theta, \theta', K)|\ \theta\right\} \end{aligned} \tag{32}$$

subject to (29), (30), and (31).

The first-order condition over investment is given by

$$E\left\{\Omega_k(\theta', K', k')\ \Pi(\theta, \theta', K)|\ \theta\right\} = \frac{w(\theta, K)}{\zeta\ \Psi_d[Q^i(\theta, K)]\ F^i(\theta, K)} + P^i(\theta, K). \tag{33}$$

Let $\varsigma(\theta, K, k)$ denote the firm's revenue induced by selling to the best market (expressed in units of shares), whether a consumption good market or an investment good market:

$$\varsigma(\theta, K, k) = \max\{\varsigma^c(\theta, K, k), \varsigma^i(\theta, K, k)\},$$

where $\varsigma^j(\theta, K, k)$ is the maximum over the available submarkets of $\varsigma^j(\theta, K, k, Q^c, P^c, F^c)$,

$$\varsigma^j(\theta, K, k, Q^j, P^j, F^j) \;=\; P^j \;\; \Psi_T(Q^j)\, F^j - w(\theta, K) \;\; n(k, F^j), \tag{34}$$

with j being both consumption and investment.

Before analyzing the search equilibrium, it is useful to establish that firms in all submarkets have the same expected revenue.

Lemma 1. $\Omega^c(\theta, K, k) = \Omega^i(\theta, K, k)$ *implies* $\varsigma^c(\theta, K, k) = \varsigma^i(\theta, K, k)$.

A direct consequence of this lemma is that it allows firms to consider only the current revenue (and so the demand for current labor) instead of lifetime revenue (and so the lifetime labor demands) in deciding which markets to enter.

3.4 Competitive search in the market for consumption goods

In addition to the decisions made by the households with respect to the main elements of the allocation (how much to consume, shop, work, and save), its shoppers choose how to conduct their shopping, i.e., which market to go to. In our environment with competitive search, this means choosing a triplet (Q^c, P^c, F^c) of market tightness, price, and quantity. These choices will give us two conditions to be satisfied by these three variables.

We can write the contribution to the utility of a household of a shopper that chooses the best price-tightness-quantity triplet as

$$\Phi = \max_{Q^c, P^c, F^c} \quad u_d(\theta, K) + \Psi_d(Q^c) F^c \;\; (u_c(\theta, K) - P^c m(\theta, K, s'))$$

subject to the constraint

$$\varsigma^c \leq P^c \Psi_T(Q^c) F^c - w(\theta, K) n(k, F^c). \tag{35}$$

This constraint reflects the fact that the only relevant markets are those that guarantee certain expected revenue for the firms. Substituting (35) with $k = K$ and the definition for $\Psi_T(Q)$ and replacing $m(\theta, K, s')$ with $M(\theta, K)$, we rewrite the problem as

$$\Phi = \max_{Q^c, F^c} \left\{ u_d(\theta, K) + A\,(Q^c)^{1-\varphi}\, F^c \left(u_c(\theta, K) - \frac{\varsigma^c + w(\theta, K)\, n(k, F^c)}{A(Q^c)^{-\varphi} F^c}\, M(\theta, K) \right) \right\}. \quad (36)$$

The first-order condition over Q^c yields an equation for equilibrium P^c and an equation for price P^c:

$$\begin{aligned} 0 &= (1-\varphi)\frac{AF^c}{(Q^c)^{\varphi}} u_c(\theta, K) - \left[\varsigma^c + w(\theta, K) n(k, F^c)\right]\ M(\theta, K) \\ &= (1-\varphi)\,\frac{AF^c}{(Q^c)^{\varphi}} u_c(\theta, K) - \frac{AP^c}{(Q^c)^{\varphi}} F^c\ M(\theta, K), \end{aligned}$$

which yields an equation for the equilibrium price P^c:

$$P^c(\theta, K) = (1-\varphi)\frac{u_c(\theta, K)}{M(\theta, K)}. \quad (37)$$

The first-order condition over F^c gives us

$$0 = A(Q^c)^{1-\varphi} u_c(\theta, K) - Q^c\ M(\theta, K)\ w(\theta, K)\frac{\partial n}{\partial F^c}.$$

Substituting the equilibrium price from equation (37) and the relation $\partial n / \partial F^c = 1/f_n$ for the given $k = K$, we have

$$\frac{w(\theta, K)}{P^c(\theta, K)} = \frac{1}{1-\varphi}\, A(Q^c)^{-\varphi}\ \ f_n\left[K, N^c(\theta, K)\right],$$

where $N^c(\theta, K) = n(K, F^c(\theta, K))$ is the labor associated with $k = K$ and proposed F^c. The market tightness Q^c is a function of the equilibrium value for producing consumption goods $\varsigma^c(\theta, K)$,

$$Q^c(\theta, K) = \left[\frac{A\ P^c(\theta, K)\ f(K, N^c(\theta, K))}{\varsigma^c(\theta, K) + w(\theta, K)\ N^c(\theta, K)}\right]^{\frac{1}{\varphi}}. \quad (38)$$

3.5 Competitive search in the market for investment goods

In the same way as households do, firms shop investment goods by sending shoppers to markets offering the best triplet of tightness, price, and quantity, (Q^i, P^i, F^i). These choices yield two conditions to be satisfied by these three variables.

A shopper for the firm chooses the best price-tightness pair $\{Q^i, P^i, F^i\}$ to solve

$$\begin{aligned}\Phi_F &= \max_{Q^i,P^i,F^i} -w(\theta,K)+\zeta\ \Psi_d(Q^i)F^i\left[E\left\{\frac{\partial\Omega(\theta',K',k')}{\partial k'}\ \Pi(\theta,\theta',K)\bigg|\,\theta\right\}-P^i\right]\\ \text{s.t.}\quad \varsigma^i &\le P^i\Psi_T(Q^i)F^i-w(\theta,K)n(k,F^i).\end{aligned}$$

Substituting P^i, we can rewrite the problem as

$$\max_{Q^i,F^i} -w(\theta,K)+\zeta\ A(Q^i)^{1-\varphi}F^i\left[E\left\{\frac{\partial\Omega(\theta',K',k')}{\partial k'}\ \Pi(\theta,\theta',K)\bigg|\,\theta\right\}-\frac{\varsigma^i+w(\theta,K)n(k,F^i)}{A(Q^i)^{-\varphi}F^i}\right].$$

The first-order condition over Q^i is given by

$$0=\frac{(1-\varphi)\zeta A}{(Q^i)^{\varphi}}\ F^i\ E\left\{\frac{\partial\Omega(\theta',K',k')}{\partial k'}\ \Pi(\theta,\theta',K)\bigg|\,\theta\right\}-\zeta(\varsigma^i+w(\theta,K)n(k,F^i)),$$

which implies that the equilibrium price is

$$P^i(\theta,K)=(1-\varphi)\ E\left\{\frac{\partial\Omega(\theta',K',k')}{\partial k'}\ \Pi(\theta,\theta',K)\bigg|\,\theta\right\}. \tag{39}$$

The first-order condition over F^i is given by

$$0=\zeta\ A\ (Q^i)^{1-\varphi}\ E\left\{\frac{\partial\Omega(\theta',K',k')}{\partial k'}\ \Pi(\theta,\theta',K)\bigg|\,\theta\right\}-\zeta\ Q^i\ w(\theta,K)\frac{\partial n}{\partial F^i}.$$

Substituting equation (39) for price and $\partial\widetilde{n}/\partial F^i=1/f_n$ for given $k=K$, we have

$$\frac{w(\theta,K)}{P^i(\theta,K)}=\frac{1}{1-\varphi}A(Q^i)^{-\varphi}f_n(K,N^i(K,\theta)),$$

where $N^i(\theta,K)=n(K,F^i(\theta,K))$ is the labor associated with $k=K$ and the amount produced by investment firms, F^i. The equilibrium market tightness Q^i as a function of ς^i is given by

$$Q^i(\theta,K)=\left[\frac{A\ P^i(\theta,K)\ f[K,N^i(\theta,K)]}{\varsigma^i(\theta,K)+w(\theta,K)N^i(\theta,K)}\right]^{\frac{1}{\varphi}}. \tag{40}$$

3.6 Equilibrium

We have now established the necessary conditions for equilibrium that arise from the households' and firm's problems.

Before formally defining equilibrium, we provide a set of results – stated in a series of lemmas – that allows us to verify our conjecture that (θ, K) is a sufficient aggregate state variable. The results show that if all firms start with the same capital, they will make the same choice of labor and investment and will, hence, have identical capital K' next period.

Lemma 2. *All firms with $k = K$ choose markets with the same quantity $F = F^c = F^i$ and the same labor input for production.*

We therefore use $N^y(\theta, K)$ to denote the aggregate labor input, $N^y(\theta, K) = N^c(\theta, K) = N^i(\theta, K)$ for any (θ, K).

Lemma 3. *The expected revenue per unit of output is the same in both sectors:*

$$P^c(\theta, K)\Psi_T[Q^c(\theta, K)] = P^i(\theta, K)\Psi_T[Q^i(\theta, K)]. \tag{41}$$

Lemma 4. *Firms with the same k choose the same k' as future capital stock.*

The following two lemmas will prove useful later. The first states properties of investment prices unveiling a relation between the direct and the indirect costs of installing capital.

Lemma 5. *The investment price is proportional to the ratio of the wage and the amount of shopping that a worker can carry out:*

$$\frac{w(\theta, K)}{\zeta\Psi_d[Q^i(\theta, K)]f(K, N^y(\theta, K))} = \frac{\varphi}{1-\varphi}P^i(\theta, K). \tag{42}$$

The last lemma characterizes firms' optimal choice of capital accumulation. When making decisions for future capital, firms face an explicit cost of investment (the price paid) and an implicit cost (the wages of shoppers). Interestingly, the Euler equation in equilibrium looks almost exactly like the one in a standard RBC model in that the implicit wage cost disappears. The reason is that competitive search links the implicit wage cost and explicit cost. In equilibrium, the following lemma holds:

Lemma 6. *The Euler equation of a firm equates the price of investment to the value of capital tomorrow.*

$$E\left\{P^i(\theta', K')\, \Pi(\theta, \theta', K)\ \left[\Psi_T(Q^i) f_k(K', N^y(\theta', K')) + (1-\delta)\right]\right\} = P^i(\theta, K). \tag{43}$$

We are now ready to define equilibrium in this economy.

Definition 1. *Equilibrium is a set of decision rules and values for the household* $\{c, d, n, s', v\}$ *as functions of its state* (θ, K, s), *the firms' decision rules and values* $\{n^y, n^k, i, k', \Omega\}$ *as functions of its state* (θ, K, k), *and aggregate functions for shopping for investment* D^i, *shopping for consumption* D^c, *consumption* C, *labor* N, *labor for production* N^y, *labor for shopping* N^k, *investment* I, *aggregate capital* G, *expected revenues* ς, *the measure of consumption-producing firms* T, *wages* w, *consumption good prices* P^c, *consumption market tightness* Q^c, *production of firms* F^c *and* F^i, *investment good prices* P^i, *investment market tightness* Q^i, *and the rate of return of the economy* R *as functions of the aggregate state* (θ, K) *that satisfy the following conditions:*

1. Households' choices and value functions $d(\theta, K, s)$, $c(\theta, K, s)$, $n(\theta, K, s)$, $s'(\theta, K, s)$, and $v(\theta, K, s)$ satisfy (15-17) and (24-25).

2. Firms choose $n^k(\theta, K, k)$, $i(\theta, K, k)$, $k'(\theta, K, k)$, and $\Omega(\theta, K, k)$ to solve their problem (27). They satisfy conditions (29-30) and (33).

3. Competitive search conditions: Shoppers and sellers go to the appropriate submarkets, i.e., equations (37-38) and (39-40).

4. Representative agent and equilibrium conditions: Individual decisions are consistent with aggregate variables.

5. Market clearing conditions:

$$
\begin{aligned}
s'(\theta, K, 1) &= 1 && (44)\\
I(\theta, K) &= D^i(\theta, K)\ \Psi_d(Q^i(\theta, K))\ F^i(\theta, K) && (45)\\
C(\theta, K) &= D^c(\theta, K)\ \Psi_d(Q^c(\theta, K))\ F^c(\theta, K) && (46)\\
N(\theta, K) &= N^y(\theta, K) + N^k(\theta, K) && (47)\\
Q^c(\theta, K) &= \frac{T(\theta, K)}{D^c(\theta, K)} && (48)\\
Q^i(\theta, K) &= \frac{1 - T(\theta, K)}{D^i(\theta, K)}. && (49)
\end{aligned}
$$

Note that since the numéraire is the stock market pre-dividends, Ω must be given by $\Omega(\theta, K, K) = 1 + R(\theta, K)$. The financial wealth of the household is $s(1 + R)$ and is equal to the stock market today including the dividends. Note also that the share of consumption expenditure equals the fraction of firms producing consumption goods T, i.e., $T = P^c C/(P^c C + P^i I)$.

3.7 The equilibrium is efficient

This section analyzes the efficiency properties of the competitive search equilibrium. To this end, we start by characterizing the efficient allocation arising from the problem of a social planner who also faces the technology constraints that searching efforts have to be exerted for consumption goods and investment goods to be found. We then prove that the competitive search equilibrium is efficient.

Definition 2. *An allocation $\{T,\ D^c,\ D^i,\ N^y,\ C,\ K'\}$ is said to be efficient if it solves the following social planner problem:*

$$
V(\theta, K) = \max_{T, D^c, D^i, N^y, C, K'} \quad u\left(C, D, N^y + \frac{D^i}{\xi}, \theta\right) + \beta E\{V(\theta', K')|\theta\}
$$

subject to

$$
\begin{aligned}
C &\leq A(D^c)^{\varphi}(T)^{1-\varphi} f(K, N^y) && (50)\\
K' - (1 - \delta)K &\leq A(D^i)^{\varphi}(1 - T)^{1-\varphi} f(K, N^y). && (51)
\end{aligned}
$$

Proposition 2. *The competitive search equilibrium is efficient.*

Note that efficiency requires that markets are indexed by per-unit price, tightness, *and* quantity. This is necessary to avoid a hold-up problem between firms and consumers. Recall that once a consumer's search cost has been sunk and she has been matched with a firm, a trade between them would be carried out regardless of the quantity offered. Therefore, if markets were characterized only by tightness and price, firms might find it optimal to deviate from the efficient quantity. However, once firms are allowed to index their market on quantity as well, this hold-up problem disappears, and the competitive equilibrium allocation is efficient.[9]

3.8 Understanding the Solow residual and the labor share

We can use our model economy to compute the Solow residual provided that we specify a particular production. Let such production function be $f(k,n) = z\ k^{\alpha_k} n^{\alpha_n}$, where z is a parameter that determines units and $\alpha_k + \alpha_n < 1$ (see Section 4 for a discussion). Measured with base year prices, GDP is given by

$$Y = P_0^c C + P_0^i I, \tag{52}$$

where P_0^c is the base year consumption price and P_0^i is the base year investment price. By replacing C and I with the aggregate production function, GDP can be expressed as

$$Y = \left[P_0^c\ A(D^c)^\varphi T^{1-\varphi} + P_0^i\ A(D^i)^\varphi (1-T)^{1-\varphi}\right] zK^{\alpha_k}(N^y)^{\alpha_n}. \tag{53}$$

The Solow residual $\overline{Z}$ is defined as $\overline{Z} = \frac{Y}{K^{1-\alpha}N^{\alpha}}$, where α denotes the average labor share of output. In our model, the labor share in steady state is

$$\alpha = \frac{1}{1-\varphi}\alpha_n + \frac{\varphi\delta}{(1-\varphi)(1/\beta - 1 + \delta)}\alpha_k. \tag{54}$$

If we use this steady-state labor share to compute the Solow residual in our model, we have

$$\overline{Z} = A\ z \underbrace{\left[P_0^c\ (D^c)^\varphi T^{1-\varphi} + P_0^i (D^i)^\varphi (1-T)^{1-\varphi}\right]}_{\text{Demand Effect}} \overbrace{\left(\frac{N^y}{N}\right)^{\alpha_n}}^{\text{Effective Work}} \underbrace{K^{\alpha_k - (1-\alpha)} N^{\alpha_n - \alpha}}_{\text{Share's Error}}. \tag{55}$$

[9] See Faig and Jerez (2005) for a related argument in economies with private information. They find that to restore efficiency, it is necessary to index markets by a nonlinear price-quantity schedule. In the case of symmetric information, their efficient indexation simplifies to our triplet index of price, tightness, and quantity.

That is, the Solow residual depends on the demand; increases in demand without changes in technology increase the Solow residual. The two additional terms are due to mismeasurement of productive labor and to the imputation of constant returns to scale. In empirical applications $N - N^y$ is small and α_n is close to α. Thus, the last two terms in eq. (55) are almost constant over the business cycle, so movements in the Solow residual are mainly due to movements in demand.

4 Mapping the model to data

We now motivate the functional forms for preferences and technology and lay out the eleven parameters to be calibrated.

Preferences (four parameters). We assume separable preferences to make the role of the Frisch labor elasticity as transparent as possible, and also to isolate the role of shopping search. The per-period utility function or felicity is given by (56),

$$u(c, n, d) = \frac{c^{1-\gamma}}{1-\gamma} - \chi \frac{n^{1+\frac{1}{\nu}}}{1+\frac{1}{\nu}} - d, \tag{56}$$

where we omit the shocks to preferences for simplicity. The parameters are the discount rate β, the inverse of the intertemporal elasticity of substitution, γ, the Frisch elasticity of labor, ν, and the parameter that determines average hours worked, χ. The disutility of shopping is assumed to be linear. This is unimportant, since the shocks that affect it will shape its properties.[10]

Production technology (five parameters). Firms have a decreasing returns Cobb-Douglas production function:

$$f(k, n) = z \;\; k^{\alpha_k} \, (n^y)^{\alpha_n}. \tag{57}$$

There is no need to impose constant returns to scale given the fact that the number of locations is fixed. Note also that z is a parameter to determine units (below we will allow for shocks to z). In addition, a worker devoted to shopping for investment goods produces ζ units of shopping services, allowing for the possibility that firms could be better at shopping investment goods than people are at shopping for consumption goods. Capital depreciates at rate δ.

[10]We have experimented with different functional forms for the disutility of search by assuming that the disutility of shopping has a constant relative risk aversion form: $v(d) = d^{(1+\gamma_d)}/(1+\gamma_d)$. We found that the quantitative results of the model are virtually unchanged when varying γ_d between zero and two.

4.1 Calibration

In this economy, most of the targets for the steady state (and associated parameters) are the standard ones in business cycle research, whereas others are specific to this economy. Table 1 reports the targets and the parameters that are most closely associated with each target. The targets are defined in yearly terms even though the model period is a quarter.

Table 1: Calibration Targets, Implied Aggregates, and (Quarterly) Parameter Values

Targets	Value	Parameter	Value
First Group: Parameters Set Exogenously			
Risk aversion	2.	γ	2.
Real interest rate	4%	β	0.99
Frisch elasticity	0.72	$\frac{1}{\nu}$	0.72
Second Group: Standard Targets			
Fraction of time spent working	30%	χ	16.81
Physical capital to output ratio	2.75	δ	0.07
Consumption share of output	0.80	α_k	0.31
Labor share of income	0.67	α_n	0.59
Steady-state output	1	z	1.21
Third Group: Targets Specific to This Economy			
Share of production workers	97%	φ	0.09
Capacity utilization of consumption sector	0.81	A	0.97
Capacity utilization of investment sector	0.81	ζ	3.16

Implications over Other Aggregate Variables	
Tobin's average Q	1.1
Percentage of GDP payable to shoppers	2%
Percentage of cost of new capital that is internal	9%
Relative price of investment in terms of consumption	1
Wealth to output ratio	3.33

The first group of parameters is set independently of the equilibrium allocation. The intertemporal elasticity of substitution is set to 0.5, and the real rate of return is 4%. The Frisch elasticity is more controversial. We choose a value of 0.72, based on Heathcote, Storesletten, and Violante (2010), who take into account the response of hours worked for both men and women in a model that explicitly incorporates households with husbands and wives.[11]

[11] Table 8 reports results for an economy with a Frisch elasticity of 1.1.

The targets in the second group are standard in the business cycle literature. Note that the consumption to output ratio is set to 0.8, since investment in our model is strictly business investment. We exclude consumption durables, since business investment and consumer durables use different shopping technologies.

The third group of targets is specific to our model. Our notion of capacity utilization is related to the series published by the Federal Reserve Board.[12] We target a steady-state capacity utilization of 81% in both the consumption good and the investment good sector, the average of the official data series (Corrado and Mattey (1997)). Equal capacity average utilization in both sectors implies that in steady state the relative price of consumption and investment must be 1.

We target 3% of the workforce as being involved in investment shopping. As the last panel of Table 1 shows, this choice implies that 2% of GDP is spent on search activities, and that 9% of the cost of installing new capital is internal to the firm. Moreover, the average Tobin's Q – including the costs of searching for investment goods – is 1.1 in this economy. We view these implied values as plausible, indicating that the magnitude of the costs associated with finding the right investment goods is plausible.[13]

5 Demand shocks in univariate economies

We will now introduce the stochastic shocks to our economy. We start by analyzing a set of economies with univariate shocks, i.e., economies where all fluctuations are driven by one shock. This will demonstrate the role of each shock and will motivate estimating economies with more than one shock. We then proceed to the full estimation in Section 6.

[12] The Federal Reserve Board's Industrial Production and Capacity Utilization series is based on estimates of capacity and capacity utilization for industries in manufacturing, mining, and electric and gas utilities. For a given industry, the capacity utilization rate is equal to an output index (seasonally adjusted) divided by a capacity index. The purpose of the capacity indexes is to capture the concept of sustainable maximum output – the greatest level of output a plant can maintain within the framework of a realistic work schedule, after factoring in normal downtime and assuming sufficient availability of inputs to operate the capital in place.

[13] Laitner and Stolyarov (2003) estimate the average Tobin's Q to be 1.21, using aggregate U.S. data over the 1953-2001 period. Ang and Beck (2000) obtain a similar estimate using cross-sectional data for US corporations from Compustat and CRSP data. These papers consider the investment costs to be only the pure purchase price of investment goods, and this omission creates an upward bias. If we ignore the search component of investment costs and focus exclusively on the pure purchase price, the adjusted Tobin's Q would be 1.21 also in our economy.

5.1 Estimating shock processes of univariate economies

Throughout the paper, we consider two pure preference shocks – one shock to the disutility of shopping, θ_d, and another to the disutility of work, θ_n, so

$$\frac{c^{1-\gamma}}{1-\gamma} - \theta_n \frac{n^{1+1/\nu}}{1+1/\nu} - \theta_d \, d.$$

In addition, we assume a shock to the firm's shopping technology, ζ, and a true technology shock, z, to total factor productivity.

In this section, we estimate each of the univariate shock processes with Bayesian methods using only data on the Solow residual.[14] For simplicity, we assume that all shocks follow AR(1) processes, where the persistence follows a Beta distribution and the volatility follows an inverse Gamma distribution. We show that each one of these shocks can, on their own, generate fluctuations in the Solow residual like those in the U.S. data. The estimated univariate processes are laid out in Table 2.

Table 2: Estimates of the Processes for Univariate Shocks

	Univariate Versions of the Shopping Model				Standard RBC
Shocks to	Shop. Disut θ_d	Labor Disut θ_n	Firm's Shop. ζ	Tech z	Tech z
ρ	0.947	0.898	0.956	0.950	0.945
Para(1)	0.94	0.85	0.95	0.94	0.94
Para(2)	0.05	0.05	0.05	0.05	0.05
90% Intv	[0.92, 0.98]	[0.86, 93]	[0.93,0.99]	[0.92, 0.99]	[0.91, 0.98]
σ	0.086	0.171	0.334	0.006	0.006
Para(1)	0.05	0.10	0.30	0.006	0.006
Para(2)	0.50	0.50	0.50	0.50	0.50
90% Intv	[0.08, 0.09]	[0.16, 0.19]	[0.31, 0.36]	[0.006, 0.007]	[0.006, 0.007]
Likelihood	734.14	733.65	735.03	734.98	735.05
Var of $\bar{Z}$	3.43	2.79	3.36	3.46	3.45
Autocorr of $\bar{Z}$	0.95	0.93	0.95	0.95	0.95

Note: Each univariate process is estimated with Bayesian methods, targeting the Solow residual series. The sample is quarterly U.S. data, from Q1 in 1960 to Q4 in 2009.

[14] See, e.g., An and Schorfheide (2007) and Ríos-Rull et al. (2009) for details.

The last column of Table 2 reports the results from a standard RBC economy without shopping, where the technology shock by construction *is* the Solow residual.[15] As could be anticipated from the theoretical analysis above, each of the shocks θ_d, θ_n, and ζ is capable of generating a process for TFP as volatile as its empirical counterpart, without having to resort to shocks to technology. Moreover, the estimates are quite precise, and in terms of likelihood, they are as good as those of the RBC economy.

5.2 Business cycle properties of univariate economies

Given estimates of each of the univariate processes, we illustrate how each shock works by documenting the quantitative business cycle properties. This exercise also illustrates what it takes for each shock to generate the Solow residual fluctuations.

As a benchmark for comparison, we start by listing second moments of the U.S. data and compare those moments to the standard neoclassical RBC model with a technology shock. Table 3 shows that the RBC model generates the right qualitative comovements: output, TFP, investment, consumption, and hours worked are strongly correlated, and investment is much more volatile than output, which in turn is more volatile than consumption. However, the variance of hours is small because of the relatively low Frisch elasticity of substitution that we use in our calibration.

Table 3: Main Business Cycle Moments: U.S. Data and Standard RBC Model

	U.S. Data			Standard RBC Model		
	Variance	Cor w Y	Autocor	Variance	Cor w Y	Autocor
Z	3.19	0.43	0.94	3.45	0.99	0.95
Y	**2.38**	1.00	0.86	**0.82**	1.00	0.71
N	**2.50**	0.87	0.91	**0.04**	0.96	0.72
C	1.55	0.87	0.87	0.05	0.95	0.76
I	34.15	0.92	0.80	13.74	0.99	0.71
cor(C, I)	**0.74**			**0.93**		

Note: all variables except the Solow residual are HP-filtered logarithms of the original series. The driving process of the RBC economy is a technology shock estimated with Bayesian methods and targeting the data series of the Solow residual. The sample is quarterly U.S. data, from Q1 in 1960 to Q4 in 2009.

[15] Table A-1 in the Appendix shows the details of its calibration, which is designed to be as close as possible to the targets of the shopping economy, listed in Table 1.

Another important failure of the standard RBC model is that investment is about 275 times more volatile than consumption, compared to a ratio of 22 in the data.[16] As is well known, investment becomes so volatile compared to consumption because the marginal product of capital responds very little to increases in the aggregate capital stock, so investment can expand a lot without lowering the incentive to invest.

Consider now the shopping economy under each of the four (univariate) driving shocks, reported in Table 4. Note first that the economy where TFP is driven by a univariate technology shock (panel d) is observationally equivalent to the pure RBC economy in Table 3.

Table 4: Main Business Cycle Moments: Various Economies with Demand Shocks

	(a) Shop Disut θ_d			(b) Labor Disut θ_n		
	Variance	Cor w Y	Autocor	Variance	Cor w Y	Autocor
Z	3.43	1.00	0.95	2.79	**-0.99**	0.93
Y	**0.45**	1.00	0.71	**47.61**	1.00	0.69
N	**0.02**	**-1.00**	0.72	**133.13**	1.00	0.69
C	0.40	1.00	0.71	1.22	0.83	0.81
I	0.66	1.00	0.71	956.91	1.00	0.69
cor(C, I)	**0.99**			**0.78**		
	(c) Firms' Shopping Tech ζ			(d) Technology Shock z		
	Variance	Cor w Y	Autocor	Variance	Cor w Y	Autocor
Z	3.36	0.91	0.95	3.20	0.98	0.95
Y	**3.19**	1.00	0.72	**0.82**	1.00	0.72
N	**2.37**	0.98	0.71	**0.04**	**0.95**	0.72
C	1.46	**-0.95**	0.72	0.07	0.97	0.75
I	184.82	0.99	0.71	12.32	1.00	0.71
cor(C, I)	**-0.98**			**0.94**		

Note: all variables except the Solow residual are HP-filtered logarithms of the original series. Each panel shows business cycle properties of univariate economies where the driving process in each case is estimated with Bayesian methods and targeting the data series of the Solow residual and with the priors assumed to be normal. The sample is quarterly U.S. data, from Q1 in 1960 to Q4 in 2009.

We now turn to the univariate economies driven by preference shocks. In the economy with

[16] Note that second moments are reported as variances of logarithms. If we had instead reported standard deviations of logarithms, the difference between the data and the RBC model would appear to be smaller.

shocks to the *shopping disutility* θ_d (panel a), the Solow residual is positively correlated with output, and consumption and investment are positively correlated. This is an important property: for a given labor supply, output in a neoclassical model would be fixed, so a demand shock to consumption would crowd out investment and, hence, induce a negative correlation between investment and consumption. However, our shopping economy has an additional margin of adjustment: search effort can change. This allows output to change in response to a demand shock, even when holding labor and capital fixed (since the demand shock increases measured TFP). However, labor supply is *negatively* correlated with output since a shock to θ_d generates a positive wealth effect: consumption goes up and work goes down. Consumer shoppers are more effective, and consumption-producing firms operate at higher capacity, allowing for lower work effort. So shocks of this type by themselves cannot be the sole driver of fluctuations (see Barro and King (1984) for a similar argument).

The *labor disutility* shock (panel (b)) generates the volatility of the Solow residual by attracting more search effort when labor is low, making productivity and output negatively correlated. The variance of output required for this to happen is tremendous, six times that of the data, and that of labor is even larger, about 15 times that of the data (recall that it is the series for the Solow residual which is being targeted in this estimation) . Moreover, the Solow residual is negatively correlated with output, which is sharply at odds with the data (see, again, Barro and King (1984)).

The shock to the *firm's shopping technology* (panel (c)) has to generate all the movements of the Solow residual from a small part of GDP, and hence its variance is large. It makes hours worked quite volatile and positively correlated with output, but consumption is negatively correlated with output, and consumption and investment are negatively correlated.

To summarize, the exercise of studying economies driven by univariate shocks has two main messages. First, it is only the shopping disutility shock θ_d that can generate a variance of investment that is not hundreds of times larger than the variance of consumption (recall that this ratio is only 28 in the data, see Table 3). Second, economies with either demand shocks or technology shocks exhibit much too low volatility of labor supply. Therefore, any successful attempt to account for business cycles must contain a labor supply shock θ_n.

Finally, note that the failures of univariate preference-shock economies to match the data are somewhat orthogonal. As we shall see below, an estimated economy that allows for both a shock to θ_d and ζ gets the sign of the comovements with output right.

6 Estimating the contribution of all shocks

So far we have compared restricted versions of the shopping model to the RBC model. We now estimate the full-blown version of the shopping model, allowing all four shocks to matter. This approach allows us to impute the contribution of each shock to aggregate fluctuations. We again use Bayesian methods. We allow the consumption and investment demand shocks to be correlated and assume that all other shocks are independent. The data that we use are the Solow residual, output, hours, and consumption, all linearly detrended. We assume that the autocorrelations follow a Beta distribution, that the standard deviation of the innovations follow an inverse Gamma distribution, and that the correlation between demand shocks are normally distributed. For the full estimation, we assume that the shock to the marginal utility of labor supply, θ_n, follows an AR(2) process. The reason for this choice is the well-known fact that aggregate U.S. labor supply has experienced both large low-frequent fluctuations and more high-frequent fluctuations over the last decades. Allowing for an AR(2) term in θ_n is a way to parsimoniously capture such low-frequent swings.

Table 5 shows the priors and posteriors for all shock parameters. The 90% intervals are tight except for the correlation between the demand shocks. The estimates for the standard deviations of most shocks are substantially smaller than in the univariate shock economies (a factor of 7 for the shock to the MRS, a factor of 2 for the technology shock, and a factor of 4 for the investment search shock, and by 13% for the consumption search shock).

The variance decomposition of the major aggregate variables is reported in Table 5. Shocks to θ_d and ζ, which we have labeled as demand shocks, are much more important than the productivity shock, not only in terms of its contribution to output (47% relative to 15%) but also in terms of its contribution to the Solow residual itself (18% relative to 18%).

The volatility of hours is still dependent mostly on shocks to the MRS, but the demand shocks contribute 16%. Productivity shocks have no effect on hours. Demand shocks also account for 75% of consumption and 70% of investment, whereas technology shocks are irrelevant for consumption and explain about 15% of investment.

The Bayesian estimation chooses shocks so as to maximize the probability of the observed aggregate time series. It turns out that in order to match the data, it is necessary to attribute a much larger role to demand shocks than to productivity shocks. This negligible role for technology shocks and the predominant role for preference shocks is a major result of our paper.

Table 5: Full Bayesian Estimation of the Shopping Model

Priors and Posteriors for the Shock Parameters (Likelihood = 2182.22)

Parameter	Density	Para(1)	Para(2)	Mean	90% Intv.	Mode
ρ_d	Beta	0.940	0.05	**0.966**	[0.942, 0.995]	0.954
σ_d	Inverse Gamma	0.090	0.50	**0.076**	[0.065, 0.085]	0.080
ρ_ζ	Beta	0.920	0.05	**0.937**	[0.892, 0.985]	0.942
σ_ζ	Inverse Gamma	0.110	0.50	**0.087**	[0.063, 0.108]	0.092
ρ_z	Beta	0.928	0.05	**0.902**	[0.821, 0.991]	0.945
σ_z	Inverse Gamma	0.003	0.50	**0.003**	[0.0008, 0.0045]	0.0014
$\rho_{n,1}$	Beta	0.587	0.05	**0.848**	[0.841,0.855]	0.856
$\rho_{n,2}$	Beta	0.132	0.05	**0.151**	[0.144, 0.158]	0.144
σ_n	Inverse Gamma	0.021	0.50	**0.024**	[0.022, 0.026]	0.024
Cor(θ_d, ζ)	Normal	0.000	0.40	**0.074**	[-0.225, 0.379]	0.01

	Variance Decomposition (%)				Business Cycle Statistics	
	θ_d	ζ	z	θ_n	Variance	Cor w Y
Y	25.21	21.60	15.37	37.82	1.13	1.00
Solow	73.64	6.72	18.11	1.52	0.61	0.64
N	2.76	12.95	1.12	83.17	1.53	0.68
C	56.92	18.32	1.12	23.64	0.66	0.52
I	0.23	70.03	15.12	14.62	20.89	0.79

The table shows the Bayesian estimation and the business cycle properties of the full model with demand shocks ($\theta_n, \theta_d, \zeta$) and a technology shock z. All variables are HP-filtered logarithms of the original series. The estimation targets the data series of consumption, investment, labor supply, and the Solow residual. All priors are assumed to be normal. The sample is quarterly U.S. data, from Q1 in 1960 to Q4 in 2009.

6.1 Inspecting the mechanism

We now explore the reason for the small role of the productivity shocks. The key to understand this result is the interaction between the two demand shocks θ_d and ζ.

Recall that these shocks have opposite effects on the amount of search in the economy – a larger θ_d would decrease household search for consumption goods (because the households are not very efficient at searching) and, hence, lower measured TFP. In contrast, a larger ζ would make the firms more efficient at searching for investment goods, so they exploit the opportunity to invest. This increases search for investment goods and, once production has been reallocated toward investment, even the search for consumption goods increases, leading to a lower TFP. Due to the ability to costlessly switch production between consumption and investment goods, these shocks would cancel each other out if they were strongly positively correlated. There would be no effect on TFP and a negative consumption-investment correlation. Conversely, if the shocks were negatively correlated, they would cause both large swings in TFP and positive co-movements in consumption and investment, qualitatively similar to the effects of technology shock. The upshot is that to account for the data, there would be no need for a technology shock if θ_d and ζ were negatively correlated, whereas if these shocks were positively correlated, the model would need a technology-like shock.

Table 6 illustrates this argument. Instead of estimating the correlation between θ_d and ζ, as we did in the benchmark estimation of Table 5, we now restrict this correlation to a specific value and reestimate the model. The productivity shock accounts for only 5% and 6% of the variance of output and TFP, respectively, when $corr(\theta_d, \zeta) = -0.2$ (column 2 Table 6). These figures increase to 56% and 62% when the correlation increases to 0.95 (see column 7).

When we estimated the (θ_d, ζ) correlation together with the other parameters (Table 5), we found it to be close to zero, given a prior of zero. However, as is clear from Table 6, when restricting this correlation to different values, ranging from -0.2 to 0.95, the likelihood of the various estimated models seems somewhat flat.[17]

One way to interpret the finding that the technology shock plays a small role is that the demand shocks must be able to deliver some of the same comovements between the aggregate variables as the technology shocks do, and in addition do better along some other dimensions. To examine this conjecture, we estimated a (bivariate) economy with shocks to θ_d and ζ, restricting the correlation between them to be zero (in this restricted estimation, we target the time series for the output). The lower panel of Table 7 shows how the business cycle statistics of this economy compare with the standard RBC economy. The bivariate demand shock economy has the same qualitative comovements as the RBC economy: consumption and investment are positively correlated, with investment being substantially more volatile, and hours, consumption, investment, and TFP are procyclical.[18]

[17] Note also that with a (substantially) flatter prior on the (θ_d, ζ) correlation, the estimated correlation would increase to 0.45 and the technology shock would accordingly accounts for more of the fluctuations in output and TFP: 34% and 39%, respectively (details available upon request).

[18] Note that the results are quite sensitive to the initial prior on the standard deviation σ_ζ. For example, if this prior were set to 0.07 instead of 0.20 (as in Table 7), the likelihood would fall only marginally but the cyclical properties of the estimated model would be quite different. In particular, the shock to θ_d would get a bigger role and the cross-correlation $corr(\ln Y, lnN)$ would be negative.

Table 6: Sensitivity Analysis: Restricting the Correlation between the Consumption and Investment Demand Shocks

	Correlation					
	-0.2	-0.1	0	0.1	0.2	0.95
	Estimates					
Likelihood	2185.90	2186.86	2185.52	2186.62	2185.84	2189.09
ρ_d	0.981	0.969	0.960	0.962	0.963	0.967
σ_d	0.079	0.079	0.079	0.075	0.073	0.066
ρ_ζ	0.925	0.932	0.940	0.954	0.947	0.976
σ_ζ	0.093	0.092	0.093	0.088	0.082	0.060
ρ_z	0.920	0.925	0.914	0.902	0.876	0.847
σ_z	0.002	0.002	0.002	0.003	0.004	0.005
$\rho_{n,1}$	0.853	0.854	0.842	0.855	0.846	0.847
$\rho_{n,2}$	0.146	0.144	0.157	0.143	0.153	0.151
σ_n	0.024	0.024	0.024	0.024	0.024	0.024
	Variance decomposition for output					
θ_d	36.65	34.15	30.78	23.67	18.40	4.15
ζ	21.01	23.05	23.31	20.80	17.42	0.78
z	5.03	5.59	8.81	17.52	26.94	55.93
θ_n	37.31	37.22	37.11	38.00	37.23	39.14
	Variance decomposition for the Solow residual					
θ_d	85.64	84.33	80.39	70.76	62.09	36.15
ζ	6.88	7.14	7.41	6.80	5.70	0.32
z	6.01	7.02	10.70	20.90	30.72	61.97
θ_n	1.46	1.51	1.49	1.54	1.49	1.57

Table 7: The Shopping Economy with Uncorrelated Demand Shocks

Priors and Posteriors for the Shock Parameters

Shopping model with (θ_d, ζ), likelihood = 714.80

Parameter	Density	Para(1)	Para(2)	Mean	90% Intv.
ρ_d	Beta	0.94	0.05	0.957	[0.926, 0.988]
σ_d	Inv. Gamma	0.07	0.50	0.065	[0.034, 0.089]
σ_ζ	Normal	0.20	0.50	0.185	[0.068, 0.309]

Main Business Cycle Statistics

	Variance			Correlation with Y		
	Data	(θ_d, ζ)	RBC	Data	(θ_d, ζ)	RBC
Solow	3.19	4.13	3.45	0.43	0.83	0.99
Y	2.38	0.69	0.82	1.00	1.00	1.00
N	2.50	0.25	0.04	0.87	0.37	0.96
C	1.55	0.52	0.05	0.87	0.31	0.95
I	34.15	18.04	13.74	0.92	0.77	1.00

All variables except the Solow residual are HP-filtered logarithms of the original series. The processes for the shocks to (θ_d, ζ) are estimated with Bayesian methods and targeting the data series of output and the Solow residual and with the priors assumed to be normal. The sample is quarterly U.S. data, from Q1 in 1960 to Q4 in 2009.

6.2 Sensitivity analysis

Consider now two variations of our benchmark economy – one with a smaller role for the search friction and one with a higher Frisch elasticity of labor supply.

Table 8: Sensitivity analysis: Frisch Elasticity 1.1 (likelihood = 2161.96)

Priors and Posteriors for the Shock Parameters (Likelihood = 2182.22)						
Parameter	Density	Para(1)	Para(2)	Mean	90% Intv.	Mode
ρ_d	Beta	0.940	0.05	**0.964**	[0.942, 0.992]	0.956
σ_d	Inverse Gamma	0.068	0.50	**0.074**	[0.061, 0.086]	0.080
ρ_ζ	Beta	0.940	0.05	**0.964**	[0.926, 0.998]	0.964
σ_ζ	Inverse Gamma	0.117	0.50	**0.086**	[0.060, 0.116]	0.097
ρ_z	Beta	0.930	0.05	**0.874**	[0.782, 0.982]	0.952
σ_z	Inverse Gamma	0.003	0.50	**0.003**	[0.001, 0.005]	0.0017
$\rho_{n,1}$	Beta	0.540	0.05	**0.818**	[0.815,0.821]	0.821
$\rho_{n,2}$	Beta	0.250	0.05	**0.181**	[0.177, 0.184]	0.179
σ_n	Inverse Gamma	0.021	0.50	**0.020**	[0.019, 0.022]	0.020
Cor(θ_d, ζ)	Normal	0.000	0.40	**0.300**	[-0.088, 0.960]	0.002

	Variance Decomposition (%)				Business Cycle Statistics	
	θ_d	ζ	z	θ_n	Variance	Cor w Y
Y	18.81	20.37	28.09	32.73	0.94	1.00
Solow	64.08	6.54	28.24	1.15	0.57	0.68
N	6.72	11.98	2.62	78.68	1.15	0.63
C	68.35	13.51	1.37	16.77	0.63	0.48
I	1.48	58.90	27.03	12.59	18.61	0.77

Note: The table shows the Bayesian estimation and the business cycle properties of the full model with demand shocks ($\theta_n, \theta_d, \zeta$) and a technology shock z. All variables are HP-filtered logarithms of the original series. The estimation targets the data series of consumption, investment, labor supply, and the Solow residual. All priors are assumed to be normal. The sample is quarterly U.S. data, from Q1 in 1960 to Q4 in 2009.

Start by increasing the Frisch elasticity to 1.1 (Table 8). In this case, the key mechanism of the RBC model – the labor supply – becomes more salient. Accordingly, the estimated value for $corr(\theta_d, \zeta)$ increases to 0.3, rendering most other parameters unchanged. Moreover, the share of the fluctuations in output and TFP accounted for by the technology shock increases to 28%.

Consider now lowering the target for the share of investment shoppers from 3% to 2%. Since the capacity utilization rate is assumed to be the same for consumption and investment goods, this change implies a lower value for φ (from 0.09 to 0.05), rendering all other parameters unchanged. The effect on the estimation can be seen in Table 9. In terms of the parameter estimates, the key change is that $corr(\theta_d, \zeta)$ increases to 0.29, while the estimated volatility of the demand shocks increase. In terms of what shocks account for fluctuations in output and TFP, the role of the technology shock is essentially unchanged.

7 Other business cycle implications of the shopping economies

In this section, we explore additional implications of the shopping economies that are absent in the standard RBC model. In the shopping model, the relative price of investment, the stock market price, and capacity utilization are all endogenous variables that move over the cycle. Table 10 reports the second moments of the empirical data and of the benchmark estimated model (including all shocks) and the univariate RBC model.

The relative price of investment. The role of the relative price of investment in shaping economic performance has been studied in various contexts, from its role in shaping the skill premia (Krusell et al. 2000) to its role as a direct source of business cycles (Fisher (2006)). In this literature, such relative price is usually exogenous (an exception is Valles (1997), which uses a non-linear production possibility frontier). In our economy, the relative price of consumption and investment is endogenous: a reduction in the disutility of shopping makes households search harder and, hence, achieve lower prices for their goods. In the data, the relative price of investment is countercyclical and less volatile than output. Our shopping economies also feature countercyclical relative prices of investment. However, in the benchmark economy, the volatility of the investment price is too large.

The stock market price. Given our normalization, the stock market is just the inverse of the price of consumption. In the shopping economy, the value of firms changes not only because of changes in the cost of shopping for new capital, but also because the value of locations capable of matching with shoppers changes. As is well known, the empirical stock market price is procyclical and extremely volatile with a variance of log about 40 times that of output. Our model does indeed generate a procyclical stock price. Not surprisingly, the variance of the price is much smaller than that of the data, albeit still sizeable given the low risk aversion that we have assumed. The correlation is similar to that of the data in both economies.

Capacity utilization. In the shopping economies, the ratio of output to potential output is constantly changing, with higher utilization resulting in higher measured productivity. In the United States, the Federal Reserve Board has constructed a series of capacity utilization in manufacturing (henceforth "FRB utilization"). Althouguh this series does not correspond directly to our notion of utilization, it is arguably related: in our model, "utilization" is the share of goods that are found by consumers and investors, whereas the Federal Reserve Board's notion of capacity utilization reflects how close production plants are to full production capacity. The empirical FRB utilization series is strongly procyclical. This correlation is consistent with our model, even though we have abstracted from frictions in production and there is no possibility of varying the utilization of capital and workers. Utilization in our model is less volatile than the FRB utilization series. One interpretation of this finding is that there might be other fixed factors in production besides capital that contribute to the larger value of the volatility of the FRB utilization.

We conclude that the shopping economy captures the qualitative aspects of the additional dimensions of business cycles.

8 Conclusions and extensions

This paper provides a business cycle theory with an explicit productive role for the demand for goods. A search friction prevents perfect matching between producers and consumers. A larger consumer demand for consumption and a larger investment demand from firms result in more intense search for goods and, hence, a larger utilization of the available production. Shocks to demand can therefore generate procyclical movements in measured TFP. A competitive search protocol resolves the matching friction, so the equilibrium outcome is efficient and unique.

We embed this search model of shopping in an otherwise standard neoclassical growth model. Our main quantitative exercise is to estimate a version of the model that features a range of demand shocks, as well as a true technology shock. The Bayesian estimation imputes a negligible role for technology shocks in terms of accounting for aggregate variables, including the Solow residual. In addition, our shopping economies have implications for several other important macroeconomic variables about which standard business cycle models are silent: the relative price of consumption and investment, Tobin's Q, and capacity utilization. Our shopping model generates correlations between output and these variables that are similar to their empirical counterparts.

In future work we plan to extend this environment to contexts where the demand shocks are generated by financial frictions, government expenditures, and foreign demand shocks. It would also be interesting to consider additional frictions that could break the efficient outcome of the competitive search model, such as for example coordination failures or additional labor market frictions. Finally, it is straightforward to embed our search friction for goods within the New Keynesian and Mortensen-Pissarides approaches to fluctuations, which assume frictions in either price setting or labor markets to generate large fluctuations in output and hours worked. Ultimately, these two traditions build on technology shocks as a major source of fluctuations, and our findings provide a rationale for substituting productivity shocks for demand shocks in these models.

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APPENDIX

A Proofs

Proof of Proposition 1.

Proof. Substituting $d = c/\Psi_d(D)$ into the period utility and differentiating u w.r.t. c, we get

$$\frac{du}{dc} = u_c + \frac{\partial u}{\partial d}\frac{\partial d}{\partial c} = u_c + \frac{u_d}{\Psi_d(D)}$$

The Euler equation can then be expressed as

$$u_c + \frac{u_d}{\Psi_d(D)} = p(\theta)m.$$

Impose the representative agent conditions $c = C = AD^{\varphi}$ and $d = D$, and use (9) to substitute out the term $p(\theta)m$. This gives one functional equation:

$$u_c\left(C(\theta), D(\theta), \theta\right) + \frac{u_d\left(C(\theta), D(\theta), \theta\right)}{\Psi_d\left(D(\theta)\right)} = (1-\varphi)\, u_c\left(C(\theta), D(\theta), \theta\right).$$

Rearranging this equation and using (11) yields the functional equation (12). The functional equation (13) is derived from the equilibrium price equation (9) and the definition of m, where we exploit the envelope theorem and (5) to express $\partial v/\partial s$ as

$$\frac{\partial v\left(\theta, s\right)}{\partial s} = u_c\left(C\left(\theta\right), D(\theta), \theta\right) + \frac{u_d\left(C\left(\theta\right), D(\theta), \theta\right)}{\Psi_d[Q(\theta)]}.$$

At the equilibrium, the agents' budget constraint (6) is satisfied. Given (12)-(13), the first-order conditions of (4) hold, which guarantees individual optimization.

Consider the planner problem $\max_{C,D}\{u(C, D, \theta)\}$ subject to the aggregate resource constraint $C = A\ D^{\varphi}$. It is straightforward to verify that the solution to equation (12) solves this planner problem, which establishes efficiency. □

Lemma 1. $\Omega^c(\theta, K, k) = \Omega^i(\theta, K, k)$ *implies* $\varsigma^c(\theta, K, k) = \varsigma^i(\theta, K, k)$.

Proof. From the firms' first-order condition over k' (33), it is clear that both marginal return and marginal cost of capital are independent of the firms' current choice over which goods to produce and choice of labor for production. This implies that firms simply search for the markets that give them the best current revenue. Thus, $\Omega^c(\theta, K, k) = \Omega^i(\theta, K, k)$ implies $\varsigma^c(\theta, K, k) = \varsigma^i(\theta, K, k)$. $\square$

Lemma 2. *All firms with $k = K$ choose markets with the same output $F = F^c = F^i$ and also the same labor input for production.*

Proof. Let's define $n^c(K, \theta)$ as the necessary labor for a consumption-producing firm with capital $k = K$ to produce output $y^c(\theta, K)$, namely, $n^c(K, \theta) = n(K, y^c(\theta, K))$. Similarly, we define $n^i(K, \theta) = n(K, y^i(\theta, K))$ for investment-producing labor. In equilibrium, firms are indifferent between producing consumption goods or investment goods, i.e., $\varsigma^c = \varsigma^i$. By definition, $\varsigma^c = P^c(\theta, K)A[Q^c(\theta, K)]^{-\varphi}y^c(\theta, K) - w(\theta, K)n^c(\theta, K)$. We can further rewrite ς^c using equilibrium conditions from the competitive search $\frac{w(\theta,K)}{P^c(\theta,K)} = \frac{1}{1-\varphi}A(Q^c)^{-\varphi}f_n[K, n^c(\theta, K)]$,

$$\begin{aligned}
\varsigma^c &= P^c(\theta, K)A[Q^c(\theta, K)]^{-\varphi}y^c(\theta, K) - w(\theta, K)n^c(\theta, K) \\
&= w(\theta, K)\left[\frac{P^c(\theta, K)A[Q^c(\theta, K)]^{-\varphi}y^c(\theta, K)}{w(\theta, K)} - n^c(\theta, K)\right] \\
&= w(\theta, K)\left[(1-\varphi)\frac{A[Q^c(\theta, K)]^{-\varphi}y^c(\theta, K)}{A[Q^c(\theta, K)]^{-\varphi}f_n[K, n^c(\theta, K)]} - n^c(\theta, K)\right] \\
&= w(\theta, K)\left[(1-\varphi)\frac{f[K, n^c(\theta, K)]}{f_n[K, n^c(\theta, K)]} - n^c(\theta, K)\right].
\end{aligned}$$

Similarly, we have

$$\varsigma^i = w(\theta, K)\left[(1-\varphi)\frac{f[K, n^c(\theta, K)]}{f_n[K, n^c(\theta, K)]} - n^c(\theta, K)\right].$$

Equalizing ς^i and ς^c implies that $n^c(\theta, K) = n^i(\theta, K)$ under the assumption that the production function is concave and strictly increasing in labor. Thus, the labor inputs are the same for the firms with the same capital $k = K$. Their outputs must be the same too. $\square$

Lemma 3. *The expected revenue per unit of output is the same in both sectors:*

$$P^c(\theta, K)\frac{\Psi_d[Q^c(\theta, K)]}{Q^c(\theta, K)} = P^i(\theta, K)\frac{\Psi_d[Q^i(\theta, K)]}{Q^i(\theta, K)}. \tag{A-1}$$

Proof. Under Lemma 2, firms with the same $k = K$ have the same labor input for production, the same output, and the same ς. This implies equation (A-1). □

Lemma 4. *Firms with the same k choose the same k' as future capital stock.*

Proof. According to Lemma 2, firms with the same k choose the same labor input. For a firm that considers producing consumption goods tomorrow, the first-order condition over k' is given by

$$E\left\{\left[-w(\theta', K')n_k(k', y(\theta', K')) + (1-\delta)\left(\frac{w(\theta', K')}{\zeta\, \Psi_d[Q^i(\theta', K')]\, f[(\theta', K')]} + P^i(\theta', K')\right)\right]\Pi(\theta, \theta', K)\middle|\,\theta\right\}$$
$$= \frac{w(\theta, K)}{\zeta\, \Psi_d[Q^i(\theta, K)]\, f[(\theta, K)]} + P^i(\theta, K).$$

For a firm that considers producing investment goods tomorrow, the first-order condition over k' is

$$E\left\{\left[-w(\theta', K')n_k(k', y(\theta', K')) + (1-\delta)\left(\frac{w(\theta', K')}{\zeta\, \Psi_d[Q^i(\theta', K')]\, f[K'^i(\theta', K')]} + P^i(\theta', K')\right)\right]\Pi(\theta, \theta', K)\middle|\,\theta\right\}$$
$$= \frac{w(\theta, K)}{\zeta\, \Psi_d[Q^i(\theta, K)]\, f[(\theta, K)]} + P^i(\theta, K). \quad \text{(A-2)}$$

With Lemma 2, it is easy to see that the first-order conditions for k' of future consumption-producing firms and investment-producing firms are identical. Thus, all the firms with the same current capital choose the same future capital. □

Lemma 5. *The investment price is proportional to the ratio of the wage and the amount of shopping that a worker can carry out:*

$$\frac{w(\theta, K)}{\zeta\Psi_d[Q^i(\theta, K)]f(K, N^y(\theta, K))} = \frac{\varphi}{1-\varphi}P^i(\theta, K).$$

Proof. From investment-producing firms' first-order condition over k', we have

$$E\left\{\Omega(\theta',K',k')\,\Pi(\theta,\theta',K)|\,\theta\right\} \;=\; \frac{w(\theta,K)}{\zeta\,\Psi_d[Q^i(\theta,K)]\,f[K,N^i(\theta,K)]}+P^i(\theta,K).$$

The equilibrium search in the investment goods market implies

$$P^i(\theta,K) \;=\; (1-\varphi)\,E\left\{\Omega(\theta',K',k')\,\Pi(\theta,\theta',K)|\,\theta\right\}.$$

Combining the above two equations proves the lemma. □

Lemma 6. *The Euler equation of a firm equates the price of investment with the value of capital tomorrow:*

$$E\left\{P^i(\theta',K')\left[\frac{\Psi_d(Q^i)}{Q^i}f_k(K',N^y(\theta',K'))+(1-\delta)\right]\,\Pi(\theta,\theta',K)\middle|\,\theta\right\}=P^i(\theta,K).$$

Proof. Recall that investment-producing firms choose future capital stock evaluated at K' according to equation (A-2). According to Lemma 5, we can replace $\frac{w(\theta,K)}{\zeta\Psi_d[Q^i(\theta,K)]f(K,N^y(\theta,K))}$ with $\frac{\varphi}{1-\varphi}P^i(\theta,K)$. The same is true for the future variables. The Euler becomes

$$E\left\{\frac{-w(\theta',K')n_k(K',y(\theta',K'))+(1-\delta)P^i(\theta',K')}{1-\varphi}\Pi(\theta,\theta',K)\middle|\,\theta\right\}=\frac{P^i(\theta,K)}{1-\varphi}.$$

Multiplying $1-\varphi$ on both sides and reorganizing the equation, we have

$$E\left\{P^i(\theta',K')\Pi(\theta,\theta',K)\left[-(1-\varphi)\frac{w(\theta',K')n_k(K',y(\theta',K'))}{P^i(\theta',K')}+(1-\delta)\right]\middle|\,\theta\right\}=P^i(\theta,K).$$

Substituting $w(\theta',K')/P^i(\theta',K')$ with $\frac{1}{1-\varphi}\frac{\Psi_d(Q^i)}{Q^i}f_n(K',N^y(\theta',K'))$ from the competitive search problem, we can rewrite the Euler as

$$E\left\{P^i(\theta',K')\Pi(\theta,\theta',K)\left[-\frac{\Psi_d(Q^i)}{Q^i}f_n(K',N^y(\theta',K'))n_k(K',y(\theta',K'))+(1-\delta)\right]\middle|\,\theta\right\}=P^i(\theta,K).$$

According to the implicit function theorem, $n_k\equiv\frac{dn}{dk}=-\frac{f_k}{f_n}$. Thus, $f_k=-f_nn_k$. Substituting

$-f_n n_k$ with f_k in the Euler equation, we have

$$E\left\{P^i(\theta', K')\left[\frac{\Psi_d(Q^i)}{Q^i}f_k(K', N^y(\theta', K')) + (1-\delta)\right]\ \Pi(\theta, \theta', K)\middle|\theta\right\} = P^i(\theta, K).$$

□

A.1 Proof of Proposition 2.

Proof. Let λ be the multiplier for condition (50) and μ be the multiplier for condition (51). The first-order conditions are given by

$$\begin{aligned}
u_C &= \lambda \quad \text{(over } C) \\
u_D &= \lambda\varphi A(D^c)^{\varphi-1}(T)^{1-\varphi}f \quad \text{(over } D^c) \\
\frac{u_N}{\zeta} &= \mu\varphi A(D^i)^{\varphi-1}(1-T)^{1-\varphi}f \quad \text{(over } D^i) \\
u_N &= \lambda A(D^c)^{\varphi}(T)^{1-\varphi}f_n + \mu A(D^i)^{\varphi}(1-T)^{1-\varphi}f_n \quad \text{(over } N^y) \\
\lambda(1-\varphi)A(D^c)^{\varphi}(T)^{-\varphi} &= \mu(1-\varphi)A(D^i)^{\varphi}(1-T)^{-\varphi} \quad \text{(over } T) \\
\mu &= \beta E\left\{\lambda' A'(D^{c\prime})^{\varphi}(T')^{1-\varphi}f_{k'} + \mu' A'(D^{i\prime})^{\varphi}(1-T')^{1-\varphi}f_{k'} + \mu'(1-\delta)|\theta\right\}
\end{aligned}$$

After simplifying, the efficient allocation $\{T,\ D^c,\ D^i,\ N^y,\ C,\ K'\}$ can be characterized by the following six equations:

$$\frac{u_N}{u_C} = A(D^c)^{\varphi}(T)^{-\varphi}f_n \tag{A-3}$$

$$\frac{u_D}{u_C} = \varphi A(D^c)^{\varphi-1}(T)^{1-\varphi}f \tag{A-4}$$

$$f_n = \frac{\varphi\zeta(1-T)f}{D^i} \tag{A-5}$$

$$u_C\frac{(D^c)^{\varphi}(T)^{-\varphi}}{(D^i)^{\varphi}(1-T)^{-\varphi}} = \beta E\left\{u_{c'}\frac{(D^{c\prime})^{\varphi}(T')^{-\varphi}}{(D^{i\prime})^{\varphi}(1-T')^{-\varphi}}\left[A'(D^{i\prime})^{\varphi}(1-T')^{1-\varphi}f_{k'} + (1-\delta)\right]\right\} \tag{A-6}$$

$$C \leq A(D^c)^{\varphi}(T)^{1-\varphi}f(K, N^y) \tag{A-7}$$

$$K' - (1-\delta)K \leq A(D^i)^{\varphi}(1-T)^{1-\varphi}f(K, N^y) \tag{A-8}$$

Equation (A-3) implies that the marginal rate of substitution between consumption and leisure equals the marginal product of labor. Equation (A-4) implies that the marginal rate of substitution between consumption and shopping effort equals the marginal product of shopping in the consumption-goods-producing sector. Equation (A-5) implies that the marginal products of production labor and search labor are the same. Equation (A-6) is the Euler equation for capital. Equations (A-7) and (A-8) are the resource constraints.

To show that the competitive search equilibrium is efficient, we must prove that the equilibrium allocation satisfies equations (A-3)-(A-8). Clearly, the resource constraints (A-7)-(A-8) are satisfied. In equilibrium, wage is equal to both the marginal product of labor of consumer-producing firms and the marginal rate of substitution between leisure and consumption of households, i.e.,

$$\begin{aligned}\frac{w}{P^c} &= \frac{1}{1-\varphi}A(D^c)^{\varphi}(T)^{-\varphi}f_n,\\ \frac{w}{P^c} &= \frac{u_N}{(1-\varphi)u_C}.\end{aligned}$$

Combining these two equations implies that the equilibrium allocation satisfies equation (A-3).

Equation (A-4) is also satisfied through the following two conditions in equilibrium:

$$u_c - \frac{u_D}{A(D^c)^{\varphi-1}(T)^{1-\varphi}f} = P^c\ M,$$

$$P^c = (1-\varphi)\frac{u_c}{M},$$

where M is the expected discounted marginal utility of an additional unit of savings. The first equation is from consumers' optimal choice between consumption and shopping effort. The second equation comes from optimal consumer search.

Similarly, combining consumers' first-order condition over labor with the firms' and consumer's search problems, we can obtain equation (A-5).

Lastly, we show that the Euler equation for capital, equation (A-6), is satisfied. According to Lemma 6 in the paper,

$$E\left\{\Pi(\theta,\theta',K)P^{i\prime}\left[\frac{\Psi_d(Q^{i\prime})}{Q^{i\prime}}f_{k'}+(1-\delta)\right]\right\} = P^i. \tag{A-9}$$

Substituting the definition for Π and $\Psi_d(Q^i)/Q^i = A(D^i)^\varphi(1-T)^{-\varphi}$ into equation (A-9), we have

$$\beta E\left\{\frac{P^c u_{C'}}{P^{c\prime} u_C} P^{i\prime}\left[A'(D^{i\prime})^\varphi(1-T')^{-\varphi} f_{k'} + (1-\delta)\right]\right\} = P^i.$$

Reorganizing the above equation, we have

$$\beta E\left\{\frac{P^{i\prime}}{P^{c\prime}} u_{C'}\left[A'(D^{i\prime})^\varphi(1-T')^{-\varphi} f_{k'} + (1-\delta)\right]\right\} = \frac{P^i}{P^c} u_c.$$

Recall that

$$\frac{P^i}{P^c} = \frac{(D^c)^\varphi(T)^{-\varphi}}{(D^i)^\varphi(1-T)^{-\varphi}}.$$

Thus, the Euler equation in the competitive search equilibrium can be written as

$$\beta E\left\{u_{C'}\frac{(D^{c\prime})^\varphi(T')^{-\varphi}}{(D^{i\prime})^\varphi(1-T')^{-\varphi}}\left[A'(D^{i\prime})^\varphi(1-T')^{-\varphi} f_{k'} + (1-\delta)\right]\right\} = \frac{(D^c)^\varphi(T)^{-\varphi}}{(D^i)^\varphi(1-T)^{-\varphi}} u_c,$$

which is exactly the Euler equation from the social planner's problem, equation (A-6).

□

B Computational Details

Data We used seven raw data series in the paper: GDP, consumption, investment, labor, capacity utilization, stock market price, and relative price of investment. The data series of GDP, consumption, investment, and labor are from the Bureau of Economic Analysis (BEA) for the period of 1948:Q1-2009:Q4. The data series of capacity utilization is the Industrial Production and Capacity Utilization published by the Federal Reserve Board. The series is from 1967:Q1 to 2009Q4 and is based on estimates of capacity utilization for industries in manufacturing, mining, and electric and gas utilities. For a given industry, the capacity utilization rate is equal to an output index (seasonally adjusted) divided by a capacity index. The raw data of S&P 500 stock market price is a monthly data series compiled by Robert Shiller based on the daily price of S&P 500 stock market price, available at *http://www.econ.yale.edu/~shiller/data.htm*. Our quarterly data of stock price is the monthly average of the raw data in each quarter. Lastly, the relative price of investment is from 1948Q1 to 2009Q4, constructed in Ríos-Rull, Schorfheide, Fuentes-Albero, Kryshko, and Santaeulalia-Llopis (2009). We detrend all data series with a Hodrick-Prescott filter.

Computation. The model is estimated using Dynare, which adopts a Metropolis-Hastings algorithm for the Bayesian estimation. Using Dynare, we exploited twelve endogenous variables $\{C,\ I,\ K',\ N^y\ N,\ T,\ D^c,\ D^i,\ P^c,\ P^i,\ R,\ w\}$ with the following twelve equations:

$$
\begin{aligned}
P^i \frac{C^{-\gamma}}{P^c} &= \beta E\left\{P^{i\prime}\frac{(C')^{-\gamma}}{P^{c\prime}}\left[\alpha_k \frac{P^{c\prime}C'}{P^{i\prime}K'T'} + (1-\delta)\right]\right\}, \\
\frac{C^{-\gamma}}{P^c} &= \beta E\left\{\frac{(1+R')(C')^{-\gamma}}{P^{c\prime}}\right\}, \\
(1-\varphi)\frac{w}{P^c} &= \chi\theta_n N^{\frac{1}{\nu}} C^{\gamma}, \\
(1-\varphi)\frac{w}{P^c} &= \alpha_n \frac{C}{N^y T}, \\
\theta_d D^c &= \varphi C^{1-\gamma}, \\
P^c (D^c)^{\varphi} T^{-\varphi} &= P^i (D^i)^{\varphi}(1-T)^{-\varphi}, \\
P^i &= \frac{1-\varphi}{\varphi}\frac{wD^i}{\zeta I}, \\
N &= N^y + D^i/\zeta, \\
C &= A(D^c)^{\varphi}(T)^{1-\varphi} z K^{\alpha_k}(N^y)^{\alpha_n}, \\
I &= A(D^i)^{\varphi}(1-T)^{1-\varphi} z K^{\alpha_k}(N^y)^{\alpha_n}, \\
I &= K' - (1-\delta)K, \\
R &= P^c C - wN.
\end{aligned}
$$

C Additional tables

Table A-1 presents the calibration for the standard RBC model. The intertemporal elasticity of substitution, $1/\gamma$, is set to 0.5, and the real rate of return is 4%. We choose a Frisch elasticity of 0.72. We calibrate the depreciation rate to match the observed consumption to output ratio of 0.8. The labor share is 0.67 in the data, which implies $\alpha_n = 0.67$. The disutility parameter χ is calibrated to match the average time spent at working of 30%. We normalize the mean of the productivity shock such that aggregate output is 1 at steady state.

Table 9: Sensitivity Analysis: Fewer investment shoppers

	Parameters	
	Benchmark	Recalibrated
χ	16.81	16.81
δ	0.07	0.07
α_k	0.31	0.31
α_n	0.59	0.59
z	1.21	1.21
φ	0.09	0.05
A	0.97	0.97
ζ	3.16	3.16

Priors and Posteriors for the Shock Parameters (Likelihood = 2181.72)

Parameter	Density	Para(1)	Para(2)	Mean	90% Intv.	Mode
ρ_d	Beta	0.940	0.05	**0.966**	[0.940, 0.992]	0.962
σ_d	Inverse Gamma	0.080	0.50	**0.126**	[0.104, 0.148]	0.142
ρ_ζ	Beta	0.920	0.05	**0.938**	[0.898, 0.987]	0.933
σ_ζ	Inverse Gamma	0.120	0.50	**0.136**	[0.090, 0.178]	0.165
ρ_z	Beta	0.930	0.05	**0.877**	[0.788, 0.976]	0.958
σ_z	Inverse Gamma	0.003	0.50	**0.004**	[0.001, 0.005]	0.0013
$\rho_{n,1}$	Beta	0.570	0.05	**0.825**	[0.818,0.834]	0.831
$\rho_{n,2}$	Beta	0.220	0.05	**0.174**	[0.162, 0.181]	0.169
σ_n	Inverse Gamma	0.023	0.50	**0.025**	[0.022, 0.027]	0.024
Cor(θ_d, ζ)	Normal	0.000	0.40	**0.288**	[-0.110, 0.896]	-0.089

	Variance Decomposition (%)				Business Cycle Statistics	
	θ_d	ζ	z	θ_n	Variance	Cor w Y
Y	28.88	30.14	16.22	24.76	1.83	1.00
Solow	79.47	6.71	13.12	0.70	1.39	0.72
N	11.37	21.67	1.64	65.32	2.05	0.52
C	74.31	15.94	0.58	9.17	1.71	0.43
I	1.88	76.92	13.19	8.01	42.69	0.69

Note: The table shows the Bayesian estimation and the business cycle properties of the full model with demand shocks ($\theta_n, \theta_d, \zeta$) and a technology shock z. All variables are HP-filtered logarithms of the original series. The estimation targets the data series of consumption, investment, labor supply, and the Solow residual. All priors are assumed to be normal. The sample is quarterly U.S. data, from Q1 in 1960 to Q4 in 2009.

Table 10: Other Business Cycle Statistics for the Full Estimation Shopping Model

	Variance			Correlation with Y		
	Data	RBC	θ_d, ζ z, θ_n	Data	RBC	θ_d, ζ z, θ_n
p_i/p_c	0.47	0	1.96	-0.23	-	-0.02
Stock Market (S&P 500)	42.64	0.01	1.89	0.41	-0.38	0.06
Capacity Utilization	10.02	0	0.62	0.89	-	0.73
Output	2.38	0.82	1.12	1	1	1

Table A-1: Calibration for the Standard RBC Model

Targets	Value	Parameter	Value
Risk aversion	2	γ	2
Real interest rate	4%	β	0.99
Frisch elasticity	0.72	$\frac{1}{\nu}$	0.72
Fraction of time spent working	30%	χ	18.49
Consumption Share of Output	0.80	δ	0.06
Labor Share of income	0.67	α_n	0.67
Units of output	1	z	0.94