

Endogenous Entry, Product Variety, and Business Cycles*

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PRELIMINARY

Comments welcome

Abstract

This paper builds a framework for the analysis of macroeconomic business cycles that incorporates the endogenous determination of the number of producers over the business cycle. Economic expansions induce higher entry rates by prospective entrants subject to irreversible investment costs. The sluggish response of the number of producers (due to the sunk entry costs) generates a new and potentially important endogenous propagation mechanism for real business cycle models (which typically rely on the accumulation of physical capital by a fixed number of producers). The model performs at least as well as the traditional setup with respect to the implied second-moment properties of key macroeconomic aggregates. In addition, consistent with the data, our framework predicts a procyclical number of producers, and procyclical profits even for preference specifications that imply countercyclical markups.

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1 Introduction

The number of firms in the economy varies over the business cycle. Figure 1 shows the quarterly growth rates of real GDP, profits, and net entry in the U.S. economy (measured as the difference between new incorporations and failures) for the period 1947-1998. Net entry is strongly procyclical and comoves with real profits, which are also procyclical. Figure 2 shows cross correlations between real GDP, profits, and net entry (Hodrick-Prescott filtered data in logs) at various leads and lags, with 95 percent confidence bands. The strong procyclicality of net entry and profits is evident, with net entry strongly correlated to profits. Importantly, Figure 2 shows that net entry tends to lead GDP and profit expansions, suggesting that entry in the expectation of future profits may play an important role in GDP expansions.¹

This paper studies the role of producer entry in propagating business cycle fluctuations in a dynamic, stochastic, general equilibrium (DSGE) model with monopolistic competition and sunk entry costs. We seek to understand the contributions of the intensive and extensive margins to the response of the economy to changes in aggregate productivity and market regulation (which affects the size of sunk entry costs). Our theoretical model will equate a producer with a production line for an individual variety/good. We naturally want to account for the empirical reality that new products are not only introduced by new firms, but also by existing firms (most often at their existing production facilities).² We therefore take a broad view of producer entry and exit as also incorporating product creation and destruction by existing firms (although our model does not address the determinants of product variety within firms). Although new firms account for a small share of overall production (for U.S. manufacturing, new firms account for 2-3% of both overall production and employment), the contribution of new products (including those produced at existing firms) is substantially larger – important enough to be a major source of aggregate output fluctuations.

This important contribution of product creation and destruction to aggregate output dynamics is convincingly documented in a new paper by Bernard, Redding, and Schott (2006). They are the first to measure product creation and destruction within firms, across an entire subset of an economy (all of U.S. manufacturing). For every firm, they record production levels (dollar values) across 5-digit

¹The procyclical pattern of net entry is the result of a strongly procyclical pattern of new incorporations and a countercyclical pattern of failures, which correlate negatively with GDP and profits.

²Bernard, Redding, and Schott (2006) report that 94% of product additions by U.S. manufacturing firms occur within their pre-existing production facilities (as opposed to new plants or via mergers and acquisitions).

U.S. SIC categories (which still represent a very coarse definition of products).³ Bernard, Redding, and Schott (2006) first document that product creation and destruction within firms is prevalent: 68% of firms change their product mix within a 5-year census period (representing 93% of firms weighted by output). Of these firms, 66% both add and drop products (representing 87% of firms weighted by output). Thus, product creation over time is not just a secular trend at the firm-level (whereby firms steadily increase the range of products they produce over time). Most importantly, Bernard, Redding, and Schott (2006) show that product creation and destruction accounts for an important share of overall production: Over a 5-year period, the value of new products (produced at existing firms) is 33.6% of overall output during that period (-30.4% of output for the lost value from product destruction at existing firms). These numbers are almost twice (1.8 times) as large as those accounted for by changes at the intensive margin – production increases and decreases for the same product at existing firms. The overall contribution of the extensive margin (product creation and destruction) would be even higher if a finer level of product disaggregation (beyond the 5-digit level) were available.⁴

Put together, product creation (both by existing firms and new firms) accounts for 46.6% of output in a 5-year period while product destruction (by existing and exiting firms) accounts for 44% of output. This represents a minimal annual contribution of 9.3% (for product creation) and 8.8% (for product destruction).⁵ As previously mentioned, annual contributions using a finer level of product disaggregation are probably substantially higher.

We assume symmetric, homothetic preferences over a continuum of goods that nest analytically tractable specifications as special cases. When preferences are specified in the familiar C.E.S. form of Dixit and Stiglitz (1977), frictionless price adjustment results in constant markups. If preferences take the translog form proposed by Feenstra (2003), demand-side pricing complementarities arise that result in time-varying markups. To keep the setup simple, we do not model multi-product firms. In our model presentation below, and in the discussion of results, there is a one-to-one identification between a producer, product, and firm. We do this for consistency with much macroeconomic

³As an example, the 5-digit SIC codes within the 4-digit SIC category 3949–Sporting and Athletics Goods– are: 39491–Fishing tackle and equipment, 39492–Golf equipment, 39493–Playground equipment, 39494–Gymnasium and exercise equipment, and 39495–Other sporting and athletic goods. For all of U.S. manufacturing, there are 1848 5-digit products.

⁴Returning to the example of 5-digit SIC 39494 (Gymnasium and exercise equipment) from the previous footnote: Any production of a new equipment product, whether a treadmill, an elliptical machine, a stationary bike, or any weight machine, would be recorded as production of the same product and hence be counted towards the intensive margin of production.

⁵The true annual contributions are higher as additions and reductions to output across years within the same 5-year interval (for a given firm-product combination) are not recorded.

literature with monopolistic competition, which similarly uses the word firm to refer to the producer of an individual good. However, each productive unit in our setup is best interpreted as a production line within a multi-product firm whose boundaries we can leave unspecified thanks to the assumption of a continuum of goods. The producer is then the profit maximizing manager of this production line. In this interpretation, producer entry and exit in our model capture the product-switching dynamics within firms documented by Bernard, Redding, and Schott (2006).⁶

In our baseline setup, each individual producer/firm produces using only labor. However, the number of firms that produce in each period can be interpreted as the capital stock of the economy, and the decision of households to finance entry of new firms is akin to the decision to accumulate physical capital in the standard real business cycle (RBC) model. In fact, we show that our model relates quite transparently to the traditional RBC model as laid out, for instance, in Campbell (1994). There are significant differences though. We show that firm entry plays an important role in the propagation of responses to shocks. If aggregate productivity increases permanently, the expansion of aggregate GDP initially takes place at the intensive margin, with an increase in output of existing firms. Higher productivity makes entry more attractive and labor is reallocated to creation of new firms. Over time, the number of firms in the economy increases, and output per firm decreases. Further aggregate GDP expansion is the result of an increasing number of producers. In the long run, when preferences are of C.E.S. form, output per firm returns to the initial steady-state level and permanent GDP expansion is entirely driven by the extensive margin. These labor reallocation dynamics and intensive-extensive margin effects are absent in the standard RBC framework. Importantly, even if total labor supply is fixed, and hence net job creation is absent, our model predicts sizeable gross job flows, precisely due to intersectoral reallocations. With translog preferences (for which the elasticity of substitution is increasing in the number of goods produced), our model is further able to generate countercyclical markups without implying countercyclical profits. This is a well-known challenge for models of countercyclical markups based on sticky prices (see Rotemberg and Woodford, 1999, for a discussion).

When it comes to matching second moments of the U.S. business cycle, our model does at least as well as the traditional RBC model, and is subject to similar shortcomings – in particular, excessive smoothness and procyclicality of consumption and labor, and not sufficient endogenous persistence. Inclusion of physical capital does not alter the general conclusions. When capital is

⁶The ability to leave the boundaries of firms unspecified afforded by continuity differentiates our approach from Jaimovich's (2004), who assumes a discrete set of producers within each sector. In that case, the boundaries of firms crucially determine the strategic interaction between individual competitors.

used both in production of goods and to set up new firms, its inclusion can improve the performance of the model along the volatility and persistence dimensions, strengthening the notoriously weak endogenous propagation mechanism of basic RBC models (see Cogley and Nason, 1995). However, a model with capital used only in production of goods is preferable to reproduce evidence on the cyclicity of entry and profits. Since our model performs comparably to the RBC benchmark relative to key aggregate business cycle statistics, and it explains and reproduces features of evidence on which RBC theory is silent, we view the balance of results as favorable to the mechanisms we highlight.

The procyclical nature of entry has been documented, and general equilibrium models with monopolistic competition to study the effect of entry and exit on the dynamics of the business cycle have been developed, before this paper – for instance, in the work of Chatterjee and Cooper (1993) and Devereux, Head, and Lapham (1996*a,b*). However, entry is frictionless in their models: There is no sunk entry cost, and firms enter instantaneously in each period until all profit opportunities are exploited. A fixed period-by-period cost then merely ensures that the number of operating firms is finite; the free-entry condition sets profits to zero in all periods, and the number of firms that produce in each period is not a state variable. This is clearly inconsistent with two pieces of evidence presented above, namely the cyclical variation of profits (Figure 1) and the fact that net entry leads both output and profits (Figure 2). Moreover, this is also inconsistent with observed barriers to entry in most industries. In contrast, entry in our model is subject to a sunk entry cost and a time-to-build lag, and the free entry condition equates the expected present discounted value of profits to the sunk cost. Thus, profits are allowed to vary and the number of firms is a state variable in our model, consistently with the evidence presented above and the widespread view that the number of producing firms is fixed in the short run.⁷ Furthermore, Devereux, Head, and Lapham interpret the number of firms as an endogenous productivity shifter, whereas it is best interpreted as the capital stock of the economy in our model.⁸ Finally, our model exhibits a steady state in which: (i) the share of profits in capital is constant and (ii) the share of investment is positively correlated with the share of profits. These are among the ‘Kaldorian’ growth facts outlined in Cooley and Prescott (1995), which neither the standard RBC model nor the frictionless entry model can account for (the former because it is based on perfect competition, the latter

⁷In fact, our model features a fixed number of producing firms within each period and a fully flexible number of firms in the long run.

⁸Benassy (1996) analyzes the persistence properties of the model developed by Devereux, Head, and Lapham. See also Kim (2004). The dynamics of firm entry and exit have recently received attention in open economy studies. See, for instance, Corsetti, Martin, and Pesenti (2005) and Ghironi and Melitz (2005).

because the share of profits is zero).⁹

Entry subject to sunk costs also distinguishes our model from more recent contributions such as Comin and Gertler (2006) and Jaimovich (2004), who also assume a period-by-period, zero-profit condition. Furthermore, our model features exogenous, RBC-type technology shocks, whereas Comin and Gertler consider endogenous technology and use shocks to the marginal rate of substitution between consumption and leisure as a driving force of business cycles.¹⁰ In addition, our model generates countercyclical markups due to demand-side pricing complementarities; whereas Jaimovich obtains this from supply-side considerations – *i.e.*, increased competition leading to lower markups – and Comin and Gertler simply postulate an *ad hoc* function for markups which is decreasing in the number of firms.¹¹ We prefer a demand-, preference-based explanation for countercyclical markups since data suggest that most of the entering and exiting firms are small, and much of the change in the product space is due to product switching within existing firms rather than entry of entirely new firms, pointing to a limited role for competitive pressures in explaining markup dynamics over the business cycle.¹²

The structure of the paper is as follows. Section 2 presents the benchmark model. Section 3 discusses some key properties of the model and solves for its steady state. Section 4 illustrates the dynamic properties of the model for transmission of economic fluctuations by means of a numerical example, computing impulse responses and second moments of the artificial economy. Section 5 extends the model to include physical capital. Section 6 concludes.

2 The Benchmark Model

Household Preferences and the Intratemporal Consumption Choice

The economy is populated by a unit mass of atomistic households. All contracts and prices are written in nominal terms. Prices are flexible. Thus, we only solve for the real variables in the model. However, as the composition of the consumption basket changes over time due to firm entry (affecting the definition of the consumption-based price index), we introduce money as a

⁹Lewis (2006) builds on the framework of this paper and estimates VAR responses (including those of profits and entry) to macroeconomic shocks, finding support for the sunk-cost driven dynamics predicted by our model.

¹⁰Consistent with standard RBC theory, aggregate productivity shocks affect all firms uniformly in our model. We abstract from the more complex technology diffusion processes across firms of different vintages studied by Caballero and Hammour (1994) and Campbell (1998). We also do not address the growth effects of changes in product variety. Bils and Klenow (2001) document that these effects are empirically relevant for the U.S.

¹¹See also Cook (2001) for a model similar to Jaimovich's.

¹²Bergin and Corsetti (2005) have used the same type of translog preferences in a similar model, looking at issues of stabilization policy.

convenient unit of account for contracts. Money plays no other role in the economy. For this reason, we do not model the demand for cash currency, and resort to a cashless economy as in Woodford (2003).

The representative household supplies L_t hours of work each period t in a competitive labor market for the nominal wage rate W_t and maximizes expected intertemporal utility $E_t [\sum_{s=t}^{\infty} \beta^{s-t} U(C_s, L_s)]$, where C is consumption and $\beta \in (0, 1)$ the subjective discount factor. The period utility function takes the form $U(C_t, L_t) = \ln C_t - \chi (L_t)^{1+1/\varphi} / (1 + 1/\varphi)$, $\chi > 0$, where $\varphi \geq 0$ is the Frisch elasticity of labor supply to wages, and the intertemporal elasticity of substitution in labor supply. As in Campbell (1994), our choice of functional form for the utility function is guided by results in King, Plosser, and Rebelo (1988): Given separable preferences, log utility from consumption ensures that income and substitution effects of real wage variation on effort cancel out in steady state; this guarantees constant steady-state effort and balanced growth – if there is productivity growth.

At time t , the household consumes the basket of goods C_t , defined over a continuum of goods Ω . At any given time t , only a subset of goods $\Omega_t \subset \Omega$ is available. Let $p_t(\omega)$ denote the nominal price of a good $\omega \in \Omega_t$. Our model can be solved for any parametrization of symmetric homothetic preferences. For any such preferences, there exists a well defined consumption index C_t and an associated welfare-based price index P_t . The demand for an individual variety, $c_t(\omega)$, is then obtained as $c_t(\omega)d\omega = C_t \partial P_t / \partial p_t(\omega)$, where we use the conventional notation for quantities with a continuum of goods as flow values.¹³

Given the demand for an individual variety, the symmetric price elasticity of demand ζ is in general a function of the number N_t of goods/producers (where N_t is the mass of Ω_t):

$$\zeta(N_t) \equiv \frac{\partial c_t(\omega)}{\partial p_t(\omega)} \frac{p_t(\omega)}{c_t(\omega)}, \quad \text{for any symmetric variety } \omega.$$

The benefit of additional product variety is described by the relative price ρ :

$$\rho_t(\omega) = \rho(N_t) \equiv \frac{p_t(\omega)}{P_t}, \quad \text{for any symmetric variety } \omega,$$

or, in elasticity form:

$$\epsilon(N_t) \equiv \frac{\rho'(N_t)}{\rho(N_t)} N_t.$$

¹³See the appendix for more details.

Together, $\zeta(N_t)$ and $\rho(N_t)$ completely characterize the effects of preferences in our model; explicit expressions can be obtained for these objects upon specifying functional forms for preferences, as will become clear in the discussion below.

Firms

There is a continuum of monopolistically competitive firms, each producing a different variety $\omega \in \Omega$. Production requires only one factor, labor. Aggregate labor productivity is indexed by Z_t , which represents the effectiveness of one unit of labor. Z_t is exogenous and follows an $AR(1)$ process (in logarithms). Output supplied by firm ω is $y_t(\omega) = Z_t l_t(\omega)$, where $l_t(\omega)$ is the firm's labor demand for productive purposes. The unit cost of production, in units of the consumption good C_t , is w_t/Z_t , where $w_t \equiv W_t/P_t$ is the real wage.

Prior to entry, firms face a sunk entry cost of $f_{E,t}$ effective labor units, equal to $w_t f_{E,t}/Z_t$ units of the consumption good. The sunk entry cost $f_{E,t}$ is exogenous and subject to shocks. (We interpret a permanent decrease as deregulation that lowers the size of entry barriers below.) There are no fixed production costs. Hence, all firms that enter the economy produce in every period, until they are hit with a “death” shock, which occurs with probability $\delta \in (0, 1)$ in every period.¹⁴

Given our modeling assumption relating each firm to an individual variety, we think of a firm as a production line for that variety, and the entry cost as the development and setup cost associated with the latter (potentially influenced by market regulation). The exogenous “death” shock also takes place at the individual variety level. Empirically, a firm may comprise more than one of these production lines. Our model does not address the determination of product variety within firms, but our main results would be unaffected by the introduction of multi-product firms.

Given the demand function for each good (where the elasticity of demand can depend on the number of goods), firms set prices in a flexible fashion as markups over marginal costs. In units of consumption, firm ω 's price is $\rho_t(\omega) \equiv p_t(\omega)/P_t = \mu_t w_t/Z_t$, where the markup is a function of the number of producers: $\mu_t = \mu(N_t) \equiv \zeta(N_t)/(\zeta(N_t) - 1)$. The firm's profit in units of consumption, returned to households as dividend, is $d_t(\omega) = d_t = \left(1 - \mu(N_t)^{-1}\right) Y_t^C/N_t$, where Y_t^C is total output of the consumption sector and will in equilibrium be equal to total consumption demand C_t .

¹⁴For simplicity, we do not consider endogenous exit. Appropriate calibration of δ makes it possible for our model to match several important features of the data.

Preference Specifications and Markups

In our quantitative exercises, we consider two alternative preference specifications. The first features constant elasticity of substitution between goods as in Dixit and Stiglitz (1977). For these C.E.S. preferences, the consumption aggregator is $C_t = \left(\int_{\omega \in \Omega} c_t(\omega)^{\theta-1/\theta} d\omega \right)^{\theta/(\theta-1)}$, where $\theta > 1$ is the symmetric elasticity of substitution across goods. The consumption-based price index is then $P_t = \left(\int_{\omega \in \Omega_t} p_t(\omega)^{1-\theta} d\omega \right)^{1/(1-\theta)}$, and the household's demand for each individual good ω is $c_t(\omega) = (p_t(\omega)/P_t)^{-\theta} C_t$. It follows that the markup and the benefit of variety are independent of the number of goods ($\epsilon(N_t) = \epsilon, \mu(N_t) = \mu$) and related by $\epsilon = \mu - 1 = 1/(\theta - 1)$.¹⁵ The second specification uses the translog expenditure function proposed by Feenstra (2003), which introduces demand-side pricing complementarities. For this preference specification, the symmetric price elasticity of demand is $1 + \sigma N_t$, $\sigma > 0$: As N_t increases, goods become closer substitutes, and the elasticity of substitution increases. If goods are closer substitutes, then the markup $\mu(N_t)$ and the benefit of additional varieties in elasticity form ($\epsilon(N_t)$) must decrease.¹⁶ The change in $\epsilon(N_t)$ is only half the change in net markup generated by an increase in the number of producers. Table 1 contains the expressions for markup and relative price, and the elasticity of each of them to the number of firms, for each preference specification.

Table 1. Two frameworks	
C.E.S.	Translog
$\mu(N_t) = \mu = \frac{\theta}{\theta-1}$	$\mu(N_t) = \mu(N_t) = 1 + \frac{1}{\sigma N_t}$
$\mu'(N_t) = 0 \Rightarrow \eta_t \equiv \frac{\mu'(N_t)N_t}{\mu(N_t)} = 0$	$\mu'(N_t) = -\frac{1}{\sigma N_t^2} \Rightarrow \eta_t \equiv \frac{\mu'(N_t)N_t}{\mu(N_t)} = -\frac{1}{1+\sigma N_t}$
$\rho(N_t) = N_t^{\mu-1} \left(N_t^{\frac{1}{\theta-1}} \right)$	$\rho(N_t) = e^{-\frac{1}{2} \frac{N_t - N_t}{\sigma N_t}}, \quad \tilde{N} \equiv Mass(\Omega)$
$\epsilon(N_t) \equiv \frac{\rho'(N_t)N_t}{\rho(N_t)} = \mu - 1$	$\epsilon(N_t) \equiv \frac{\rho'(N_t)N_t}{\rho(N_t)} = \frac{1}{2\sigma N_t} = \frac{1}{2} [\mu(N_t) - 1]$

Firm Entry and Exit

In every period, there is a mass N_t of firms producing in the economy and an unbounded mass of prospective entrants. These entrants are forward looking, and correctly anticipate their expected

¹⁵ An alternative setup would have the household consume a homogeneous good produced by a competitive sector that bundles intermediate goods using a production function that has the form of our consumption basket. All our results would hold also in that setup, though the interpretation would be different. In our setup, consumers derive welfare directly from availability of more varieties. In the alternative setup, an increased range of intermediate goods shows up as increasing returns to specialization. Empirical problems associated with increasing returns to specialization and a C.E.S. production function induce us to adopt the specification without intermediate varieties.

¹⁶ This property for the markup **occurs** whenever the price elasticity of residual demand decreases with quantity consumed along the residual demand curve.

future profits $d_s(\omega)$ in every period $s \geq t + 1$ as well as the probability δ (in every period) of incurring the exit-inducing shock. Entrants at time t only start producing at time $t + 1$, which introduces a one-period time-to-build lag in the model. The exogenous exit shock occurs at the very end of the time period (after production and entry). A proportion δ of new entrants will therefore never produce. Prospective entrants in period t compute their expected post-entry value ($v_t(\omega)$) given by the present discounted value of their expected stream of profits $\{d_s(\omega)\}_{s=t+1}^\infty$:

$$v_t(\omega) = E_t \sum_{s=t+1}^{\infty} [\beta(1-\delta)]^{s-t} \left(\frac{C_s}{C_t}\right)^{-1} d_s(\omega). \quad (1)$$

This also represents the value of incumbent firms *after* production has occurred (since both new entrants and incumbents then face the same probability $1 - \delta$ of survival and production in the subsequent period). Entry occurs until firm value is equalized with the entry cost, leading to the free entry condition $v_t(\omega) = w_t f_{E,t}/Z_t$. This condition holds so long as the mass $N_{E,t}$ of entrants is positive. We assume that macroeconomic shocks are small enough for this condition to hold in every period. Finally, the timing of entry and production we have assumed implies that the number of producing firms during period t is given by $N_t = (1 - \delta)(N_{t-1} + N_{E,t-1})$. The number of producing firms represents the stock of capital of the economy. It is an endogenous state variable that behaves much like physical capital in the benchmark RBC model.

Symmetric Firm Equilibrium

All firms face the same marginal cost. Hence, equilibrium prices, quantities, and firm values are identical across firms: $p_t(\omega) = p_t$, $\rho_t(\omega) = \rho_t$, $l_t(\omega) = l_t$, $y_t(\omega) = y_t$, $d_t(\omega) = d_t$, $v_t(\omega) = v_t$. In turn, equality of prices across firms implies that the consumption-based price index P_t and the firm-level price p_t are such that $p_t/P_t \equiv \rho_t = \rho(N_t)$. An increase in the number of firms implies necessarily that the relative price of each individual good increases $\rho'(N_t) > 0$. When there are more firms, households derive more welfare from spending a given nominal amount, *i.e.*, *ceteris paribus*, the price index decreases. It follows that the relative price of each individual good must rise.¹⁷ The aggregate consumption output of the economy is $Y_t^C = N_t \rho_t y_t = C_t$.

Importantly, in the symmetric firm equilibrium, the value of waiting to enter is zero, despite the entry decision being subject to sunk cost and exit risk; *i.e.*, there are no option-value considerations

¹⁷In the alternative setup with homogeneous consumption produced by aggregating intermediate goods, an increase in the number of intermediates available implies that the competitive sector producing consumption becomes more efficient, and the relative price of each individual input relative to consumption rises accordingly.

pertaining to the entry decision.¹⁸ This happens because all uncertainty in our model (including the “death” shock) is aggregate. Let the option value of waiting to enter for firm ω be $\Lambda_t(\omega) \geq 0$. In all periods t , $\Lambda_t(\omega) = \max[v_t(\omega) - w_t f_{E,t}/Z_t, \beta \Lambda_{t+1}(\omega)]$, where the first term is the payoff of undertaking the investment and the second term is the discounted payoff of waiting. If firms are identical (there is no idiosyncratic uncertainty) and exit is exogenous (uncertainty related to firm death is also aggregate), this becomes: $\Lambda_t = \max[v_t - w_t f_{E,t}/Z_t, \beta \Lambda_{t+1}]$. Because of free entry, the first term is always zero, so the option value obeys: $\Lambda_t = \beta \Lambda_{t+1}$. This is a contraction mapping because of discounting, and by forward iteration, under the assumption $\lim_{T \rightarrow \infty} \beta^T \Lambda_{t+T} = 0$ (*i.e.*, there is a zero value of waiting when reaching the terminal period), the only stable solution for the option value is $\Lambda_t = 0$.

Household Budget Constraint and Intertemporal Decisions

Households hold two types of assets: shares in a mutual fund of firms and risk-free bonds. (We assume that bonds pay risk-free, consumption-based real returns.) Let x_t be the share in the mutual fund of firms held by the representative household *entering* period t . The mutual fund pays a total profit in each period (in units of currency) equal to the total profit of all firms that produce in that period, $P_t N_t d_t$. During period t , the representative household buys x_{t+1} shares in a mutual fund of $N_{H,t} \equiv N_t + N_{E,t}$ firms (those already operating at time t and the new entrants). Only $N_{t+1} = (1 - \delta) N_{H,t}$ firms will produce and pay dividends at time $t + 1$. Since the household does not know which firms will be hit by the exogenous exit shock δ at the *very end* of period t , it finances the continuing operation of all pre-existing firms and all new entrants during period t . The date t price (in units of currency) of a claim to the future profit stream of the mutual fund of $N_{H,t}$ firms is equal to the nominal price of claims to future firm profits, $P_t v_t$.¹⁹

The household enters period t with bond holdings B_t in units of consumption and mutual fund share holdings x_t . It receives gross interest income on bond holdings, dividend income on mutual fund share holdings and the value of selling its initial share position, and labor income. The household allocates these resources between purchases of bonds and shares to be carried into

¹⁸This is in contrast with models such as Caballero and Hammour (1995) and Campbell (1998).

¹⁹New entrants finance entry on the stock market in our model. This is consistent with observed behavior of existing firms, raising capital on the stock market to finance new projects – new production lines – as in our favored model interpretation. On the other hand, the empirical evidence on new firms is that they mostly borrow from banks to cover entry costs. Cetorelli and Strahan (2006) find that monopoly power in banking constitutes a barrier to firm entry in the U.S. economy. Stebunovs (in progress) extends the model of this paper to study the consequences of finance as a barrier to entry.

next period, and consumption. The period budget constraint (in units of consumption) is:

$$B_{t+1} + v_t N_{H,t} x_{t+1} + C_t = (1 + r_t) B_t + (d_t + v_t) N_t x_t + w_t L_t, \quad (2)$$

where r_t is the consumption-based interest rate on holdings of bonds between $t - 1$ and t (known with certainty as of $t - 1$). The household maximizes its expected intertemporal utility subject to (2).

The Euler equations for bond and share holdings are:

$$(C_t)^{-1} = \beta (1 + r_{t+1}) E_t \left[(C_{t+1})^{-1} \right], \quad \text{and} \quad v_t = \beta (1 - \delta) E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} (v_{t+1} + d_{t+1}) \right].$$

As expected, forward iteration of the equation for share holdings and absence of speculative bubbles yield the asset price solution in equation (1).²⁰

Finally, the allocation of labor effort obeys the standard intratemporal first-order condition:

$$\chi (L_t)^{\frac{1}{\varphi}} = \frac{w_t}{C_t}. \quad (3)$$

Aggregate Accounting, Equilibrium, and the Labor Market

Aggregating the budget constraint (2) across households and imposing the equilibrium conditions $B_{t+1} = B_t = 0$ and $x_{t+1} = x_t = 1 \forall t$ yields the aggregate accounting identity $C_t + N_{E,t} v_t = w_t L_t + N_t d_t$: Total consumption plus investment (in new firms) must be equal to total income (labor income plus dividend income).

Different from the benchmark, one-sector, RBC model of Campbell (1994) and many other studies, our model economy is a two-sector economy in which one sector employs part of the labor endowment to produce consumption and the other sector employs the rest of the labor endowment to produce new firms. The economy's GDP, Y_t , is equal to total income, $w_t L_t + N_t d_t$. In turn, Y_t is also the total output of the economy, given by consumption output, $Y_t^C (= C_t)$, plus investment output, $N_{E,t} v_t$. With this in mind, v_t is the relative price of the investment "good" in terms of consumption.

Labor market equilibrium requires that the total amount of labor used in production and to set

²⁰We omit the transversality conditions for bonds and shares that must be satisfied to ensure optimality. Note that the interest rate is determined residually in our economy (it appears only in the Euler equation for bonds and is fully determined once consumption is determined). This is due to the absence of physical capital. Indeed, what is crucial in our economy for the allocation of intertemporal consumption is the return on shares.

up the new entrants' plants must equal aggregate labor supply: $L_t^C + L_t^E = L_t$, where $L_t^C = N_t l_t$ is the total amount of labor used in production of consumption, and $L_t^E = N_{E,t} f_{E,t} / Z_t$ is labor used to build new firms.²¹ In the benchmark RBC model, physical capital is accumulated by using as investment part of the output of the same good used for consumption. In other words, all labor is allocated to the only productive sector of the economy. When labor supply is fixed, there are no labor market dynamics in the model, other than the determination of the equilibrium wage along a vertical supply curve. In our model, even when labor supply is fixed (the case $\varphi = 0$), labor market dynamics arise in the allocation of labor between production of consumption and creation of new plants. The allocation is determined jointly by the entry decision of prospective entrants and the portfolio decision of households who finance that entry. The value of firms, or the relative price of investment in terms of consumption v_t , plays a crucial role in determining this allocation.²²

Aggregate Production and the Role of Variety

Rearranging the labor market clearing condition yields the following expression for aggregate production of the consumption good:

$$Y_t^C = C_t = Z_t \rho_t \left(L_t - \frac{f_{E,t}}{Z_t} N_{E,t} \right).$$

In turn, substituting this into $C_t + N_{E,t} v_t = Y_t$ and using firm pricing and free entry gives:

$$Y_t = Z_t \rho_t \left(L_t - \frac{\mu_t - 1}{\mu_t} \frac{f_{E,t}}{Z_t} N_{E,t} \right).$$

These expressions resemble analogous expressions in Chatterjee and Cooper (1993) and Devereux, Head, and Lapham (1996a,b). An increase in the number of entrants $N_{E,t}$ absorbs productive resources in the form of effective labor and acts like an overhead cost. This cost is accounted for differently in GDP, since this recognizes that firm entry is productive. *Ceteris paribus*, when $\mu_t \rightarrow 1$ (perfect competition), $\rho_t \rightarrow 1$, and the expression for Y_t reduces to a familiar Cobb-Douglas production function with a zero share of capital: $Y_t = Z_t L_t$.²³

Chatterjee and Cooper (1993) and Devereux, Head, and Lapham (1996a,b) interpret the effect

²¹We used the equilibrium condition $y_t = Z_t l_t = c_t = (\rho_t)^{-\theta} C_t$ in the expression for L_t^C .

²²With elastic labor supply, labor market dynamics operate along two margins as the interaction of household and entry decisions determines jointly the total amount of labor and its allocation to the two sectors of the economy.

²³In the C.E.S. case, $\rho_t = (N_t)^{\frac{1}{\theta-1}} \rightarrow 1$ when $\theta \rightarrow \infty$. In the translog case, perfect competition similarly corresponds to infinite substitutability across goods, with $\rho_t = \rho(N_t) \rightarrow 1$ (see Table 1).

of changes in the number of active firms N_t in the expressions above as an endogenous aggregate productivity shifter. Since $\rho'(N_t) > 0$, an increase in the number of active firms N_t has a similar effect to that of an endogenous increase in productivity. As there is no sunk entry cost nor time-to-build lag in those studies, such endogenous productivity changes do not impart endogenous persistence in those models, in contrast to ours. If we think of the effect of entry as endogenously affecting productivity in our model, entry at time t affects labor demand at $t + 1$ because it affects productivity of labor at $t + 1$ by causing N_{t+1} to rise.

We prefer to interpret N_t as the stock of capital (production lines) of the economy during period t , treating aggregate productivity Z_t as exogenous in production of the consumption good, $Y_t^C = Z_t \rho_t N_t l_t$, and in production of new plants. There are three reasons for this. First, it is transparent to treat labor per firm and the number of firms as the factors of production in the aggregate function $Y_t^C = Z_t \rho_t N_t l_t$, in which Z_t is exogenous productivity, and the relative price ρ_t converts units of individual goods into units of consumption. In this interpretation, which does not hinge on the properties of homothetic-preferences-based demand to endogenize productivity relative to the number of firms, entry at t affects labor demand at $t + 1$ because it increases the number of producing firms at $t + 1$. This is akin to the benchmark RBC model, where investment at t affects labor demand at $t + 1$ by increasing the capital stock used in production at $t + 1$. Second, capital accumulation in the RBC model can be viewed as an extreme case in which all observed investment goes toward the production of existing goods. Our baseline framework studies another possible extreme case, in which all investment is accounted for by the creation of new products. In a final section, we study a setup in which investment is split endogenously between the creation of new products and augmenting the physical capital stock of the economy. Finally, as argued in Ghironi and Melitz (2005), empirically relevant variables – as opposed to welfare-consistent concepts – net out the effect of changes in the range of available varieties. The reason is that construction of CPI data by statistical agencies does not adjust for availability of new varieties as in the welfare-consistent price index.²⁴ CPI data are closer to p_t than P_t . For this reason, when investigating the properties of the model in relation to the data (for instance, when computing second moments or impulse responses for comparison with empirical evidence), one wants to focus on real variables deflated by a data-consistent price index. For any variable X_t in units of the consumption basket, such data-consistent counterpart is obtained as $X_{R,t} \equiv P_t X_t / p_t = X_t / \rho_t = X_t / \rho(N_t)$. Therefore,

²⁴ Adjustment for variety, when it happens, certainly does not happen at the frequency represented by periods in our model.

data-consistent measures of consumption output and GDP in our model are $Y_{R,t}^C = Z_t L_t - f_{E,t} N_{E,t}$ and $Y_{R,t} = Z_t L_t - \frac{\mu_t - 1}{\mu_t} f_{E,t} N_{E,t}$, which remove the role of variety as an endogenous productivity shifter.²⁵

Model Summary

Table 2 summarizes the main equilibrium conditions of the model.²⁶ The equations in the table constitute a system of ten equations in ten endogenous variables: $\rho_t, \mu_t, d_t, w_t, L_t, N_{E,t}, N_t, r_t, v_t, C_t$. Of these endogenous variables, two are predetermined as of time t : the total number of firms, N_t , and the risk-free interest rate, r_t . Additionally, the model features two exogenous variables: aggregate productivity, Z_t , and the sunk entry cost, $f_{E,t}$. The latter may be interpreted in at least two ways. Part of the sunk entry cost $f_{E,t}$ originates in the economy's technology for creation of new plants, which is exogenous and outside the control of policymakers. But another part of the entry cost is motivated by regulation and entry barriers induced by policy. Holding the technology component of $f_{E,t}$ given, we interpret changes in $f_{E,t}$ below as changes in market regulation facing firms.²⁷

Table 2. Benchmark Model, Summary

Pricing	$\rho_t = \mu_t \frac{w_t}{Z_t}$
Markup	$\mu_t = \mu(N_t)$
Variety effect	$\rho_t = \rho(N_t)$
Profits	$d_t = \left(1 - \frac{1}{\mu_t}\right) \frac{C_t}{N_t}$
Free entry	$v_t = w_t \frac{f_{E,t}}{Z_t}$
Number of firms	$N_t = (1 - \delta)(N_{t-1} + N_{E,t-1})$
Intratemporal optimality	$\chi(L_t)^{\frac{1}{\varphi}} = \frac{w_t}{C_t}$
Euler equation (bonds)	$(C_t)^{-1} = \beta(1 + r_{t+1}) E_t \left[(C_{t+1})^{-1} \right]$
Euler equation (shares)	$v_t = \beta(1 - \delta) E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} (v_{t+1} + d_{t+1}) \right]$
Aggregate accounting	$C_t + N_{E,t} v_t = w_t L_t + N_t d_t$

²⁵Treating aggregate productivity as exogenous in the absence of firm heterogeneity and endogenous exit is also consistent with Melitz (2003).

²⁶The labor market equilibrium condition is redundant once the variety effect equation is included in the system in Table 2.

²⁷We focus on random shocks to Z_t as the source of business cycle fluctuations in our model, assuming that changes in market regulation do not take place at business cycle frequency. Results on the consequences of government spending shocks in our model are available on request.

3 Benchmark Model Properties and Solution

We can reduce the system in Table 2 to a system of two equations in two variables, N_t and C_t . To see this, write firm value as a function of the endogenous state N_t and the exogenous state $f_{E,t}$ by combining free entry, the pricing equation, and the two equations emphasizing the dependence of markup and variety effect on the number of firms:

$$v_t = f_{E,t} \frac{\rho(N_t)}{\mu(N_t)}. \quad (4)$$

Equation (4) and the free entry condition in Table 2 yield a first, important set of results: Since the number of producing firms is predetermined and does not react to exogenous shocks on impact, firm value and the real wage are also predetermined with respect to some exogenous shocks. Namely, firm value is predetermined with respect to all shocks but deregulation, while the real wage ($w_t = Z_t \rho(N_t) / \mu(N_t)$) is predetermined with respect to all shocks but productivity. A fall in the sunk entry cost encourages entry and decreases firm value since more firms start producing at $t+1$, which implies an expected decrease in demand for each individual firm. An increase in productivity results in a proportional increase in the real wage on impact through its effect on labor demand. Since the entry cost is paid in effective labor units, this does not affect firm value. An implication of the wage schedule $w_t = Z_t \rho(N_t) / \mu(N_t)$ is also that marginal cost, w_t / Z_t , is predetermined with respect to all shocks.

The number of new entrants as a function of consumption and number of firms is $N_{E,t} = Z_t L_t / f_{E,t} - C_t / (f_{E,t} \rho(N_t))$. Substituting this, equations (4) and (3), and the expression for profits in the law of motion for N_t (scrolled one period forward) and the Euler equation for shares yields:

$$N_{t+1} = (1 - \delta) \left[N_t + \frac{Z_t}{f_{E,t}} \left(\frac{1}{C_t} \frac{\rho(N_t)}{\mu(N_t)} \frac{Z_t}{\chi} \right)^\varphi - \frac{C_t}{f_{E,t} \rho(N_t)} \right], \quad (5)$$

$$f_{E,t} \frac{\rho(N_t)}{\mu(N_t)} = \beta (1 - \delta) E_t \left\{ \frac{C_t}{C_{t+1}} \left[f_{E,t+1} \frac{\rho(N_{t+1})}{\mu(N_{t+1})} + \left(1 - \frac{1}{\mu(N_{t+1})} \right) \frac{C_{t+1}}{N_{t+1}} \right] \right\}. \quad (6)$$

Steady State and Calibration

We assume that exogenous variables are constant in steady state and denote steady-state levels of variables by dropping the time subscript: $Z_t = Z$, and $f_{E,t} = f_E$. We conjecture that all endogenous variables are constant in steady state and show that this is indeed the case.²⁸ The

²⁸Our model would exhibit endogenous growth if the cost of entry were a decreasing function of the number of producers, as in Grossman and Helpman (1991). We abstract from by now well understood growth considerations in

steady-state interest rate is pinned down as usual by the rate of time preference, $1 + r = \beta^{-1}$; the gross return on shares is $1 + d/v = (1 + r)/(1 - \delta)$, which captures a premium for expected firm destruction. The number of new entrants makes up for the exogenous destruction of existing firms: $N_E = \delta N / (1 - \delta)$. We follow Campbell (1994) below and exploit $1 + r = \beta^{-1}$ to treat r as a parameter in the solution.

Calculating the shares of profit income and investment in consumption output and GDP allows us to draw another transparent comparison between our model and the standard RBC setup. The steady-state profit equation gives the share of profit income in consumption output: $dN/Y^C = (\mu - 1)/\mu$. Using this result in conjunction with those obtained above, we have the share of investment in consumption output:

$$\frac{vN_E}{Y^C} = \frac{\delta}{r + \delta} \frac{\mu - 1}{\mu}.$$

This expression is similar to its RBC counterpart. There, the share of investment in output is given by $s_K \delta / (r + \delta)$, where δ is the depreciation rate of capital and s_K is the share of capital income in total income. In our framework, $(\mu - 1)/\mu$ can be regarded as governing the share of “capital” since it dictates the degree of monopoly power and hence the share of profits that firms generate from producing consumption output (dN/Y^C). Noting that $Y = Y^C + vN_E$, the shares of investment and profit income in GDP are $vN_E/Y = \delta / \left[\delta + \frac{\mu}{\mu - 1} (r + \delta) \right]$ and $dN/Y = (r + \delta) / \left[\delta + \frac{\mu}{\mu - 1} (r + \delta) \right]$, respectively. It follows that the share of private consumption in GDP is $C/Y = \frac{\mu}{\mu - 1} (r + \delta) / \left[\delta + \frac{\mu}{\mu - 1} (r + \delta) \right]$. The share of labor income in total income is $wL/Y = 1 - (r + \delta) / \left[\delta + \frac{\mu}{\mu - 1} (r + \delta) \right]$. Importantly, all these ratios are constant (which would hold also along a balanced growth path if we incorporated exogenous productivity growth) as consistent with the Kaldorian growth facts.²⁹ In fact, our model’s long-run properties are consistent with two stylized facts – originally found by Kaldor – pertaining to growth that are absent from the standard RBC model. Namely, our model embeds a constant share of profits in total capital, $dN/vN = (r + \delta) / (1 - \delta)$, and, relatedly, a high correlation between the profit share in GDP and the investment share in GDP. These facts are absent from both the standard RBC model and the frictionless entry models reviewed in the Introduction.

Equations (5)-(6) allow us to solve for the steady-state number of firms and consumption (and

order to focus on the business cycle implications of entry.

²⁹Note that all ratios calculated above are identical if we compute them in terms of empirically relevant variables deflated by the average price p .

therefore all other variables) by solving the equations:

$$N = [\chi(r + \delta)]^{-\varphi} \left[(1 - \delta) \frac{Z}{f_E} \right]^{1+\varphi} \frac{\left(\frac{\mu(N)-1}{N\mu(N)} \right)^\varphi}{\delta + \frac{r+\delta}{\mu(N)-1}}, \quad (7)$$

$$C = \frac{r + \delta}{1 - \delta} \frac{\rho(N)}{\mu(N) - 1} N f_E. \quad (8)$$

To obtain a closed-form solution for the steady state, we distinguish according to the two functional forms for preferences (and therefore the markup and variety functions) considered above. In the C.E.S. case, the markup is always equal to a constant: $\mu(N) = \theta / (\theta - 1)$, and the variety effect is governed by $\rho(N) = N^{\frac{1}{\theta-1}}$. The solution is:

$$N^{CES} = \frac{(1 - \delta)}{\chi\theta(r + \delta)} \left[\frac{\chi\theta(r + \delta)}{\theta(r + \delta) - r} \right]^{\frac{1}{1+\varphi}} \frac{Z}{f_E}, \quad (9)$$

$$C^{CES} = \frac{(r + \delta)(\theta - 1)}{1 - \delta} f_E (N^{CES})^{\frac{\theta}{\theta-1}}. \quad (10)$$

Intuitively, an increase in long-run productivity results in a larger number of firms (and hence higher firm value, $v = [(\theta - 1) / \theta] f_E (N^{CES})^{\frac{1}{\theta-1}}$, and consumption). Deregulation (a lower sunk entry cost) also generates an increase in the long-run number of firms and consumption, and it increases firm value as a proportion of the sunk cost itself (v/f_E).³⁰ The effect of deregulation on v^{CES} depends on whether θ is larger or smaller than two. Empirically plausible values of θ , which satisfy $\theta > 2$, imply that deregulation has a negative effect on firm value. Importantly, C^{CES} and N^{CES} tend to zero if θ tends to infinite. For firms to find it profitable to enter, the expected present discounted value of the future profit stream must be positive, so as to offset the sunk entry cost. But profits tend to zero in all periods if firms have no monopoly power. This implies that no firm will enter the economy, driving N^{CES} and C^{CES} to zero.

Of particular interest is the behavior of the real wage, given by:

$$w^{CES} = \frac{\theta - 1}{\theta} Z (N^{CES})^{\frac{1}{\theta-1}} = \frac{\theta - 1}{\theta} Z \left[\frac{Z}{f_E} \frac{(1 - \delta)}{\chi\theta(r + \delta)} \right]^{\frac{1}{\theta-1}} \left[\frac{\chi\theta(r + \delta)}{\theta(r + \delta) - r} \right]^{\frac{1}{(1+\varphi)(\theta-1)}}.$$

Both higher productivity and deregulation result in a higher wage, as a larger number of firms puts pressure on labor demand. Most importantly, deregulation and higher productivity cause

³⁰See Alesina, Ardagna, Nicoletti, and Schiantarelli (2005) for empirical evidence supporting the view that deregulation generates entry and therefore stimulates investment.

steady-state marginal cost w/Z to increase (the long-run elasticity being $1/(\theta - 1)$). This is in sharp contrast to models with a constant number of firms, where marginal cost would be constant relative to long-run changes in productivity. (To see this, set $N = 1$ for convenience and note that $w/Z = (\theta - 1)/\theta$ in this case.) Changes in productivity would be reflected in equal percentage changes in the real wage, so that marginal cost remains constant.³¹ In a model with endogenous number of firms, higher productivity results in a more attractive business environment, which leads to more entry and a larger number of firms. This puts pressure on labor demand that causes w to increase by more than Z , so that the new long-run marginal cost is higher than the original one.³² Given solutions for v , C , N , and w/Z , it is easy to recover solutions for all other variables in Table 2, which we omit. To complete the information on the steady-state properties of the model with CES preferences, Table 3 reports the long-run elasticities of endogenous variables to permanent changes in Z and f_E .

Table 3. Benchmark Model, C.E.S., Long-Run Elasticities

Elasticity of \Downarrow w.r.t. \Rightarrow	Z	f_E
N, N_E	1	-1
w	$\frac{\theta}{\theta-1}$	$-\frac{1}{\theta-1}$
v, d	$\frac{1}{\theta-1}$	$\frac{\theta-2}{\theta-1}$
C, Y	$\frac{\theta}{\theta-1}$	$-\frac{1}{\theta-1}$

In the translog case, the steady-state markup function is $\mu(N) = 1 + \frac{1}{\sigma N}$. Substituting this in (7), we obtain:

$$N = \left((1 - \delta) \frac{Z}{f_E} \right)^{1+\varphi} \left(\frac{1}{\chi(r + \delta)} \right)^\varphi \frac{[N(1 + \sigma N)]^{-\varphi}}{(\delta + \sigma N(r + \delta))} \equiv H(N), \quad (11)$$

which shows that N^{Trans} is a fixed point of the function $H(N)$. Since $H(N)$ is continuous and $\lim_{N \rightarrow 0} H(N) = \infty$ and $\lim_{N \rightarrow \infty} H(N) = 0$, $H(N)$ has a unique fixed point if and only if $H'(N) \leq 0$. Straightforward differentiation of $H(N)$ shows that this is indeed the case, and hence there exists

³¹In fact, marginal cost ($w_t/Z_t = \rho_t/\mu_t$) would be constant in all periods, in and out of the steady state, if the number of firms were constant – and $N_t = 1$ would imply $\rho_t = 1$ and $\mu_t = \mu$, as in standard models without entry. (To see this in the translog case in Table 2, set $N_t = \tilde{N} = 1$.) In our model, even the data-consistent measure of marginal cost $w_{R,t}/Z_t = (w_t/Z_t)/\rho_t = 1/\mu_t$ is not constant (except for C.E.S. preferences): Indeed, it is procyclical whenever markups are countercyclical.

³²This mechanism is central for Ghironi and Melitz's (2005) result that a permanent increase in productivity results in higher average prices and an appreciated real exchange rate in the country that experiences such higher productivity relative to its trading partners.

a unique N^{Trans} that solves the nonlinear equation (11). In the special case of inelastic labor ($\varphi = 0$), a closed-form solution can be obtained as:

$$N_{\varphi=0}^{Trans} = \frac{-\delta + \sqrt{\delta^2 + 4\sigma \frac{Z}{f_E} (r + \delta) (1 - \delta)}}{2\sigma (r + \delta)}. \quad (12)$$

An intuitive explanation of the effects of long-run increases in technology and deregulation is possible. Suppose that $Z = f_E = 1$. An increase in Z , or a decrease in f_E , from the initial value of 1 shifts the $H(N)$ schedule upward, and hence leads to an increase in N^{Trans} . This increase is larger, the larger the elasticity of labor supply. Since $\rho'(N) > 0$ and $\mu'(N) < 0$, the increase in technology also translates into a permanent increase in consumption, the value of the firm, wage and marginal cost (recall that for $f_E = 1$, $v = w/Z = \rho(N)/\mu(N)$).

In the quantitative exercises below, we use a specific calibration scheme, which ensures that steady-state number of firms and markup under translog preferences are the same as under C.E.S. (We make this assumption since we only observe one set of data, and hence only one value for N and μ .) We can achieve this for translog preferences by an appropriate choice of the parameter σ , which can be explained intuitively for the case $\varphi = 0$ with reference to Figure 3. In the C.E.S. case, the relevant $H(N)$ function is a constant, and the equilibrium is given by $H^{CES} \equiv \frac{1-\delta}{\theta(r+\delta)-r} \frac{Z}{f_E} = N$, represented by the dotted horizontal line. The intersection of this with the 45 degree line determines the number of firms in steady state. Choosing the value of σ that equates the steady-state number of firms across C.E.S. and translog cases (denoted σ^*) amounts to choosing the $H(N)$ function for the translog case whose fixed point is precisely the same (*i.e.*, which crosses the 45 degree line at the same point); this is given by the solid curve in the figure.

Algebraically, this can be achieved as follows in the general case $\varphi \geq 0$. For any preference specification, the steady-state number of firms solves equation (7), which can be rewritten as:

$$N = [\chi(r + \delta)]^{-\frac{\varphi}{1+\varphi}} (1 - \delta) \frac{Z}{f_E} \frac{\left(\frac{\mu(N)-1}{\mu(N)}\right)^{\frac{\varphi}{1+\varphi}}}{\left[\delta + \frac{r+\delta}{\mu(N)-1}\right]^{\frac{1}{1+\varphi}}}.$$

Since the terms up to Z/f_E in the right-hand side of this equation are independent of N , equalization of N for translog and C.E.S. preferences reduces to ensuring that the last fraction is invariant to

the preference specifications. That is, we need to find the value of σ that ensures that

$$N^{Trans} = \frac{\left(\frac{1}{1+\sigma N^{CES}}\right)^{\frac{\varphi}{1+\varphi}}}{[\delta + (r + \delta) \sigma N^{CES}]^{\frac{1}{1+\varphi}}} = \frac{\left(\frac{1}{\theta}\right)^{\frac{\varphi}{1+\varphi}}}{[\delta + (r + \delta) (\theta - 1)]^{\frac{1}{1+\varphi}}} = N^{CES},$$

where we used the expression for N^{CES} in (9). It is easily verified that $\sigma^* = (\theta - 1)/N^{CES}$ is a solution, and is unique (exploiting monotonicity of the markup function). Substituting the expression for N^{CES} , the value of σ^* can then be written as a function of structural parameters:

$$\sigma^* = \frac{\theta - 1}{1 - \delta} \frac{[\chi \theta (r + \delta)]^{\frac{\varphi}{1+\varphi}} f_E}{[\theta (r + \delta) - r]^{-\frac{1}{1+\varphi}} Z}.$$

In our baseline calibration, we interpret periods as quarters and set $\beta = .99$ – a standard choice for quarterly business cycle models. We set the size of the exogenous firm exit shock $\delta = .025$ to match the U.S. empirical level of 10 percent job destruction per year.³³ Under C.E.S. preferences, we use the value of θ from Bernard, Eaton, Jensen, and Kortum (2003) and set $\theta = 3.8$, which was calibrated to fit U.S. plant and macro trade data.³⁴ We set initial productivity to $Z = 1$. The initial steady-state entry cost f_E does not affect any of the impulse responses under C.E.S. preferences and under translog for the σ^* calibration;³⁵ we therefore set $f_E = 1$ without loss of generality. The value of σ that ensures equality of steady-state markup and number of firms across preference specifications for the baseline parameterization is $\sigma^* = .35323$. Steady-state labor effort under both preference scenarios is:

$$L = \left\{ \frac{1}{\chi} \left[1 - \frac{r}{\theta (r + \delta)} \right] \right\}^{\frac{\varphi}{1+\varphi}}. \quad (13)$$

³³Empirically, job destruction is induced by both firm exit and contraction. In our model, the “death” shock δ takes place at the product level. In a multi-product firm, the disappearance of a product generates job destruction without firm exit. Since we abstract from the explicit modeling of multi-product firms, we include this portion of job destruction in δ . As a higher δ implies less persistent dynamics, our choice of δ is also consistent with not overstating the ability of the model to generate persistence.

³⁴It may be argued that the value of θ results in a steady-state markup that is too high relative to the evidence. However, it is important to observe that, in models without any fixed cost, $\theta/(\theta - 1)$ is a measure of both markup over marginal cost and average cost. In our model with entry costs, free entry ensures that firms earn zero profits *net* of the entry cost. This means that firms price at average cost (inclusive of the entry cost). Thus, although $\theta = 3.8$ implies a fairly high markup over marginal cost, our parametrization delivers reasonable results with respect to pricing and average costs. The main qualitative features of the impulse responses below are not affected if we set $\theta = 6$, resulting in a 20 percent markup of price over marginal cost as in Rotemberg and Woodford (1992) and several other studies.

³⁵The total number of firms in steady state is inversely proportional to f_E – and the size and value of all firms are similarly proportional to f_E . Basically, changing f_E amounts to changing the unit of measure for output and number of firms. As in the C.E.S. case, the ‘long-run scale’ of the economy Z/f_E does not matter for dynamics under translog preferences under the σ^* calibration.

(Note that hours are indeed constant relative to variation in productivity and regulation.) We consider different values for the elasticity of labor supply (though Figure 3 above is plotted for $\varphi = 0$), and we set the weight of the disutility of labor in the period utility function, χ , so that the steady-state level of labor effort in (13) is 1 – and steady-state levels of all variables are the same – regardless of φ .³⁶

Dynamics

We solve for the dynamics in response to exogenous shocks by log-linearizing the model around the steady state obtained above. For simplicity, we assume initial steady-state levels of productivity and sunk cost $Z = f_E = 1$. Using sans-serif fonts to denote percent deviations from steady-state levels, log-linearization under assumptions of log-normality and homoskedasticity yields:

$$\begin{aligned} \mathbf{N}_{t+1} = & \left[1 - \delta + \frac{r + \delta}{\mu - 1} \epsilon + \left(\frac{r + \delta}{\mu - 1} + \delta \right) \varphi (\epsilon - \eta) \right] \mathbf{N}_t - \left[\varphi \left(\frac{r + \delta}{\mu - 1} + \delta \right) + \frac{r + \delta}{\mu - 1} \right] \mathbf{C}_t + \\ & + (1 + \varphi) \left(\frac{r + \delta}{\mu - 1} + \delta \right) \mathbf{Z}_t - \delta \mathbf{f}_{E,t}, \end{aligned} \quad (14)$$

$$\begin{aligned} \mathbf{C}_t = & \frac{1 - \delta}{1 + r} E_t \mathbf{C}_{t+1} - \left[\frac{1 - \delta}{1 + r} (\epsilon - \eta) - \frac{r + \delta}{1 + r} \right] \mathbf{N}_{t+1} + \left(\epsilon - \eta - \frac{1}{\mu - 1} \frac{r + \delta}{1 + r} \eta \right) \mathbf{N}_t - \\ & - \frac{1 - \delta}{1 + r} E_t \mathbf{f}_{E,t+1} + \mathbf{f}_{E,t}. \end{aligned} \quad (15)$$

Equation (14) states that the number of firms producing at $t + 1$ increases if consumption at time t is lower (households save more in the form of new firms), if the sunk entry cost is below the initial level, or if productivity is higher. Equation (15) states that consumption at time t is higher the higher expected future consumption and the larger the number of firms producing at time t (recall that the elasticity of the markup to the number of firms, η , defined in Table 2, is such that $\eta \leq 0$). Current deregulation lowers current consumption, because households save more to finance faster firm entry. However, expected future deregulation boosts current consumption as households anticipate the availability of more varieties in the future. The effect of \mathbf{N}_{t+1} depends on parameter values. For realistic parameter values, we have $\epsilon - \eta > (r + \delta) / (1 - \delta)$: An increase in the number of firms producing at $t + 1$ is associated with lower consumption at t . (Higher productivity at time t lowers contemporaneous consumption through this channel, as households save to finance faster entry in a more attractive economy. However, we shall see below that the general equilibrium effect of higher productivity will be that consumption rises.)

³⁶This requires $\chi = 924271$.

In the appendix, we find conditions under which the system (14)-(15) has a unique, non-explosive solution. To solve the system, we assume $Z_t = \phi_Z Z_{t-1} + \varepsilon_{Z,t}$, where $\varepsilon_{Z,t}$ is an i.i.d., Normal innovation with zero mean and variance $\sigma_{\varepsilon_Z}^2$. Differently from productivity, we do not treat $f_{E,t}$ as a stochastic process subject to random innovations at business cycle frequency. We think of changes in sunk entry costs as changes in market regulation, and we assume that market regulation is controlled by a policymaker, who can change it in more or less persistent fashion, so that $f_{E,t} = \phi_{f_E} f_{E,t-1}$ in all periods after an initial change.

4 Business Cycles with Firm Dynamics

In this section we explore the properties of our benchmark model by means of a numerical example. We compute impulse responses to productivity and deregulation shocks. The responses substantiate the results and intuitions in the previous section. Then, we compute second moments of our artificial economy and compare them to second moments in the data and those produced by a standard RBC model.

Impulse responses

Productivity

Figure 4 shows the responses (percent deviations from steady state) to a permanent 1 percent increase in productivity for the inelastic labor case, comparing the two alternative preference structures, C.E.S. and translog. Periods are interpreted as quarters, and the number of years after the shock is on the horizontal axis. Consider first the long-run effects in the new steady state for C.E.S. preferences (round markers). As was previously described, the business environment becomes more attractive, drawing a permanently higher number of entrants (N_E), which translates into a permanently higher number of producers (N). This induces marginal cost (w/Z) and the relative price of each product ρ to be higher. GDP Y and consumption (C) also rise permanently, and they do so by more than the increase in productivity due to the expansion in the range of available varieties. Individual firm output (y) is not affected as the increase in the relative price offsets the larger demand resulting from higher consumption. Profits per firm (d) and firm value (v) are also permanently higher.³⁷

³⁷Permanently higher firm value and number of entrants result in permanently higher investment (in units of consumption), $v^E \equiv v N_E$.

The long-run effects in the case of translog preferences (cross markers) are clearly different from the C.E.S. ones, despite the initial steady state being the same by construction. The main difference comes from the dampening effect of the increase in the number of producers on the markup (μ), due to the demand-side pricing complementarities generated by these preferences. The increased profitability drawing new producers into the market is lower than under C.E.S. preferences precisely because of this negative effect on the markup. Hence, the new steady-state number of producers is lower, and firm value, relative price, real wage, and marginal cost are all lower than under C.E.S. Since less resources are used for the creation of new firms, relatively more resources are used for producing existing goods. Thus, individual firm output is permanently above its initial steady state, in contrast to the C.E.S. case.

Transition dynamics highlight the role of the number of firms as the key endogenous state variable in our model. Absent sunk entry costs, and the associated time-to-build lag before production starts, the number of producing firms N_t would immediately adjust to its new steady-state level. Sunk costs and time-to-build imply that N_t is a state variable that behaves very much like the capital stock in the standard RBC model: The number of entrants (new production lines) $N_{E,t}$ represents the consumers' investment, which translates into increases in the stock of production lines N_t over time. Marginal cost and the relative price ρ_t react to the shock with a lag and start increasing only in the period after the shock as a larger number of producing firms puts pressure on labor demand.

The responses of firm-level output and GDP highlight the different roles of intensive and extensive margins during economic expansions in response to permanent productivity improvements. In both cases, firm-level output booms on impact in response to larger consumption. In the C.E.S. case, the increase in ρ_t pushes firm-level output back to the initial steady state. Over time, the expansion along the intensive margin is reabsorbed as the increase in the number of firms puts pressure on labor costs. Since output per firm returns to the initial steady state in the long run, the increase in productivity is offset by a matching decrease in firm-level employment as the cost of labor increases during the transition. Eventually, the expansion operates only through the extensive margin. Thus, our model predicts that the expansionary effect of higher productivity is initially transmitted through the intensive margin as output per firm rises, but it is the extensive margin that delivers GDP expansion in the long run with C.E.S. preferences. In the translog case, the intensive margin does not fade out in the long run, since the increase in the number of firms is not enough to prevent output per firm from increasing; therefore, while it is still true that the

intensive margin accounts for all of the initial GDP expansion, the intensive and extensive margins coexist in the long run.³⁸

Importantly, during the transition in both cases, there is a reallocation of the fixed labor supply from production of consumption to production of new firms, as implied by the increase in L_t^E and the decrease in L_t^C . As the increase in productivity boosts entry, labor shifts to the construction of new production lines. Over time, the rising cost of effective labor – and thus the rising burden of the entry cost – redistributes this labor back to production of consumption. The gradual increase in the cost of effective labor explains why the number of new entrants overshoots its new long-run equilibrium in the short run. This effect is weaker with translog preferences because of the negative effect on profit opportunities of an increased number of producers.

An important implication of our model is that, in the translog case, it generates a countercyclical markup without necessarily implying countercyclical profits. Both firm-level and aggregate profits ($D_t \equiv N_t d_t$) increase in response to the shock. Generating this result is a notorious difficulty of other models of countercyclical markups with a constant number of producers (for instance, based on sticky prices). These models imply that profits become countercyclical, in stark contrast with the data (see Rotemberg and Woodford, 1999). We return to this issue when computing the second moments of our artificial economy.

The responses of several key macroeconomic variables deflated by average prices rather than with the consumption based price index are qualitatively similar to those in Figure 4.³⁹ Two key results are worth mentioning: Aggregate real profits ($D_{R,t} \equiv N_t d_t / \rho_t$) still increase in procyclical fashion under both preference specifications, consistent with the evidence in Figure 1. The data-consistent firm value $v_{R,t} = f_{E,t} / \mu(N_t)$ is not affected at all by the shock in the C.E.S. case (because the markup is constant and the real wage $w_{R,t}$ increases exactly as much as the shock); but, in the translog case, it increases in response to technology since markups are countercyclical.

To further illustrate the properties of our model, Figure 5 shows the responses to a transitory but persistent 1 percent productivity shock (with persistence .9). The direction of movement of endogenous variables on impact is the same as in Figure 4, though all variables return to the steady state in the long run. Interestingly, for C.E.S. preferences, firm-level output is below the steady

³⁸ A muted increase in the number of firms with translog preferences is consistent with the fact that the benefit of variety is now smaller than the markup, reducing the household's incentive to invest in new firms.

³⁹ For instance, this is the case for $C_{R,t}$ and $Y_{R,t}$ for C.E.S. preferences, even if the increase after the initial impact is muted and removal of the variety effect implies that these empirically-consistent variables do not increase by more than the size of the shock in the new steady state. For translog preferences, however, $C_{R,t}$ and $Y_{R,t}$ still increase by more than the size of the shock. This is a consequence of markups being countercyclical, best illustrated by the dynamics of the data-consistent firm value $v_{R,t}$ mentioned below.

state during most of the transition, except for a short-lived initial expansion. Different from the permanent shock case, the relative price effect prevails on the expansion in consumption demand to push individual firm output below the steady state for most of the transition. For translog preferences, however, the initial expansion is more persistent for reasons described above (it is relatively more profitable to keep producing old goods since investing in new ones would erode profit margins). As in the permanent-shock case, despite markups being countercyclical, total profits are still procyclical. Notably, the dynamics of firm entry result in responses that persist beyond the duration of the exogenous shock in both cases (but relatively more so in the C.E.S. case), and, for some key variables, display a hump-shaped pattern.

Figure 6 plots responses to a transitory productivity shock with persistence .9 for C.E.S. preferences, varying labor supply elasticity between 0 (round markers), 2 (cross markers), and 10 (square markers).⁴⁰ The responses of most variables with elastic labor are qualitatively similar to the inelastic-labor case. However, elastic labor implies that the household has an additional margin of adjustment in the face of shocks. This enhances the model’s propagation mechanism and, as the figure shows, amplifies the impact responses of most endogenous variables with respect to the inelastic-labor case. Faced with an increase in the real wage, the household optimally decides to work more hours in order to attain a higher consumption level. Moreover, expectations of increased profitability, as before, make the household more willing to invest in new firms (and hence the impact responses of labor in the investment sector and investment in new production lines are correspondingly larger as labor supply becomes more elastic). This adds to the capital stock of the economy (the number of firms) and makes both GDP and consumption increase by relatively more as φ increases. (The long-run responses are identical – independent of labor supply elasticity – as explained in Section 2.) Except in the initial quarters, where the increase is amplified, firm-level profits decrease by more than in the inelastic-labor case since profit margins are eroded by the increased entry of new firms. But total profits increase more than in the inelastic-labor case, since the increase in the number of producers is more than enough to compensate for the fall of profits per firm.

Figure 7 repeats the exercise of Figure 6 for translog preferences, with largely similar results. With elastic labor, the markup becomes relatively more countercyclical and this amplifies the fall in firm-level profits that follows the initial expansion, but total profits remain more procyclical

⁴⁰The case in which $\varphi \rightarrow \infty$ corresponds to linear disutility of effort and is often studied in the business cycle literature. See, for instance, Christiano and Eichenbaum (1992). With $\varphi = 10$, disutility of labor is essentially linear in a neighborhood of $L = 1$ (the steady-state level of effort in our model).

than under inelastic labor, as in the C.E.S. scenario, because of the larger increase in the number of producers. This points to elastic labor as an important margin in fitting the cyclical properties of markups and profits in our model.

Deregulation

Figure 8 shows the responses to a 1 percent permanent deregulation shock under four scenarios: C.E.S. preferences with inelastic labor (round markers) and $\varphi = 2$ (cross markers), and translog preferences with inelastic labor (square markers) and $\varphi = 2$ (star markers). As for productivity shocks, given a preference specification, the long-run responses are identical regardless of φ . However, the transition dynamics are different. Consider first the C.E.S., inelastic-labor case. Deregulation attracts new entrants and firm value decreases (the relative price of the investment good falls). Since investment is relatively more attractive than consumption, there is intersectoral labor reallocation from the latter to the former. Consumption falls initially as households postpone consumption to invest more in firms whose productivity has not increased. The number of firms starts increasing, but GDP initially falls as the decline in consumption dominates the increase in investment. All variables then move monotonically toward their new steady-state levels. In the C.E.S., elastic-labor case, while the mechanism above still applies, the additional margin of adjustment induces consumers to decide optimally to supply more labor and accommodate the extra labor demand generated by the increasing number of firms. The initial decrease in labor used in production of consumption goods is thus muted. The number of entrants (and hence investment) increases relatively more, and, as for a permanent productivity shock, the total number of firms, firm value, and the real wage all converge faster to their new steady-state levels, the more so the larger labor supply elasticity. GDP now increases due to a larger increase in investment and a smaller decrease in consumption. Finally, focusing on the translog case with $\varphi = 2$ for brevity, the same intuition as in the case of a productivity shocks applies: Compared to the C.E.S. case, the number of producers increases by less due to the demand complementarity leading to falling markups; a weaker expansion of GDP occurs, but output per firm falls by less, precisely because there is less entry into the market. A key difference between C.E.S. and translog preferences in this case is that deregulation eventually results in higher aggregate profits with C.E.S. preferences, whereas aggregate profits fall in the translog case, because muted entry is not enough to offset the effect of lower markups.

Second Moments

To further evaluate the properties of our baseline model, we compute the implied second moments of our artificial economy for some key macroeconomic variables and compare them to those of the data and those produced by the benchmark RBC model. To start with, we compute standard moments of GDP, consumption, investment, and hours worked. Table 4 presents the results for our C.E.S. model with elastic labor. We use the same productivity process as King and Rebelo (1999), with persistence .979 and a standard deviation of innovations equal to .0072, to facilitate comparison of results with the baseline RBC setup. As in King and Rebelo’s benchmark calibration, we set $\varphi = 2$.⁴¹ In each column of Table 4, the first number (bold fonts) is the empirical moment implied by the U.S. data reported in King and Rebelo (1999), the second number (in parenthesis) is the moment generated by King and Rebelo’s baseline RBC model, and the third number (normal fonts) is the moment implied by our model. We measure investment in our model with the real value of household investment in new firms ($v_R N_E$). Remarkably, the performance of the simplest model with entry subject to sunk costs and constant markups is very similar to that of the baseline RBC model in reproducing some key features of U.S. business cycles. On the other hand, our baseline framework faces the same well-known difficulties of the standard RBC model: Consumption and hours are too smooth relative to output; there is not enough endogenous persistence (as indicated by the first-order autocorrelations); and all variables are too procyclical relative to the data.

Table 4. Moments for: Data, Baseline RBC, C.E.S. Model ($\varphi = 2$)

Variable X	σ_X	σ_X/σ_{Y_R}	$E[X_t X_{t-1}]$	$corr(X, Y_R)$
Y_R	1.81 (1.39) 1.34	1.00	0.84 (0.72) 0.70	1.00
C_R	1.35 (0.61) 0.65	0.74 (0.44) 0.48	0.80 (0.79) 0.75	0.88 (0.94) 0.97
Investment, $v_R N_E$	5.30 (4.09) 5.23	2.93 (2.95) 3.90	0.87 (0.71) 0.69	0.80 (0.99) 0.99
L	1.79 (0.67) 0.63	0.99 (0.48) 0.47	0.88 (0.71) 0.69	0.88 (0.97) 0.98
Source for data and (<i>RBC</i>) moments: King and Rebelo (1999)				

Table 5 shows the second moment properties for three alternative scenarios of our model: C.E.S. preferences with $\varphi = 10$ (bold fonts), translog preferences with $\varphi = 2$ (in parenthesis), and translog preferences with $\varphi = 10$ (normal fonts). The main qualitative features of the results are the same

⁴¹The period utility function is defined over leisure ($1 - L_t$) in King and Rebelo (1999), where the endowment of time in each period is normalized to 1. The elasticity of labor supply is then the risk aversion to variations in leisure (set to 1 in their benchmark calibration) multiplied by $(1 - L)/L$, where L is steady-state effort, calibrated to 1/3. This yields $\varphi = 2$ in our specification.

as in Table 4. For instance, translog preferences with $\varphi = 10$ match GDP volatility, result in more volatile consumption and labor effort, and match the correlation between consumption and GDP. But they also generate increased excess volatility of investment and lower GDP persistence.

Table 5. Moments for: C.E.S. Model ($\varphi = 10$), Translog Model ($\varphi = 2$), Translog Model ($\varphi = 10$)

Variable X	σ_X	σ_X/σ_{Y_R}		$E[X_t X_{t-1}]$	$corr(X, Y_R)$	
Y_R	2.15 (1.25)	1.80	1.00	0.65 (0.70)	0.63	1.00
C_R	0.79 (0.75)	0.91	0.37 (0.60)	0.50	0.75 (0.78)	0.79 0.92 (0.95)
Investment, $v_R N_E$	9.89 (4.27)	7.41	4.60 (3.42)	4.12	0.63 (0.66)	0.58 0.99 (0.96)
L	1.70 (0.49)	1.24	0.79 (0.39)	0.69	0.63 (0.66)	0.58 0.98 (0.95)

Tables 4 and 5 show that the quantitative performance of our model in terms of matching time series properties of some key U.S. macroeconomic aggregates is close to that of the baseline RBC setup. We view this as a positive result: Our model does not do worse than the RBC framework, and it improves along a number of dimensions, generating countercyclical markups, procyclical profits, and procyclical firm entry – all features of the data on which the benchmark RBC model remains silent.

To substantiate this point, Figure 9 plots model-generated cross-correlations of GDP, entry, and aggregate real profits at various lags and leads for the four scenarios of our model considered in Tables 4 and 5.⁴² In all cases, entry and profits are strongly procyclical, and the contemporaneous correlation of profits and entry is positive, as in the data reviewed in the Introduction. Quantitative differences emerge, and the model-implied correlations involving entry peak at the contemporaneous horizon rather than one period later, as in the data for U.S. net entry. But the qualitative pattern generated by the model for variables that the RBC benchmark is silent about is broadly consistent with the evidence, and we view the ability to generate procyclical profits with a countercyclical markup as a major plus of our model relative to sticky-price-based theories of cyclical markup variation.⁴³

⁴²The numbers in parenthesis in each panel’s legend indicate the relevant value of φ .

⁴³With $\varphi = 2$ ($\varphi = 10$), the contemporaneous correlation between markup and GDP generated by the model is $-.22$ ($-.20$). The correlation becomes more negative if one considers the relation between current GDP and the future markup.

5 The Role of Physical Capital

In this section we extend our setup to incorporate physical capital as usually featured in RBC models. There are two reasons for this. First, our benchmark model studies an extreme case in which all investment goes toward the creation of new production lines and the associated new products. While this is useful to emphasize the new transmission mechanism provided by firm entry, it is certainly unrealistic: Part of observed investment is accounted for by the need to augment the capital stock used in production of existing goods. Second, the introduction of physical capital may improve the model's performance in explaining observed macroeconomic fluctuations. Since inclusion of capital in the model does not represent a major modeling innovation, we relegate the presentation of the augmented setup to an appendix, and limit ourselves to mentioning the main assumptions here.

We consider two versions of the model with capital, depending on whether physical capital is used only in production of consumption (and investment) goods or also in setting up new firms. We assume that households accumulate the stock of capital (K_t), and rent it to firms producing at time t in a competitive capital market. Investment in the physical capital stock (I_t) requires the use of the same composite of all available varieties as the consumption basket. Physical capital obeys a standard law of motion with rate of depreciation δ^K .

Capital in Production of Goods Only

For simplicity, we initially follow Grossman and Helpman (1991) and assume that the creation of new firms does not require physical capital – this is also the most natural way to make the decision to invest in physical capital accumulation consistent with our other timing conventions. Producing firms then use capital and labor to produce goods according to the Cobb-Douglas production function $y_t(\omega) = Z_t l_t(\omega)^\alpha k_t(\omega)^{1-\alpha}$.

Figure 10 repeats the exercise of Figure 4 and presents the responses to a permanent 1 percent productivity increase for the model with capital, with labor share parameter $\alpha = .67$ and physical capital depreciation $\delta^K = .025$.⁴⁴ Round markers denote the C.E.S. case, and cross markers denote the translog case. The differences in responses across preference specifications are explained by the now familiar consequences of countercyclical markup variation in the translog case, which results in muted variety expansion relative to C.E.S. preferences. Households now invest in both creation

⁴⁴ All other parameter values are as in the previous figures.

of new firms and expansion of physical capital at existing firms.⁴⁵ A larger physical capital stock is responsible for the main difference relative to Figure 4: Absent physical capital, the entire GDP expansion takes place at the extensive margin with C.E.S. preferences, with firm-level output returning to the original steady state. This is no longer the case in Figure 10, where a permanent increase in physical capital results in the fact that firm-level output is permanently higher also in the C.E.S. case.

To illustrate the consequences of labor elasticity, Figure 11 presents responses to a 1 percent increase in productivity with persistence .9, for C.E.S. and translog preferences, with inelastic labor and $\varphi = 2$. Round markers denote the C.E.S. inelastic-labor case, cross markers denote the C.E.S. elastic-labor case, square markers denote the translog inelastic-labor case, and star markers denote the translog elastic-labor case. The results are similar to those of the model without capital, with the margin of adjustment generated by endogenous labor supply resulting in amplified fluctuations for given preference specification, and countercyclical markup variation dampening variety expansion (and its consequences) in the translog case relative to the corresponding C.E.S. parametrization.

Finally, Figure 12 shows the consequences of permanent deregulation, for the same cases as Figure 11. The results are intuitive, based on the discussion in the previous section. Interestingly, deregulation results in an initial decrease in physical capital investment (and thus an initially lower capital stock) as households allocate relatively more of their saving to entry of new firms in the more attractive business environment. With elastic labor, deregulation no longer results in an initial fall in consumption under C.E.S. preferences – and the initial consumption drop is very small under translog preferences: The labor adjustment margin dampens the fall in total output of the consumption basket and allows households to utilize the drop in physical capital investment to shield their consumption from unfavorable initial dynamics.

Second Moments

As for the baseline model, we use the model with physical capital to compute second moments of the artificial economy. Table 6 reports results for key macro aggregates, for C.E.S. preferences (bold fonts) and translog preferences (normal fonts). We focus on the case $\varphi = 2$ and continue to assume the same process for productivity as in King and Rebelo (1999). For comparison with investment data, we now measure investment with the real value of total investment in physical

⁴⁵In Figure 10, r_t^K is the rental rate on capital, $I_t^E \equiv v_t N_{E,t}$, TI_t is total investment $TI_t \equiv I_t + I_t^E$, and λ_t is firms' marginal cost.

capital and new firm creation.

Table 6. Moments for Model with Capital in Production of Goods, C.E.S. vs. Translog

Variable X	σ_X	σ_X/σ_{Y_R}	$E[X_t X_{t-1}]$	$corr(X, Y_R)$
Y_R	1.40 1.40	1.00	0.70 0.71	1.00
C_R	0.57 0.55	0.41 0.39	0.65 0.70	0.99 0.97
Investment, TI_R	3.33 3.40	2.38 2.43	0.73 0.72	1.00 1.00
L	0.97 0.90	0.69 0.64	0.71 0.70	0.99 0.97

Inclusion of capital in production of goods does not alter the second-moment properties of the model substantially relative to Tables 4 and 5. The performance remains close to that of the baseline RBC setup, with the same problems of excessive smoothness of consumption and labor, not enough persistence, and too much procyclicality of consumption, investment, and labor. Thus, as far as these properties are concerned, we thus reach the same conclusion as Grossman and Helpman (1991), who showed that extending their variety-based endogenous growth model to incorporate physical capital in production of goods did not alter the main conclusions of the model pertaining to growth. In our case, including capital in production of goods only does not affect the business cycle properties of the model significantly.

Capital in Production of Goods and Creation of Firms

To further explore the consequences of physical capital, we develop an alternative version of the model with capital in appendix, where capital is also used as a factor of production in creation of new firms.⁴⁶ However, this scenario poses problems for determinacy and non-explosiveness of the solution, which are no longer guaranteed for standard parameter values (as there are now increasing returns to an accumulated factor, physical capital). Determinacy and non-explosiveness are now guaranteed only if we assume very fast physical capital depreciation – specifically, $\delta^K \geq .32$, holding the other parameter values unchanged. In fact, values of δ^K close to the threshold .32 result in empirically implausible (converging) oscillations in impulse responses. For these reasons, we set $\delta^K = .5$ and limit ourselves to repeating the exercise of Table 6 and studying how this version of the model with capital affects the second moment properties of the model. The results are reported

⁴⁶We assume a Cobb-Douglas production function for new firm creation with the same labor share α as for production of goods. Thus, the technology for setting up the mass $N_{E,t}$ of new entrants is: $f_{E,t} N_{E,t} = Z_t (L_t^E)^\alpha (K_t^E)^{1-\alpha}$, where L_t^E and K_t^E are labor and capital used in setting up new firms, respectively.

in Table 7. Again, bold fonts denote the C.E.S. case, normal fonts denote the translog case, $\varphi = 2$, and we use the same productivity process as in King and Rebelo (1999).

Table 7. Moments for Model with Capital in Production of Goods, C.E.S. vs. Translog

Variable X	σ_X	σ_X/σ_{Y_R}	$E[X_t X_{t-1}]$	$corr(X, Y_R)$
Y_R	1.82 1.69	1.00	0.82 0.82	1.00
C_R	0.85 0.97	0.47 0.57	0.76 0.77	0.96 0.95
Investment, TI_R	3.30 2.83	1.81 1.67	0.81 0.80	0.99 0.99
L	0.85 0.68	0.47 0.40	0.69 0.59	0.93 0.89

Inclusion of physical capital in creation of new firms increases the volatility of GDP (which essentially matches the data with C.E.S. preferences) and consumption, and it improves the performance of the model on the persistence dimension relative to the setup without capital and the baseline RBC model (recall Table 4). Thus, the results suggest that combining the traditional capital accumulation mechanism of RBC theory with the variety expansion channel of this paper with capital used also in creation of new firms strengthens the endogenous propagation mechanism of business cycle models. On the other hand, excessive procyclicality of consumption, investment, and labor remains a feature of results, and so does too little volatility of consumption and labor. Also, the issue remains open of how to introduce capital in creation of new firms while preserving determinacy and non-explosiveness for standard values of physical capital depreciation.

Discussion

Inclusion of capital in the model yields mixed results: When capital is used only in production of goods, there is no significant effect on the business cycle properties of the model. The performance improves when capital is used also in setting up new firms, but the model requires implausibly fast depreciation of physical capital to avoid indeterminacy, explosiveness, and implausible oscillatory responses.

Overall, the quantitative performance of the setup – with or without physical capital – is at least as good as that of the standard RBC model. We view this as a positive result for our framework, in the light of its ability to reproduce and explain features of evidence that escape the traditional RBC model. The properties of the scenarios with capital with regard to the cyclical behavior of GDP, real profits, and entry are in fact broadly similar to those in Figure 9 for the model without capital, as illustrated in Figure 13 (where K1 denotes the model with capital in production of

goods only and K2 denotes the model with capital also in creation of new firms). Contemporaneous correlations remain positive, but Figure 13 suggests that the model with capital in production of goods only is preferable for two reasons if the purpose is explaining the cyclical pattern of entry and profits: Capital also in creation of new firms “shifts” the peak correlations by one period in the wrong direction and no longer generates the negative correlation between (sufficiently) lagged GDP and profits and current entry that is a feature of the data.⁴⁷

There are certainly avenues for improvement of the model’s performance: First, its ability to replicate business cycle moments improves along most dimensions if we include government spending shocks as an additional source of business cycle fluctuations. Assuming wasteful government consumption (with the same composition as private consumption) that follows the same $AR(1)$ process (in logs) as in Christiano and Eichenbaum (1992), in addition to the King-Rebelo (1999) productivity process, results in standard deviations and contemporaneous correlations with GDP for the model without capital or that with capital in production of goods only that are much closer to the data.⁴⁸ The only moment along which the performance of the model worsens is the correlation between $C_{R,t}$ and $Y_{R,t}$, which becomes negative in most scenarios due to the familiar crowding-out effect of government consumption on private consumption.⁴⁹

A second dimension along which there is much room for improvement is measurement. To facilitate comparison with results from RBC models, we have used an off-the-shelf productivity process in our second-moment calculations. However, the structure of our model requires corrections to the standard formula for calculation of the Solow residual in order to estimate a model-consistent productivity process.⁵⁰ A measurement problem arises also with reference to a government spending shock process: One should pay attention to the fact that, while the spending shocks may be specified in terms of G_t (measured in units of the consumption basket), estimation will in fact yield a process for $G_{R,t}$ ($\equiv G_t/\rho_t$).for reasons discussed above.

Computation of model-consistent Solow residuals for the setup of this paper and use of a data-

⁴⁷With capital in production of goods only (or in both sectors), the contemporaneous correlation between markup and GDP generated by the model is $-.32$ (.07). The correlation becomes increasingly negative (negative and increasingly so), if one considers the relation between current GDP and the future markup.

⁴⁸Details are available on request.

⁴⁹While the empirical evidence is that positive government spending shocks cause consumption to increase (for instance, Blanchard and Perotti, 2002), the negative wealth effect of higher expected taxes causes government spending shocks to crowd out real private consumption $C_{R,t}$ in our model and in standard RBC models, as explained by Baxter and King (1993). A solution to this problem pursued in the literature is to introduce non-Ricardian features in the model in the form of a fraction of households who simply consume their disposable income in each period (e.g., Galí, López-Salido, and Vallés, 2004).

⁵⁰See the appendix for details. Devereux, Head, and Lapham (1996a) address the issue of measurement of Solow residuals in their model with varying product space.

consistent government spending process in a model in which non-Ricardian elements solve the consumption-crowding-out problem will be directions along which this work will evolve in the future.

6 Conclusions

We developed a model of business cycle transmission with an endogenous number of producers subject to sunk entry costs, a time-to-build lag, and exogenous risk of firm destruction. The assumption of a general structure of homothetic preferences allows the model to nest the familiar C.E.S. specification with constant markups and a translog setup with time-varying markups as special cases. The model shows that variation in the number of producers and products over the horizon generally associated to the length of a business cycle can be an important propagation mechanism for fluctuations, consistent with the evidence documented by Bernard, Redding, and Schott (2006). Our setup explains stylized facts such as the procyclical behavior of entry and profits. Assuming translog preferences, it results in countercyclical markups with procyclical profits, resolving a puzzle for models that motivate cyclical markup variation with nominal rigidity. Also consistent with evidence of slow adjustment in the number of producers, the model predicts that output expansion by existing producers – *i.e.*, expansion at the intensive margin – is the main channel through which a GDP expansion takes place in the short run, but a large portion of the expansion takes place at the extensive margin in the long run. Finally, when it comes to the second moment properties of variables that are the focus of traditional RBC models, our setup does at least as well as the latter for a benchmark productivity process.

Bergin and Corsetti (2005) use a model with entry to study issues of stabilization policy. We take on the implications of a monetary version of our model for inflation dynamics and the conduct of monetary policy in Bilbiie, Ghironi, and Melitz (in progress).⁵¹ Further developments of this project will deal with measurement of model-consistent Solow residuals and the role of government spending.

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Appendix

A Homothetic Consumption Preferences

Consider an arbitrary set of homothetic preferences over a continuum of goods Ω . Let $p(\omega)$ and $c(\omega)$ denote the prices and consumption level (quantity) of an individual good $\omega \in \Omega$. These preferences are uniquely represented by a price index function $P \equiv h(\mathbf{p})$, $\mathbf{p} \equiv [p(\omega)]_{\omega \in \Omega}$, such that the optimal expenditure function is given by PC , where C is the consumption index (the utility level attained for a monotonic transformation of the utility function that is homogeneous of degree 1). Any function $h(\mathbf{p})$ that is non-negative, non-decreasing, homogeneous of degree 1, and concave, uniquely represents a set of homothetic preferences. Using the conventional notation for quantities with a continuum of goods as flow values, the derived Marshallian demand for any variety ω is then given by:

$$c(\omega)d\omega = C \frac{\partial P}{\partial p(\omega)}.$$

B Local Equilibrium Determinacy and Non-Explosiveness

To analyze local determinacy and non-explosiveness of the rational expectation equilibrium, we can focus on the perfect foresight version of the system (14)-(15) and restrict attention to endogenous variables. Rearranging yields:

$$\begin{bmatrix} \mathbf{C}_{t+1} \\ \mathbf{N}_{t+1} \end{bmatrix} = M \begin{bmatrix} \mathbf{C}_t \\ \mathbf{N}_t \end{bmatrix}, \quad M \equiv \begin{bmatrix} \frac{1+r}{1-\delta} - A \frac{r+\delta}{\mu-1} & AB - \frac{1+r}{1-\delta}(\epsilon - \eta) - \frac{1}{\mu-1} \frac{r+\delta}{1-\delta} \eta \\ -\frac{r+\delta}{\mu-1} & B \end{bmatrix}.$$

where $A \equiv \epsilon - \eta - \frac{r+\delta}{1-\delta}$ and $B \equiv 1 - \delta + \frac{r+\delta}{\mu-1}\epsilon$. Existence of a unique, non-explosive, rational expectations equilibrium requires that one eigenvalue of M be inside and one outside the unit circle. The characteristic polynomial of M takes the form $J(\lambda) = \lambda^2 - (\text{trace}(M))\lambda + \det(M)$, where the trace is

$$\text{trace}(M) = 1 - \delta + \frac{1+r}{1-\delta} + \left(\eta + \frac{r+\delta}{1-\delta} \right) \frac{r+\delta}{\mu-1},$$

and the determinant

$$\det(M) = 1 + r + \frac{r+\delta}{\mu-1} \frac{\eta}{1-\delta} \left(1 + r - \frac{r+\delta}{\mu-1} \right).$$

The condition for existence of a unique, non-explosive rational expectations equilibrium is $J(-1)J(1) < 0$, where

$$\begin{aligned} J(1) &= \delta - \frac{1+r}{1-\delta} - \left(\eta + \frac{r+\delta}{1-\delta} \right) \frac{r+\delta}{\mu-1} + 1 + r + \frac{r+\delta}{\mu-1} \frac{\eta}{1-\delta} \left(1 + r - \frac{r+\delta}{\mu-1} \right) = \\ &= -\frac{r+\delta}{1-\delta} \left[\delta + \frac{r+\delta}{\mu-1} \left(1 - \eta \frac{\mu-2}{\mu-1} \right) \right] < 0 \text{ if and only if } \eta < \frac{1 + \delta \frac{\mu-1}{r+\delta}}{1 - \frac{1}{\mu-1}}, \end{aligned} \quad (16)$$

$$\begin{aligned} J(-1) &= (2-\delta) \frac{2+r-\delta}{1-\delta} + \frac{r+\delta}{1-\delta} \frac{r+\delta}{\mu-1} + \eta \frac{r+\delta}{\mu-1} \frac{1}{1-\delta} \left[2+r-\delta - \frac{r+\delta}{\mu-1} \right] > 0 \\ \text{if and only if } \eta &> -\frac{(2-\delta)(2+r-\delta) \frac{\mu-1}{r+\delta} + (r+\delta)}{2+r-\delta - \frac{r+\delta}{\mu-1}}. \end{aligned} \quad (17)$$

Note that $\mu < 2$ is a sufficient condition for $J(1) < 0$. The conditions for determinacy and non-explosiveness of the rational expectations equilibrium in (16) and (17) are satisfied for all the parametrizations we consider (specifically, they are always satisfied for C.E.S. preferences since $\eta = 0$ in that case). The elasticity of the number of firms producing in period $t+1$ to its past level is the stable root of $J(\lambda) = 0$, *i.e.*, $\left[\text{trace}(M) - \sqrt{(\text{trace}(M))^2 - 4 \det(M)} \right] / 2$.

C The Model with Physical Capital

Capital in Production of Goods Only

On the household side, we now have the capital accumulation equation (I_t is investment):

$$K_{t+1} = (1 - \delta^K)K_t + I_t, \quad (18)$$

where $\delta^K \in (0, 1)$ is the rate of depreciation, which acts as an additional dynamic constraint.

The budget constraint becomes:

$$B_{t+1} + v_t N_{H,t} x_{t+1} + C_t + I_t + T_t = (1 + r_t)B_t + (d_t + v_t) N_t x_t + w_t L_t + r_t^K K_t,$$

where r_t^K is the rental rate of capital.

Euler equations for bonds and share holdings, and the labor supply equation, are unchanged.

The Euler equation for capital accumulation requires:

$$1 = \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} (r_{t+1}^K + 1 - \delta^K) \right]. \quad (19)$$

On the firm side, the production function is now Cobb-Douglas in labor and capital: $y_t(\omega) = Z_t l_t(\omega)^\alpha k_t(\omega)^{1-\alpha}$. When $\alpha = 1$, this model reduces to our previous model without physical capital.

Imposing symmetry of the equilibrium, cost minimization taking factor prices w_t, r_t^K as given implies:

$$r_t^K = (1 - \alpha) \frac{y_t}{k_t} \lambda_t, \quad (20)$$

$$w_t = \alpha \frac{y_t}{l_t} \lambda_t, \quad (21)$$

where λ_t is marginal cost. The profit function becomes $d_t = \rho_t y_t - w_t l_t - r_t^K k_t$, where optimal pricing yields $\rho_t = \mu_t \lambda_t$. Finally, market clearing for physical capital requires:

$$K_{t+1} = N_{t+1} k_{t+1}, \quad (22)$$

since capital entering $t + 1$ is rent to firms that are producing at time $t + 1$. Importantly, at the end of the period (when the capital market clears) there is a ‘reshuffling’ of capital among firms such that there is no scrap value for the capital of disappearing firms. The other equations remain unchanged.

We have thus introduced five new variables: $K_t, k_t, I_t, r_t^K, \lambda_t$, and five new equations (all the equations displayed above except for the budget constraint). We can write the equations as in the version without capital, using only aggregate variables. Take factor prices, multiply numerator and denominator by N_t , and substitute out marginal cost from the pricing equation:

$$\begin{aligned} r_t^K &= (1 - \alpha) \frac{\rho_t}{\mu_t} \frac{N_t y_t}{N_t k_t} = \frac{1 - \alpha}{\mu_t} \frac{Y_t^C}{K_t}, \\ w_t &= \frac{\alpha}{\mu_t} \frac{Y_t^C}{L_t^C}, \text{ where } L_t^C \equiv N_t l_t. \end{aligned}$$

Finally, note that labor market clearing and the profits equation are unchanged, and the resource constraint becomes:

$$C_t + I_t + N_{E,t} v_t + G_t = w_t L_t + N_t d_t + r_t^K K_t.$$

The complete model can then be summarized by adding the equations in the following table to the equations in Table 2 that remain unchanged (markup, variety effect, free entry, number of firms, intratemporal optimality, Euler equations for bonds and shares).

Table C.1. Model with Physical Capital in Manufacturing, Summary

Pricing	$\rho_t = \mu(N_t) \lambda_t$
Profits	$d_t = \left(1 - \frac{1}{\mu(N_t)}\right) \frac{Y_t^C}{N_t}$
Capital accumulation	$K_{t+1} = (1 - \delta^K) K_t + I_t$
Euler equation (capital)	$1 = \beta E_t \left[\left(\frac{C_{t+1}}{C_t}\right)^{-1} (r_{t+1}^K + 1 - \delta^K) \right]$
Aggregate accounting	$Y_t^C + v_t N_{E,t} = w_t L_t + N_t d_t + r_t^K K_t$
Total manufacturing output	$Y_t^C = C_t + I_t$
Real wage	$w_t = \frac{\alpha}{\mu_t} \frac{Y_t^C}{L_t^C}$
Rental rate	$r_t^K = \frac{(1-\alpha)}{\mu_t} \frac{Y_t^C}{K_t}$
Labor in manufacturing	$Y_t^C = \rho_t Z_t (L_t^C)^\alpha K_t^{1-\alpha}$
Labor in entry	$L_t^E = N_{E,t} f_{E,t} / Z_t$

An additional variable of interest is then total investment, $TI_t \equiv I_t + v_t N_{E,t}$, which aggregates investment in physical capital for production of consumption goods and in new firms.

The Steady State

In steady state, the Euler equation for shares, combined with expressions for firm value, pricing and profits, yields:

$$\alpha \frac{f_E}{Z} = \frac{1 - \delta}{r + \delta} (\mu(N) - 1) \frac{L^C}{N}.$$

From labor market clearing (or the aggregate accounting identity), combined with factor prices, the free entry condition, profit and pricing equations, and the steady-state number of entrants, labor used to produce goods is:

$$L^C = L - \frac{f_E}{Z} \frac{\delta}{1 - \delta} N.$$

Combining these two results, we have:

$$N = \frac{(1 - \delta) Z L}{\left(\alpha \frac{r + \delta}{\mu(N) - 1} + \delta \right) f_E}.$$

This equation yields a value for N that depends on structural parameters, including parameters pertaining to preferences.⁵² For example, under C.E.S. with inelastic labor ($L = 1$), we have:

$$N_{\varphi=0}^{CES} = \frac{(1 - \delta) Z}{[\alpha (r + \delta) (\theta - 1) + \delta] f_E}.$$

Otherwise, N is a function of the parameters governing the functional forms of $\rho(N)$ and $\mu(N)$, and N^{Trans} is the positive solution of the equation

$$\alpha (r + \delta) \sigma f_E (N^{Trans})^2 + \delta f_E N^{Trans} - (1 - \delta) Z L = 0.$$

Precisely the same calibration scheme as in the baseline model ensure that the steady-state markup and number of firms are the same under C.E.S. and translog preferences: $\sigma N^{Trans} = \theta - 1$. Since both steady-state elasticities of markup and variety effect depend only on σN^{Trans} , for quantitative purposes this implies that, in the translog case, the two elasticities are:

$$\eta(N) \equiv \frac{\mu'(N) N}{\mu(N)} = -\frac{1}{1 + \sigma N^{Trans}} = -\frac{1}{\theta} \quad \text{and} \quad \epsilon(N) \equiv \frac{\rho'(N) N}{\rho(N)} = \frac{1}{2\sigma N^{Trans}} = \frac{1}{2(\theta - 1)}.$$

Finally, from the rental rate expression, the steady-state stock of capital can be determined once the steady-state number of firms N is known:

$$K = \left[Z \frac{(1 - \alpha) \rho(N)}{r + \delta^K \mu(N)} \right]^{\frac{1}{\alpha}} \left(L - N \frac{f_E}{Z} \frac{\delta}{1 - \delta} \right).$$

All other variables can be easily determined once N and K are known.

The steady-state shares dN/Y^C and vN_E/Y^C are the same as in the model without physical capital. From the factor price expressions, the shares of physical capital and manufacturing labor income into manufacturing output Y^C are:

$$\frac{r^K K}{Y^C} = \frac{1 - \alpha}{\mu} \quad \text{and} \quad \frac{wL^C}{Y^C} = \frac{\alpha}{\mu}.$$

It follows that the share of total labor income into manufacturing output is:

$$\frac{wL}{Y^C} = \frac{1}{\mu} \left[\alpha + \frac{\delta}{r + \delta} (\mu - 1) \right].$$

⁵²Note that when $\alpha = 1$, we obtain the same level of N as in: (i) the model without capital and (ii) the model with capital in both production of goods and creation of new firms for $\alpha = 1$ (see below).

The fraction of labor used by the manufacturing sector into total labor is hence:

$$\frac{L_C}{L} = \frac{1}{1 + \frac{\mu-1}{\alpha} \frac{\delta}{(r+\delta)}}, \quad \text{which implies} \quad \frac{L_E}{L} = 1 - \frac{1}{1 + \frac{\mu-1}{\alpha} \frac{\delta}{(r+\delta)}}.$$

The share of manufacturing output in GDP is:

$$\frac{Y^C}{Y} = \frac{1}{1 + \frac{vN_E}{Y^C}}.$$

The share of total investment is also made up of two components: investment in new products/firms vN_E and investment in new capital I . The latter can be found from the expression for the rental rate, using also $I/K = \delta^K$ and $r^K = r + \delta^K$:

$$\begin{aligned} \frac{K}{Y^C} &= \frac{1-\alpha}{r+\delta^K} \frac{1}{\mu} \Rightarrow \frac{K}{Y} = \frac{1-\alpha}{r+\delta^K} \frac{1}{\mu} \frac{1}{1 + \frac{vN_E}{Y^C}}, \\ \frac{I}{Y^C} &= \frac{\delta^K}{r+\delta^K} \frac{1-\alpha}{\mu} \Rightarrow \frac{I}{Y} = \frac{\delta^K}{r+\delta^K} \frac{1-\alpha}{\mu} \frac{1}{1 + \frac{vN_E}{Y^C}} \end{aligned}$$

Note that the share of investment in physical capital is smaller than its RBC counterpart $((1-\alpha)\delta^K/(r+\delta^K))$. But the share of total investment in total GDP can be higher since it includes investment in new firms:

$$\frac{TI}{Y} = \frac{\delta}{r+\delta} \frac{\mu-1}{\mu} \frac{1}{1 + \frac{vN_E}{Y^C}} + \frac{\delta^K}{r+\delta^K} \frac{1-\alpha}{\mu} \frac{1}{1 + \frac{vN_E}{Y^C}}.$$

In principle, it is possible to use this expression to calibrate the shares of labor α and capital $1-\alpha$ as follows. TI/Y can be found from NIPA data, as usual in RBC exercises. Then we can use micro data on firm (job) destruction and markups to find the share of new goods' investment in GDP, and get $1-\alpha$ from the equation above (using also a standard value for physical capital depreciation).

Capital in Production of Goods and Creation of New Firms

In an alternative specification of the model with physical capital, we assume that capital is used also in creation of new firms. The law of motion for aggregate physical capital and the Euler equation for capital are the same as before, and so are the production function for consumption goods, the profit function, and pricing and factor price equations.

As for entry, we now assume that the production technology is uniform across sectors, *i.e.*, the production function for setting up new firms is Cobb-Douglas with the same parameters as

the consumption sector. Creating a new firm/product requires an aggregate of labor (l_t^E) and capital (k_t^E) in amount $f_{E,t} = Z_t (l_t^E)^\alpha (k_t^E)^{1-\alpha}$. Therefore, the technology for setting up all new entrants, $N_{E,t}$, is: $f_{E,t} N_{E,t} = Z_t (L_t^E)^\alpha (K_t^E)^{1-\alpha}$. The free entry condition requires $v_t = f_{E,t} \lambda_t$. Cost minimization in this sector implies $r_t^K = (1 - \alpha) \lambda_t f_{E,t} N_{E,t} / K_t^E$ and $w_t = \alpha \lambda_t f_{E,t} N_{E,t} / L_t^E$. Since both capital and labor are perfectly mobile across sectors, the relative capital/labor shares are equalized across sectors (by comparing the expressions for factor prices): $(k_t^E / l_t^E) = K_t^E / L_t^E = K_t^C / L_t^C (= k_t^C / l_t^C)$.

Finally, market clearing for physical capital requires: $K_{t+1} = N_{t+1} k_{t+1}^C + N_{E,t+1} k_{t+1}^E = K_{t+1}^C + K_{t+1}^E$, *i.e.*, capital is rent both to firms that are producing at time $t+1$ and for setting up new firms at $t+1$. As before, at the end of the period (when the capital market clears) there is a ‘reshuffling’ of capital among firms such that there is no scrap value for the capital of disappearing firms. The other equations remain unchanged.

Again, we can write the equations as in the version without capital, using only aggregate variables. The complete model can then be summarized by adding the equations in the following table to the equations in Table 2 that remain unchanged (markup, variety effect, number of firms, intratemporal optimality, Euler equations for bonds and shares).

Table C.2. Model with Physical Capital in Manufacturing and Firm Creation, Summary

Pricing	$\rho_t = \mu(N_t) \lambda_t$
Profits	$d_t = \left(1 - \frac{1}{\mu(N_t)}\right) \frac{Y_t^C}{N_t}$
Free entry	$v_t = f_{E,t} \lambda_t$
Capital accumulation	$K_{t+1} = (1 - \delta^K) K_t + I_t$
Euler equation (capital)	$1 = \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} (r_{t+1}^K + 1 - \delta^K) \right]$
Aggregate accounting	$Y_t^C + v_t N_{E,t} = w_t L_t + N_t d_t + r_t^K K_t$
Total manufacturing output	$Y_t^C = C_t + I_t$
Real wage	$w_t = \alpha Z_t \left(\frac{L_t}{K_t} \right)^{\alpha-1} \lambda_t$
Rental rate	$r_t^K = (1 - \alpha) Z_t \left(\frac{L_t}{K_t} \right)^\alpha \lambda_t$
Capital market clearing	$K_{t+1} = K_{t+1}^C + K_{t+1}^E$
Labor market clearing	$L_t = L_t^C + L_t^E$
Factor shares equalization	$K_t^E / L_t^E = K_t^C / L_t^C$
New firm creation	$f_{E,t} N_{E,t} = Z_t (L_t^E)^\alpha (K_t^E)^{1-\alpha}$

The Steady State

In steady state, the Euler equation for shares, combined with expressions for firm value, pricing and profits, gives:

$$f_E \rho(N) = \frac{1 - \delta}{r + \delta} \frac{Y_C}{N} (\mu(N) - 1).$$

From the aggregate accounting identity, combined with factor prices, the free entry condition, profit and pricing equations, and the steady-state number of entrants, manufacturing output is:

$$Y^C = \rho(N) \left(Z L^\alpha K^{1-\alpha} - f_E \frac{\delta}{1 - \delta} N \right).$$

Combining these two results, we have:

$$N = \frac{(1 - \delta) Z L^\alpha K^{1-\alpha}}{\left(\frac{r + \delta}{\mu(N) - 1} + \delta \right) f_E}.$$

From the rental rate expression:

$$K = \left(\frac{1 - \alpha}{r + \delta^K} \frac{\rho(N)}{\mu(N)} Z \right)^{\frac{1}{\alpha}} L$$

Thus, when labor supply is inelastic ($L = 1$), N solves:

$$N = \frac{(1 - \delta) Z^{\frac{1}{\alpha}} \left[\frac{1 - \alpha}{r + \delta^K} \right]^{\frac{1}{\alpha} - 1} \left[\frac{\rho(N)}{\mu(N)} \right]^{\frac{1}{\alpha} - 1}}{f_E \frac{r + \delta}{\mu(N) - 1} + \delta}$$

This equation yields N as a function of structural parameters, including parameters pertaining to preferences. For example, under C.E.S. preferences, we have

$$N^{CES} = \left\{ \frac{(1 - \delta) Z^{\frac{1}{\alpha}} \left[\frac{1 - \alpha}{r + \delta^K} \frac{\theta}{\theta - 1} \right]^{\frac{1}{\alpha} - 1}}{f_E [(r + \delta)(\theta - 1) + \delta]} \right\}^{1 + \frac{1 - \alpha}{\alpha(\theta - 1)}}.$$

Otherwise, N is a function of the parameters governing the functional forms of $\rho(N)$ and $\mu(N)$, and the now familiar calibration scheme $\sigma N^{Trans} = \theta - 1$ ensures that the steady-state markup and number of firms are the same under C.E.S. and translog, so that, again:

$$\eta(N) \equiv \frac{\mu'(N) N}{\mu(N)} = -\frac{1}{1 + \sigma N^{Trans}} = -\frac{1}{\theta} \quad \text{and} \quad \epsilon(N) \equiv \frac{\rho'(N) N}{\rho(N)} = \frac{1}{2\sigma N^{Trans}} = \frac{1}{2(\theta - 1)}.$$

The shares vN_E/Y^C and dN/Y^C are unchanged relative to the baseline model without capital. The shares of (physical) capital and labor income in manufacturing output Y^C are now:

$$\frac{r^K K}{Y^C} = (1 - \alpha) \left(\frac{1}{\mu} + \frac{vN_E}{Y^C} \right) \quad \text{and} \quad \frac{wL}{Y^C} = \alpha \left(\frac{1}{\mu} + \frac{vN_E}{Y^C} \right).$$

Each of these shares consists of two parts: the share in Y^C of the respective factor's portion used in the manufacturing and 'new products' sectors, respectively. The share of manufacturing output in GDP is: $Y^C/Y = (1 + vN_E/Y^C)^{-1}$. The share of total investment also consists of two components: investment in new products/firms vN_E (which includes the part of capital installed last period that is used to produce these new firms, $r^K K^E$) and investment in new capital I . The latter can be found from the expression for the rental rate, using also $I/K = \delta^K$ and $r^K = r + \delta^K$:

$$\begin{aligned} \frac{K}{Y^C} &= \frac{1 - \alpha}{r + \delta^K} \left(\frac{1}{\mu} + \frac{vN_E}{Y^C} \right) \Rightarrow \frac{K}{Y} = \frac{1 - \alpha}{r + \delta^K} \left(1 - \frac{\mu - 1}{\mu} \frac{1}{1 + \frac{vN_E}{Y^C}} \right), \\ \frac{I}{Y^C} &= (1 - \alpha) \frac{\delta^K}{r + \delta^K} \left(\frac{1}{\mu} + \frac{vN_E}{Y^C} \right) \Rightarrow \frac{I}{Y} = (1 - \alpha) \frac{\delta^K}{r + \delta^K} \left(1 - \frac{\mu - 1}{\mu} \frac{1}{1 + \frac{vN_E}{Y^C}} \right). \end{aligned}$$

Note that the share of physical capital investment in GDP is smaller than its RBC counterpart $((1 - \alpha) \delta^K / (r + \delta^K))$. But the share of total investment in total GDP can be higher since it includes investment in new firms. Specifically, the share of total investment in GDP is now:

$$\frac{TI}{Y} = \frac{vN_E}{Y} + \frac{I}{Y} = \frac{vN_E}{Y^C} \frac{1}{1 + \frac{vN_E}{Y^C}} + (1 - \alpha) \frac{\delta^K}{r + \delta^K} \left(1 - \frac{\mu - 1}{\mu} \frac{1}{1 + \frac{vN_E}{Y^C}} \right).$$

D Measuring the Solow Residual

In computing the second moment properties of our model, we used the same productivity process as in King and Rebelo (1999) to facilitate comparison of results. This productivity process is based on a Solow residual calculation. However, our framework also has implications for measurement of technological progress, to which we now briefly turn.

Capital in Production of Goods Only

To start with, we can write an aggregate 'production function' for output of the consumption good, as in the baseline model:

$$Y_t^C = \rho_t Z_t (L_t^C)^\alpha K_t^{1-\alpha}.$$

Similarly, aggregate real GDP, $Y_t = Y_t^C + v_t N_{E,t}$, can be rewritten as:

$$Y_t = \rho(N_t) Z_t (L_t^C)^\alpha K_t^{1-\alpha} \left(1 + \frac{\alpha}{\mu_t} \frac{L_t^E}{L_t^C}\right),$$

by using the free entry condition, the real wage schedule, and the ‘production function’ for new firms. Remembering that data-consistent GDP is $Y_{R,t} = Y_t/\rho(N_t)$, we log-linearize this equation to obtain:

$$\Upsilon_{R,t} - Z_t = \frac{Z\rho(N) (L^C)^\alpha K^{1-\alpha}}{Y} [\alpha \mathbb{L}_t^C + (1-\alpha) \mathbb{K}_t] + \frac{Z\rho(N) (L^C)^\alpha K^{1-\alpha}}{Y} \frac{\alpha L^E}{\mu L^C} [\alpha \mathbb{L}_t^C + (1-\alpha) \mathbb{K}_t + \mathbb{L}_t^E - \mathbb{L}_t^C - \mu_t]$$

Now note that:

$$\begin{aligned} \frac{Z\rho(N) (L^C)^\alpha K^{1-\alpha}}{Y} &= \frac{Y_C}{Y} = \frac{1}{1+v}, \text{ where } v \equiv \frac{vN_E}{Y^C} = \frac{\delta}{r+\delta} \frac{\mu-1}{\mu} \\ \frac{\alpha L^E}{\mu L^C} &= \frac{\alpha}{\mu} \frac{\mu-1}{\alpha} \frac{\delta}{(r+\delta)} = v. \end{aligned}$$

Substituting and simplifying, we obtain the model-implied Solow residuals as:

$$Z_t = \Upsilon_t^R - \alpha \mathbb{L}_t^C - (1-\alpha) \mathbb{K}_t - \frac{v}{1+v} (\mathbb{L}_t^E - \mathbb{L}_t^C - \mu_t).$$

Finally, to facilitate comparison with the ‘standard’ Solow residuals, use the labor market clearing condition to obtain:

$$\begin{aligned} Z_t &= \Upsilon_t^R - \alpha \mathbb{L}_t - (1-\alpha) \mathbb{K}_t + \alpha (\mathbb{L}_t - \mathbb{L}_t^C) - \frac{v}{1+v} (\mathbb{L}_t^E - \mathbb{L}_t^C - \mu_t), \\ &= \Upsilon_t^R - \alpha \mathbb{L}_t - (1-\alpha) \mathbb{K}_t + \left[\alpha - \frac{v}{1+v} \left(\frac{\alpha}{v\mu} + 1 \right) \right] (\mathbb{L}_t - \mathbb{L}_t^C) + \frac{v}{1+v} \mu_t. \end{aligned}$$

To emphasize the difference with the standard RBC-calculated residual, write this as:

$$Z_t = S_t + \left[\alpha - \frac{v}{1+v} \left(\frac{\alpha}{v\mu} + 1 \right) \right] (\mathbb{L}_t - \mathbb{L}_t^C) + \frac{v}{1+v} \mu_t,$$

where $S_t \equiv \Upsilon_{R,t} - [\alpha \mathbb{L}_t + (1-\alpha) \mathbb{K}_t]$ is the traditional, RBC Solow residual. There are two differences: The first is related to the difference between the total amount of labor and the part of labor used for producing goods. The second is related to markup variation.

Capital in Production of Goods and Creation of New Firms

When physical capital is used also to set up new firms, the aggregate ‘production function’ for manufacturing is:

$$Y_{C,t} = \rho(N_t) (Z_t L_t^\alpha K_t^{1-\alpha} - f_{E,t} N_{E,t}).$$

Similarly, aggregate GDP is:⁵³

$$Y_t = Z_t \rho(N_t) \left[L_t^\alpha K_t^{1-\alpha} - \frac{\mu(N_t) - 1}{\mu(N_t)} (L_t^E)^\alpha (K_t^E)^{1-\alpha} \right].$$

Remembering that data-consistent GDP is $Y_{R,t} = Y_t / \rho(N_t)$, we log-linearize this equation to obtain:

$$\Upsilon_{R,t} - Z_t = \frac{Z \rho(N) L^\alpha K^{1-\alpha}}{Y} [\alpha \mathsf{L}_t + (1 - \alpha) \mathsf{K}_t] - \frac{\mu - 1}{\mu} \frac{Z \rho(N) (L^E)^\alpha (K^E)^{1-\alpha}}{Y} \left[\alpha \mathsf{L}_t^E + (1 - \alpha) \mathsf{K}_t^E + \frac{1}{\mu - 1} \mu_t \right].$$

Note now that:

$$\begin{aligned} \frac{Z \rho(N) (L^E)^\alpha (K^E)^{1-\alpha}}{Y} &= \frac{f_E N_E \rho(N)}{Y} = \mu \frac{v N_E}{Y}, \\ \frac{Z \rho(N) L^\alpha K^{1-\alpha}}{Y} &= \frac{Y^C}{Y} + \mu \frac{v N_E}{Y} = 1 + (\mu - 1) \frac{v N_E}{Y}. \end{aligned}$$

Substituting, we obtain the model-consistent Solow residual:

$$Z_t = \Upsilon_{R,t} - \left[1 + (\mu - 1) \frac{v N_E}{Y} \right] [\alpha \mathsf{L}_t + (1 - \alpha) \mathsf{K}_t] + (\mu - 1) \frac{v N_E}{Y} [\alpha \mathsf{L}_t^E + (1 - \alpha) \mathsf{K}_t^E] + \frac{v N_E}{Y} \mu_t,$$

or, to emphasize the difference with the standard RBC-calculated residual:

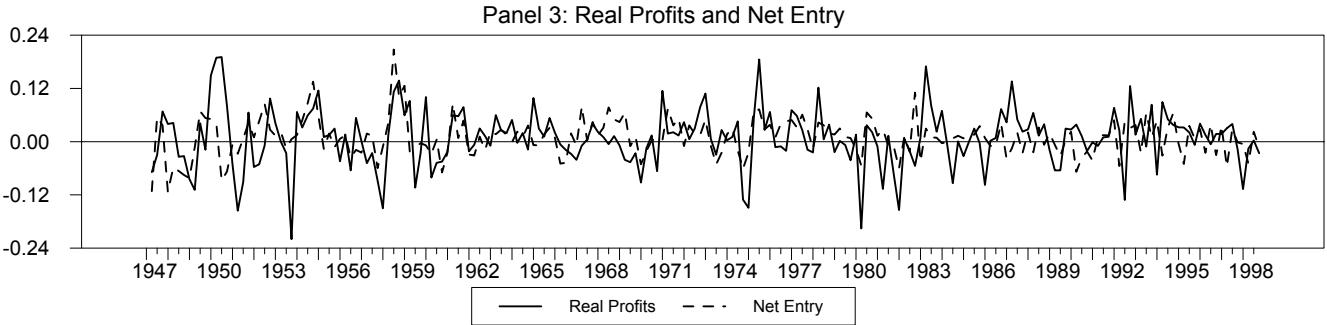
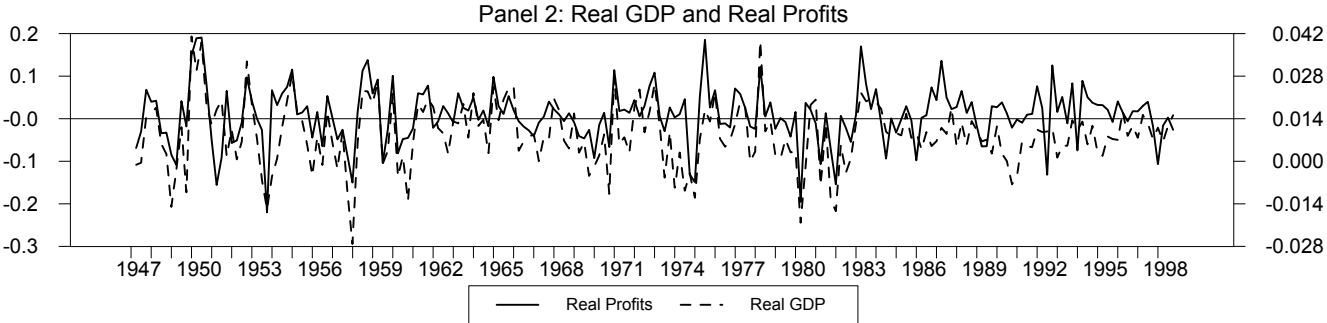
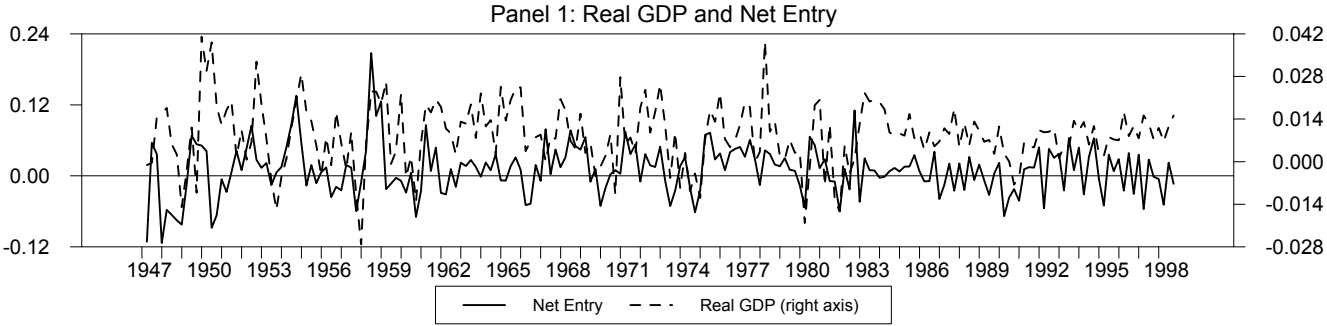
$$Z_t = S_t - (\mu - 1) \frac{v N_E}{Y} (\alpha (\mathsf{L}_t - \mathsf{L}_t^E) + (1 - \alpha) (\mathsf{K}_t - \mathsf{K}_t^E)) + \frac{v N_E}{Y} \mu_t,$$

where $S_t \equiv \Upsilon_{R,t} - [\alpha \mathsf{L}_t + (1 - \alpha) \mathsf{K}_t]$. Again, there are two differences: The first is related to the differences between the total amounts of each factor and the part of that factor used for setting up new firms. The second is related to markup variation.

⁵³Note that $L_t^\alpha K_t^{1-\alpha} = (L_t^C)^\alpha (K_t^C)^{1-\alpha} + (L_t^E)^\alpha (K_t^E)^{1-\alpha}$.

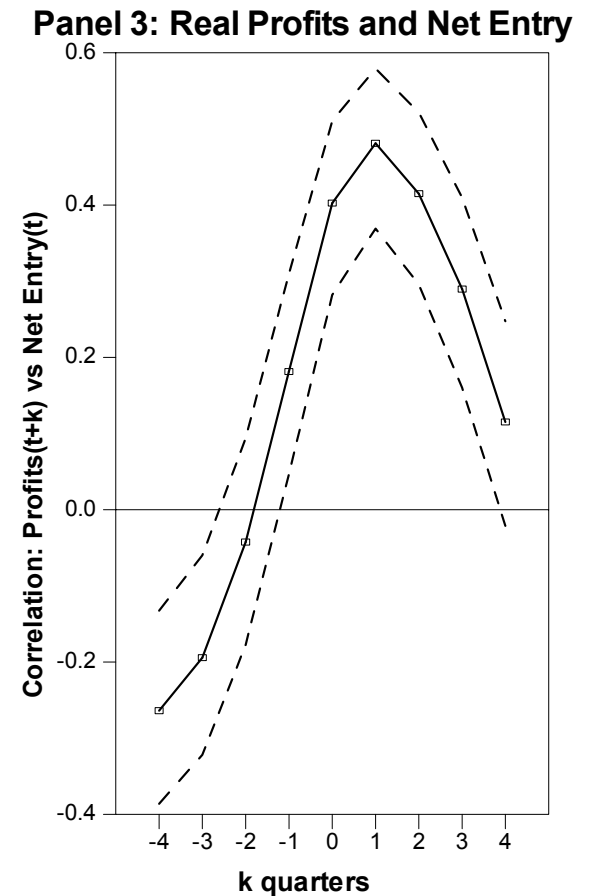
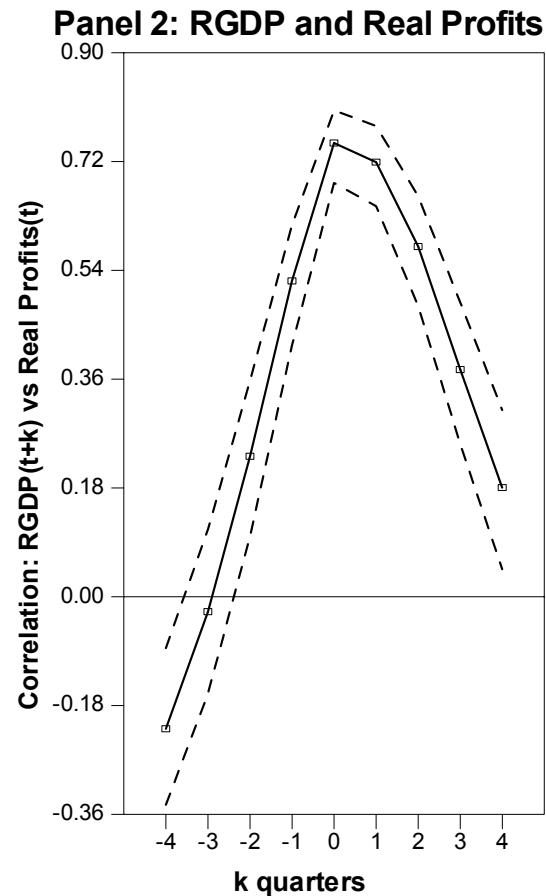
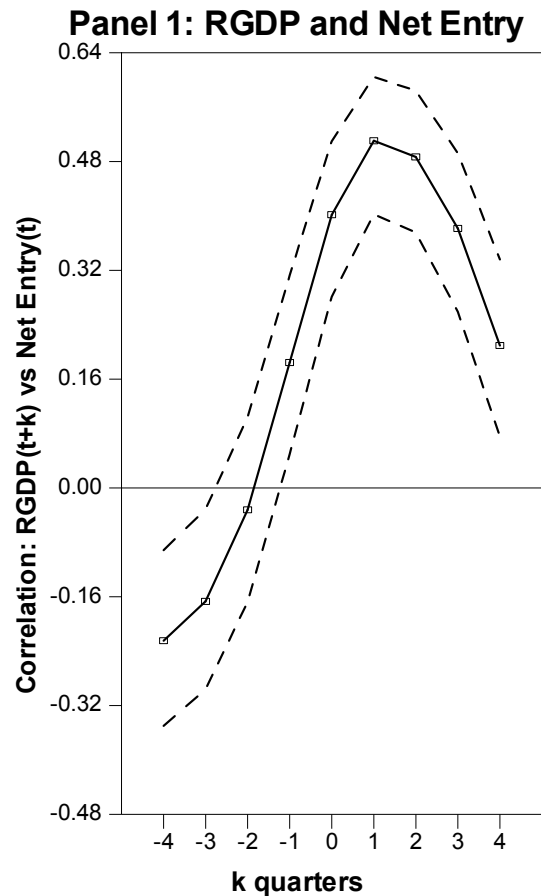
Growth Rates of Real GDP, Net Entry, and Real Profits

Sample period: 1947 - 1998



Cross Correlation: RGDP, Net Entry, and Real Profits

Hodrick-Prescott filtered data in logs, 95% confidence intervals, sample period: 1947 - 1998



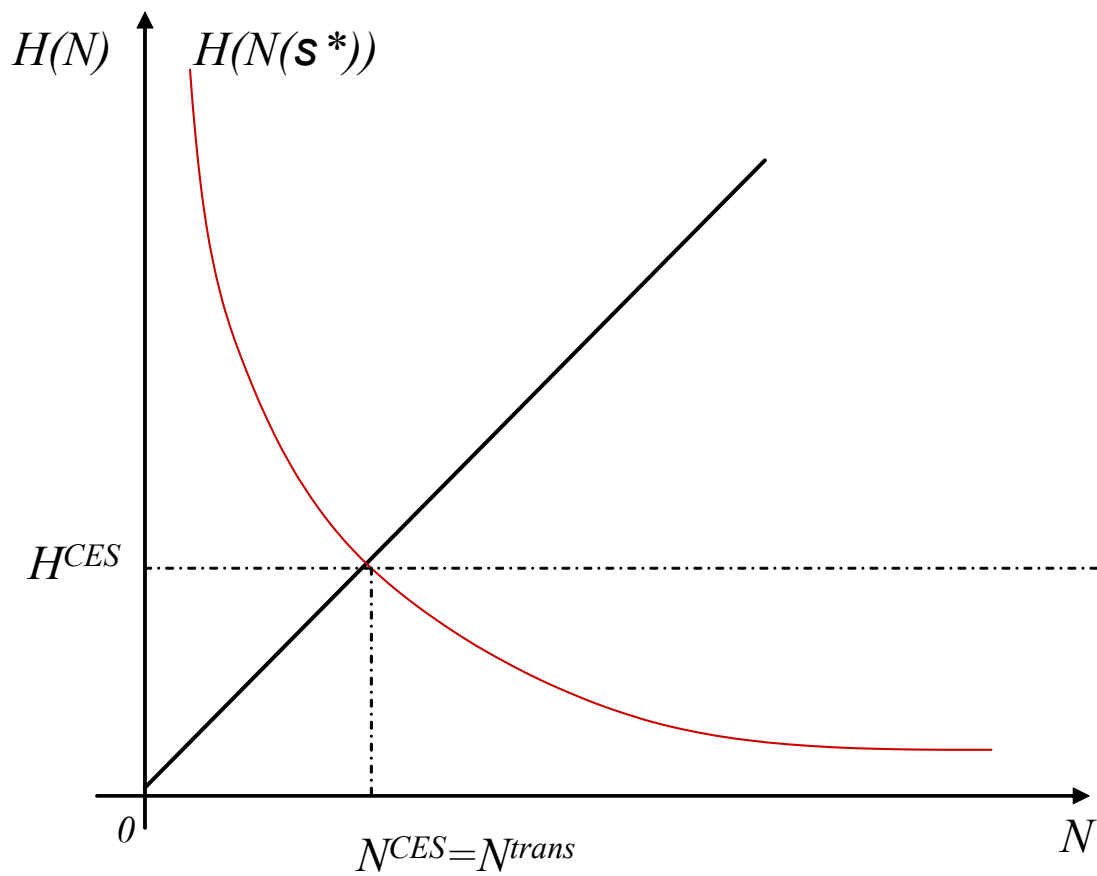


Figure 3. The Steady-State Number of Firms, C.E.S. vs. Translog

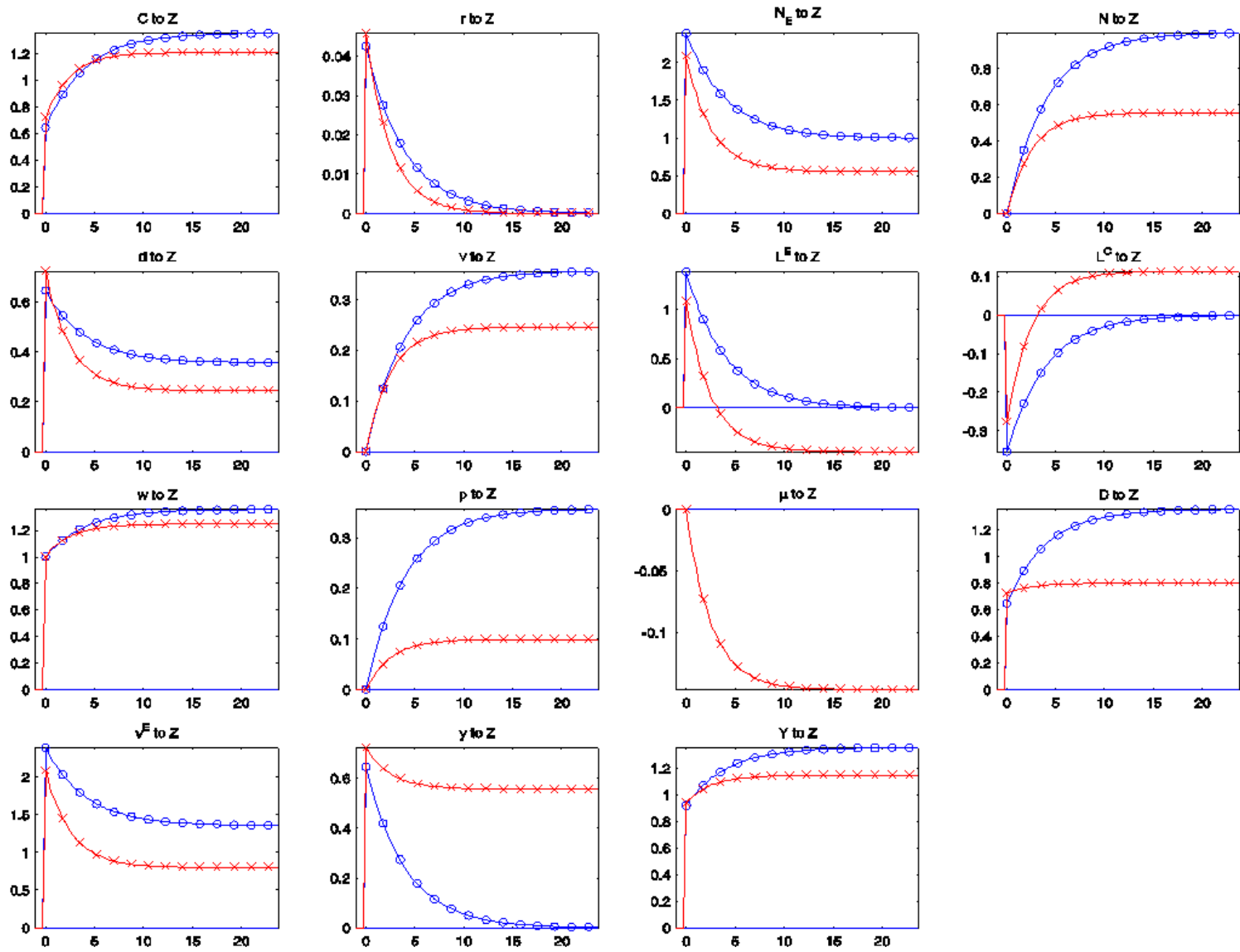


Figure 4. Responses to a Permanent Productivity Increase, C.E.S. vs. Translog, Inelastic Labor

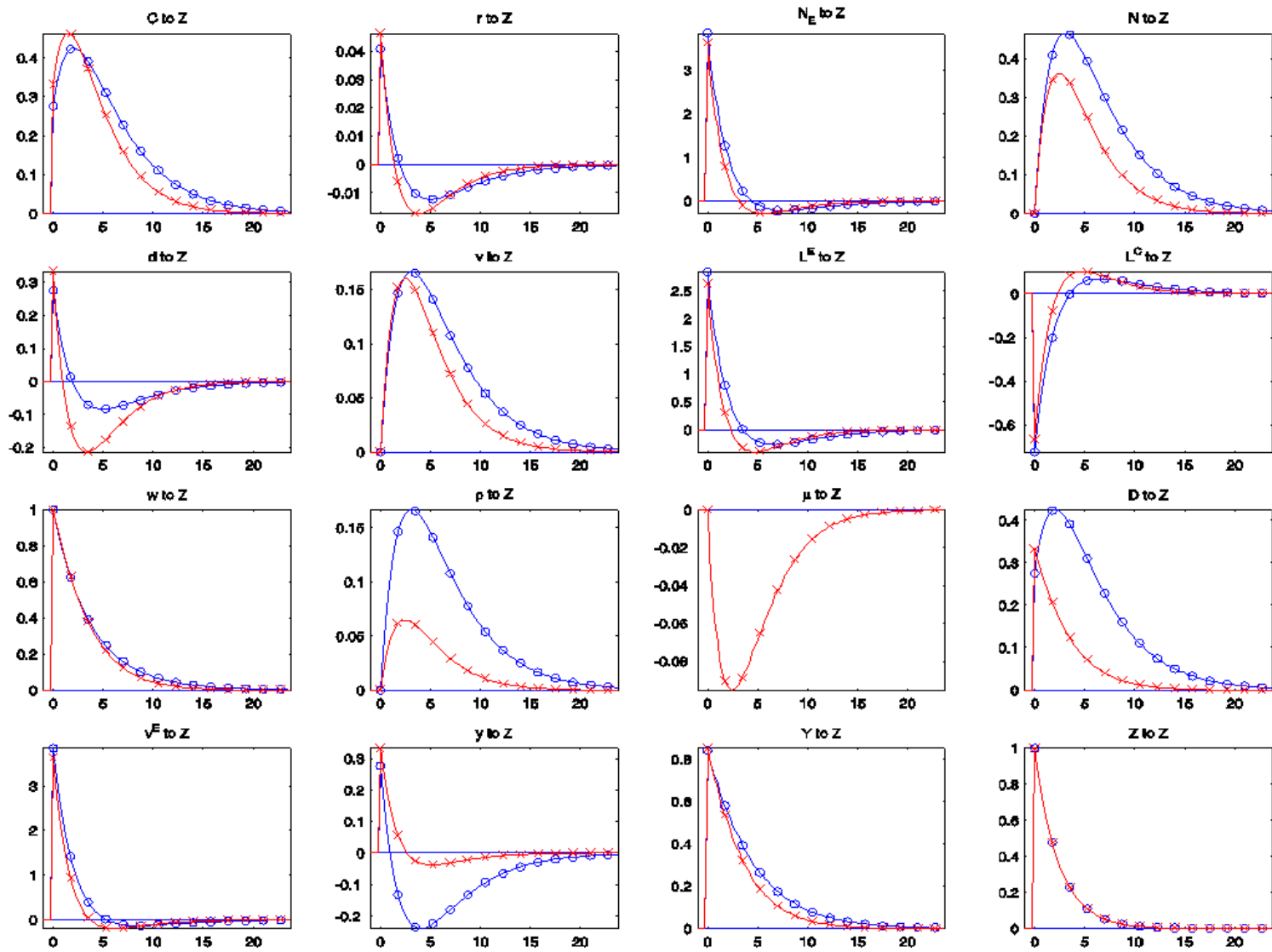


Figure 5. Responses to a Transitory Productivity Increase, Persistence .9, C.E.S. vs. Translog, Inelastic Labor

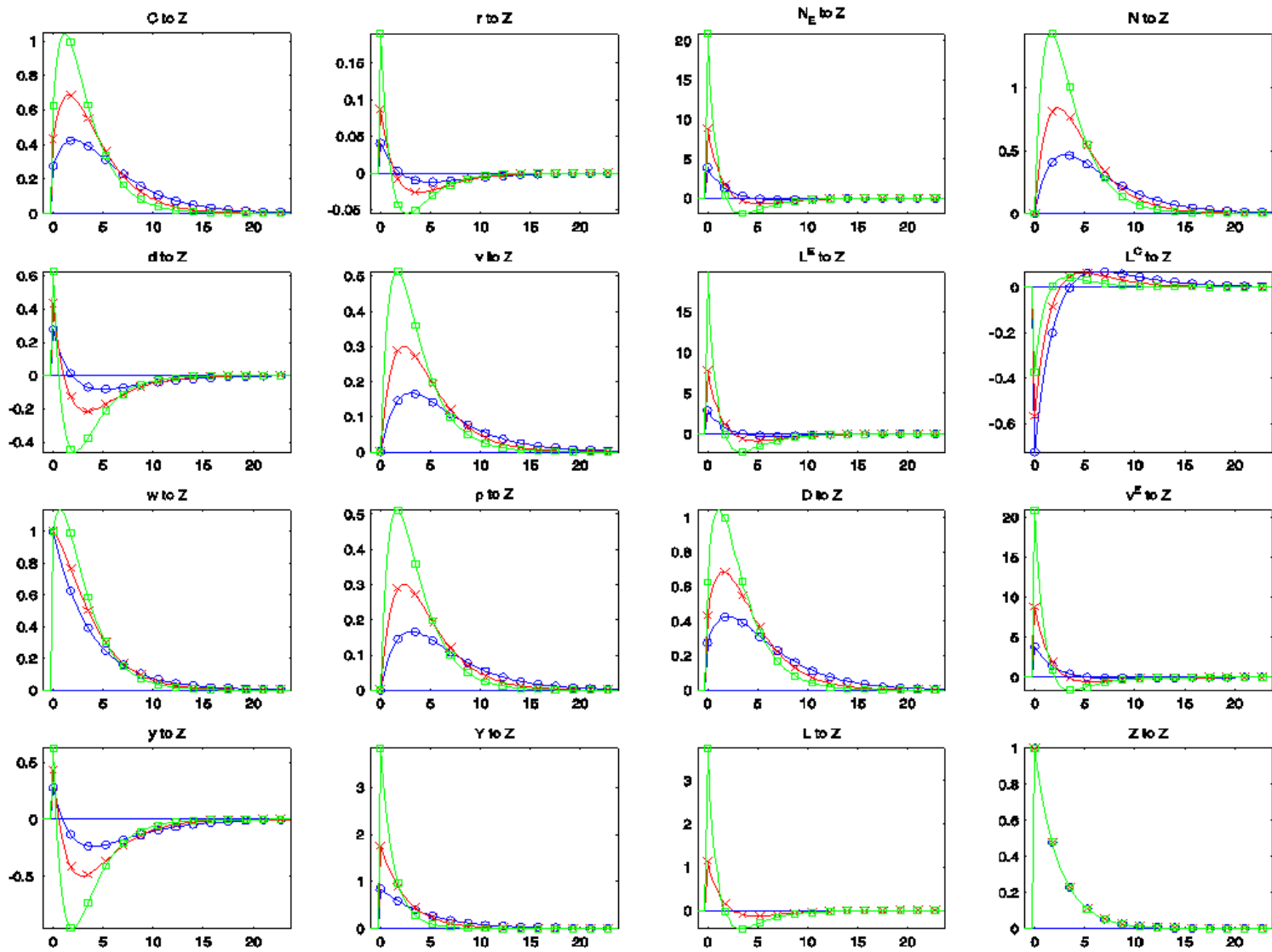


Figure 6. Responses to a Transitory Productivity Increase, Persistence .9, C.E.S., Varying Labor Elasticity

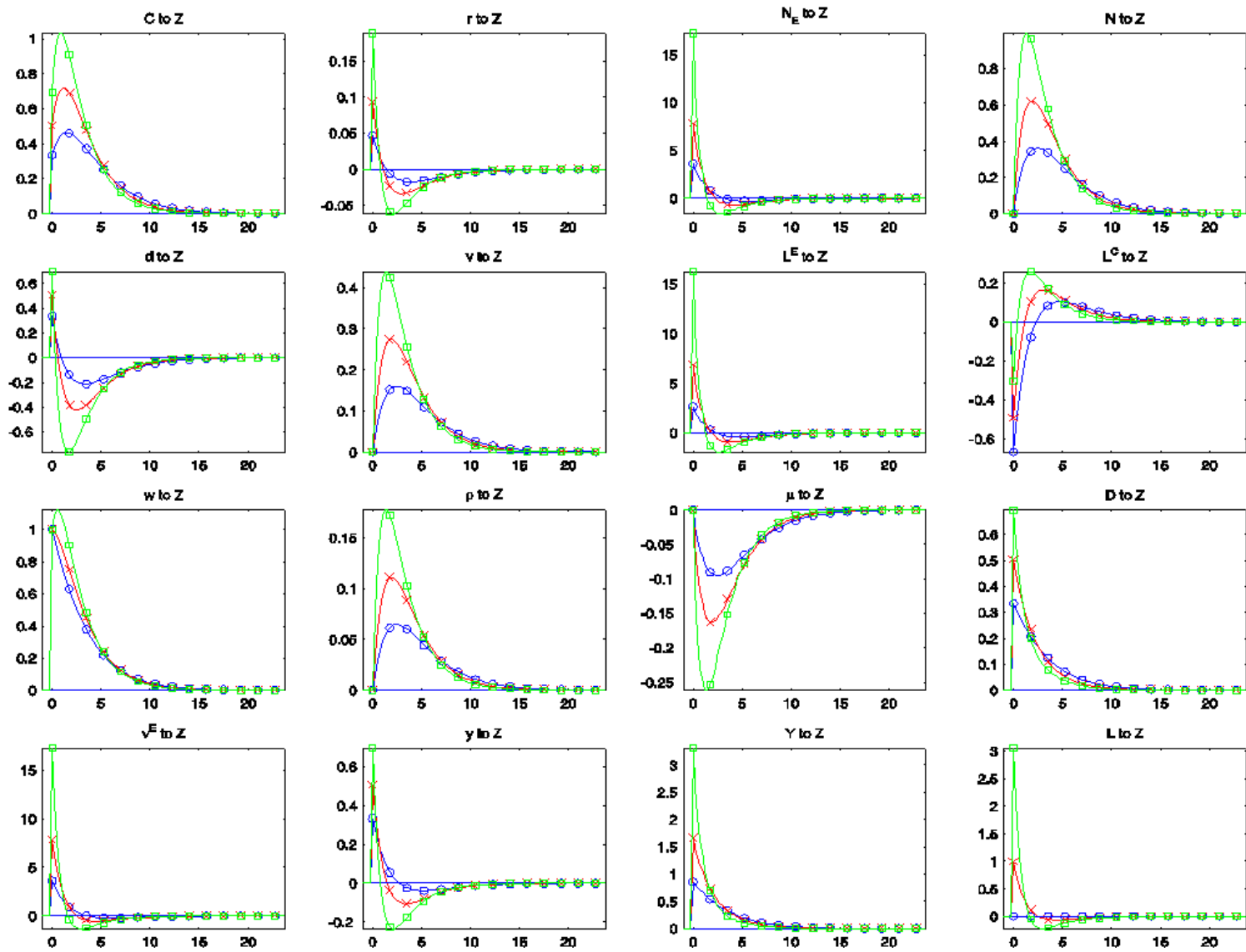


Figure 7. Responses to a Transitory Productivity Increase, Persistence .9, Translog, Varying Labor Elasticity

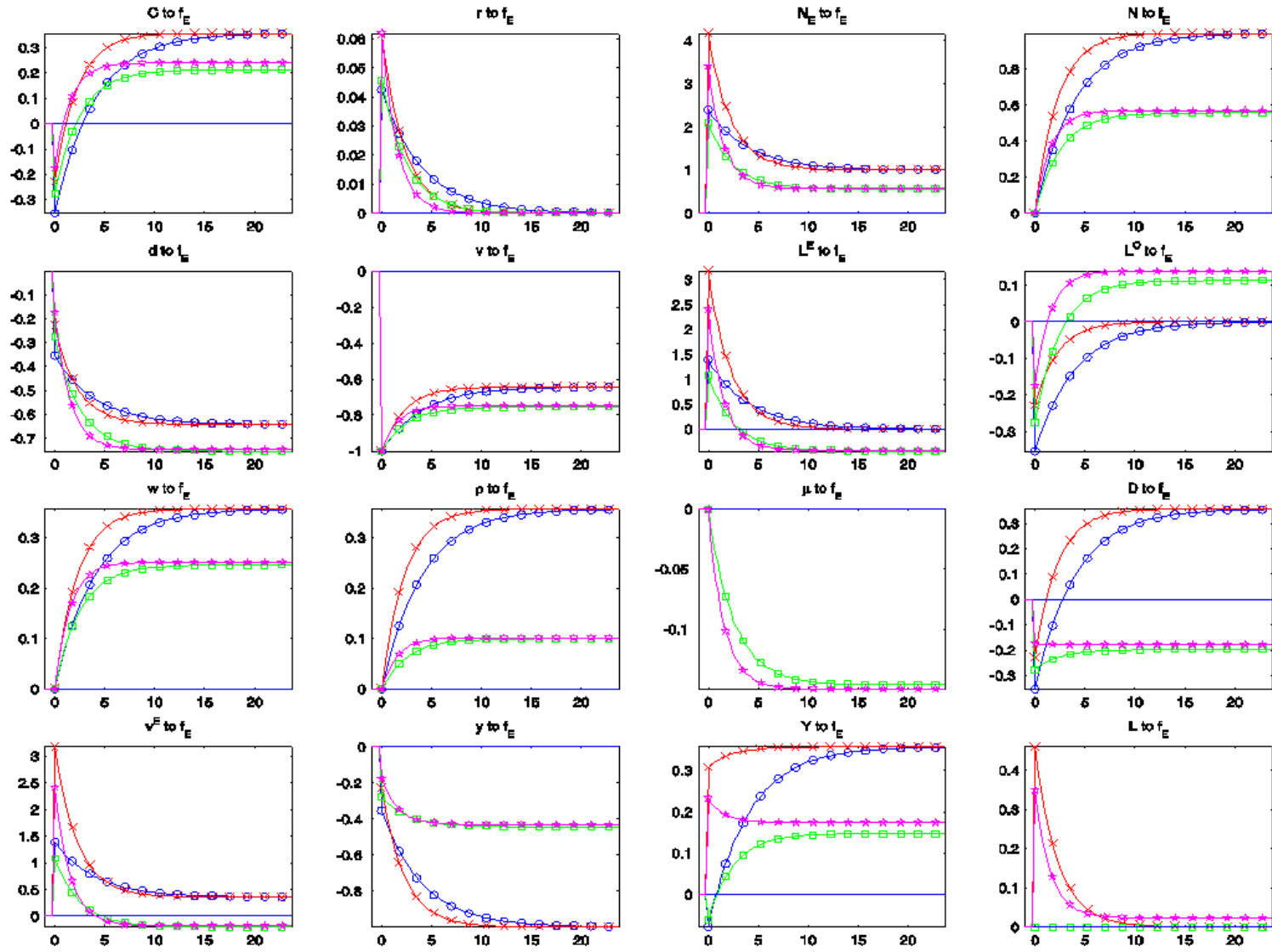


Figure 8. Responses to a Permanent Deregulation, C.E.S. vs. Translog, Inelastic Labor vs. $\varphi = 2$

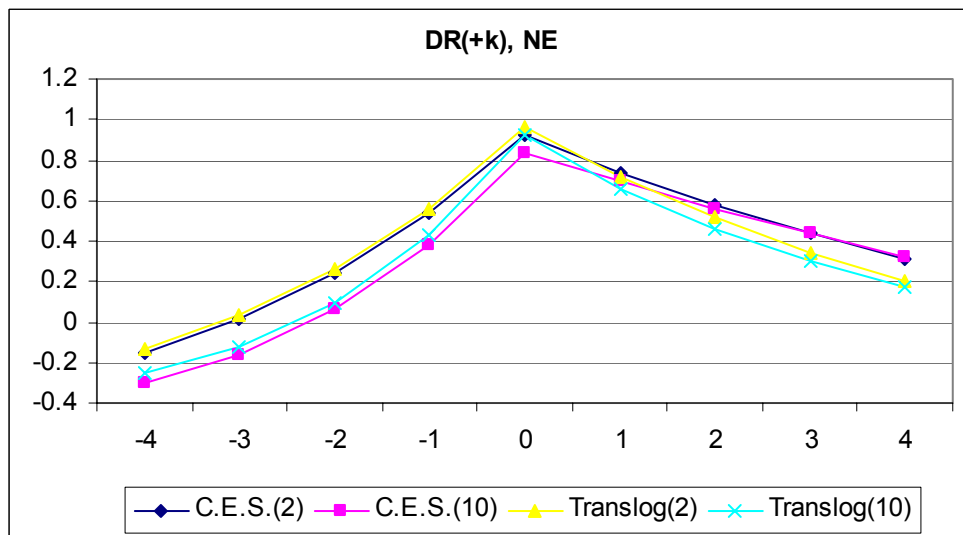
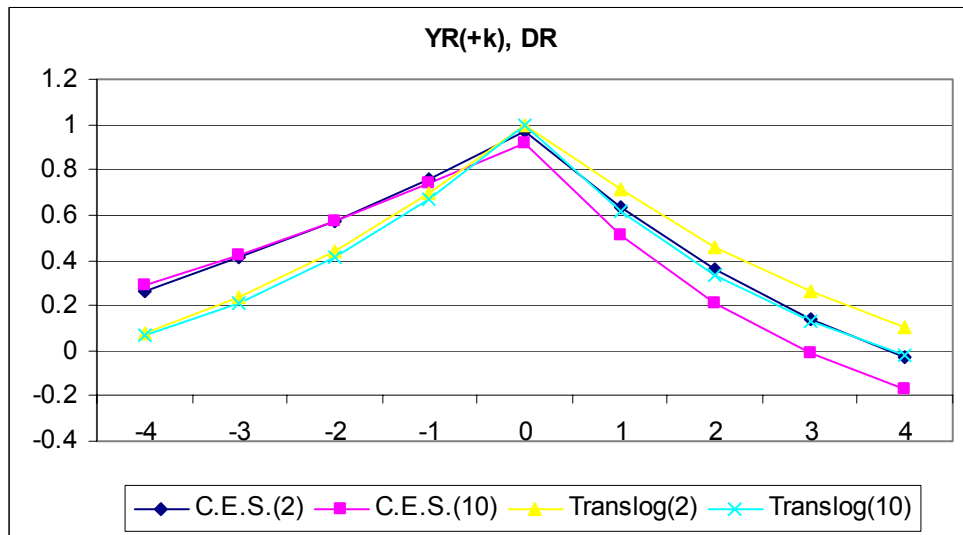
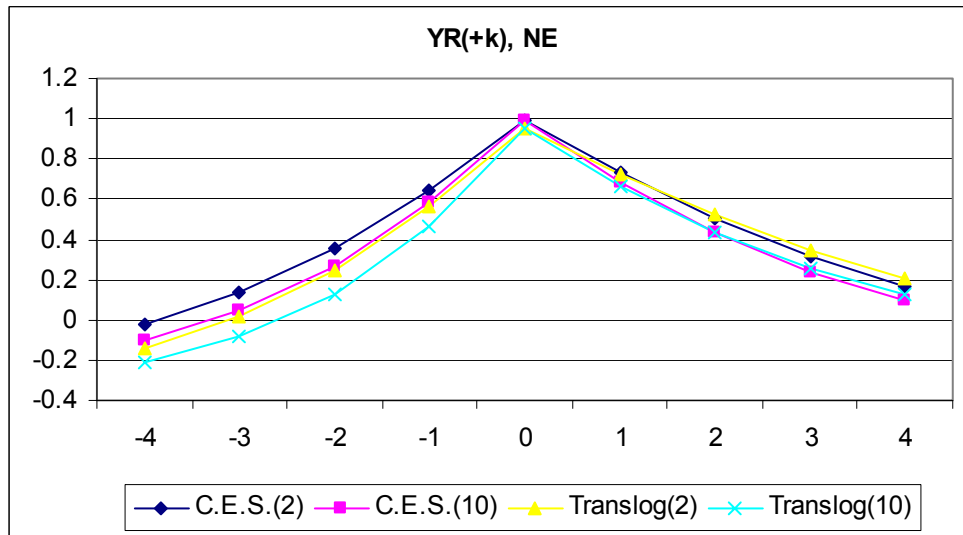


Figure 9. Model-Based Cross Correlations: GDP, Entry, and Real Profits

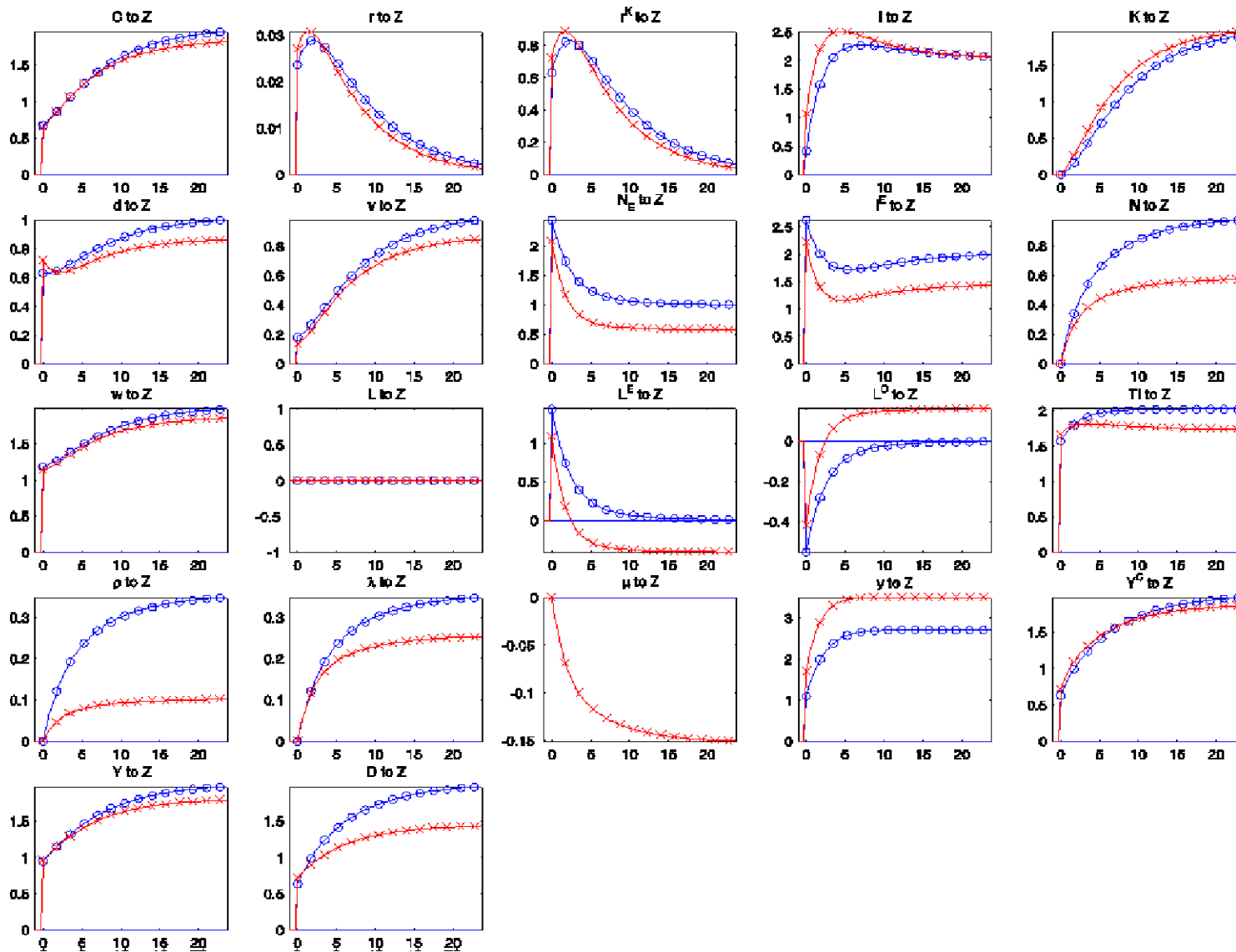


Figure 10. Responses to a Permanent Productivity Increase, C.E.S. vs. Translog, Inelastic Labor, Capital in Production of Goods

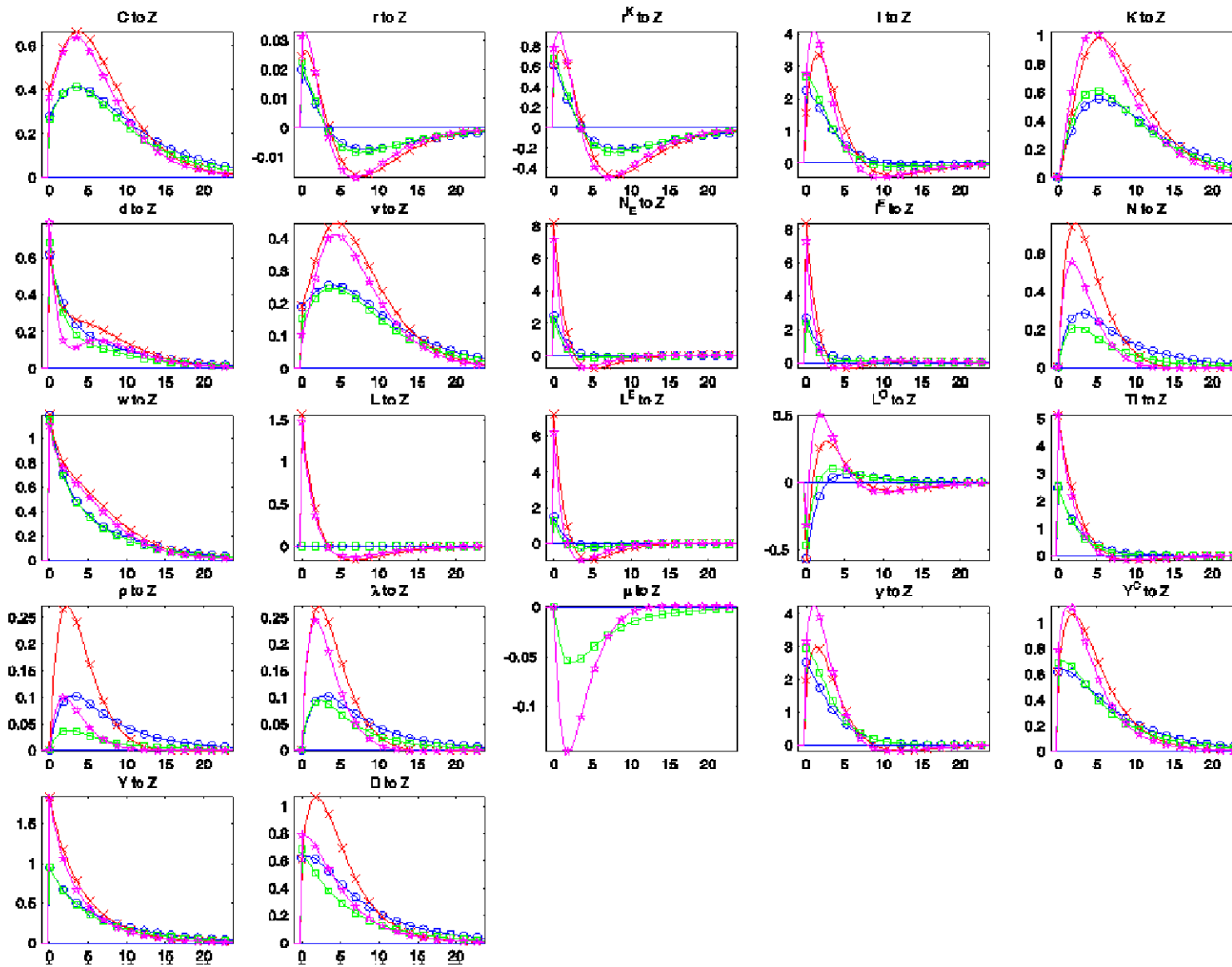


Figure 11. Responses to Transitory Productivity, C.E.S. vs. Translog, Varying Labor Elasticity, Capital in Production of Goods

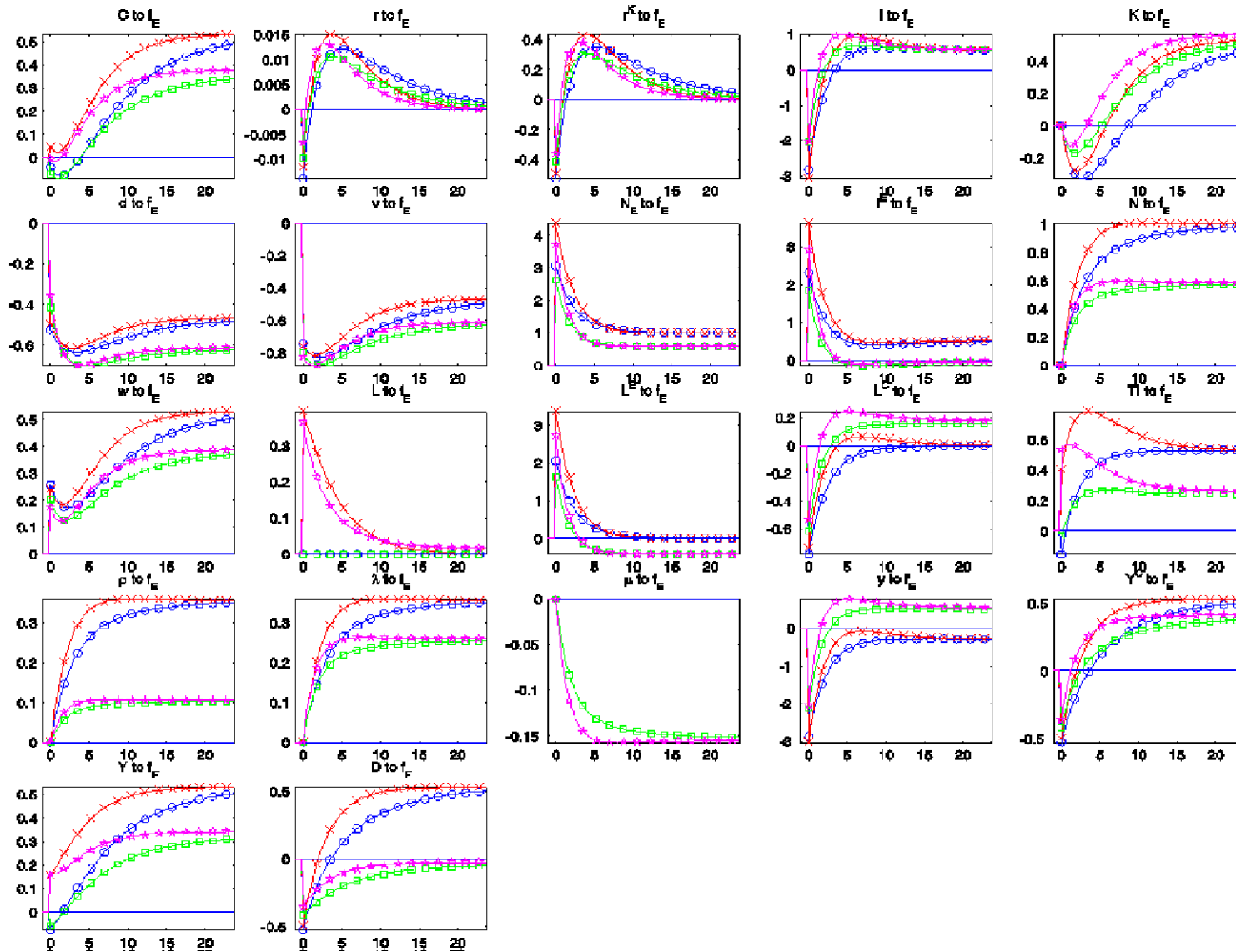


Figure 12. Responses to a Permanent Deregulation, C.E.S. vs. Translog, Inelastic Labor vs. $\varphi = 2$, Capital in Production of Goods

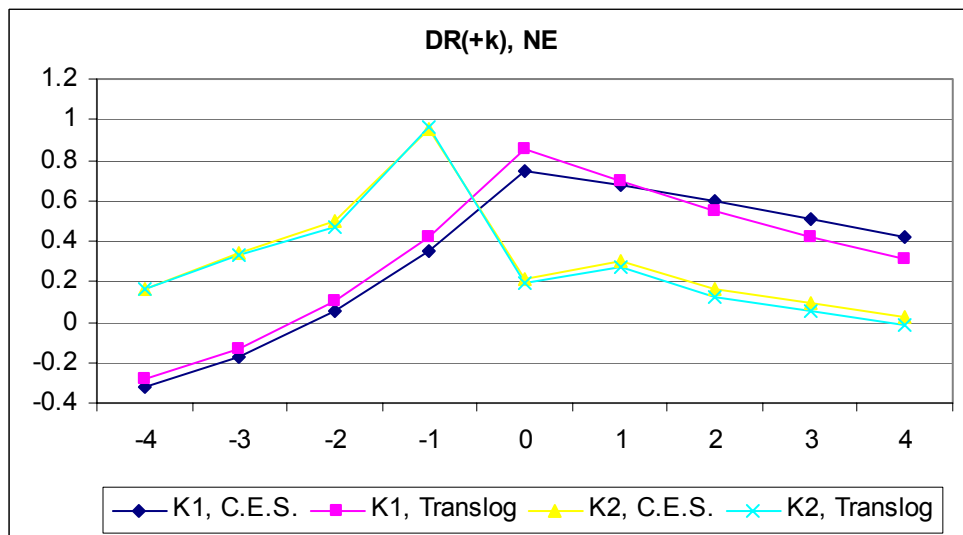
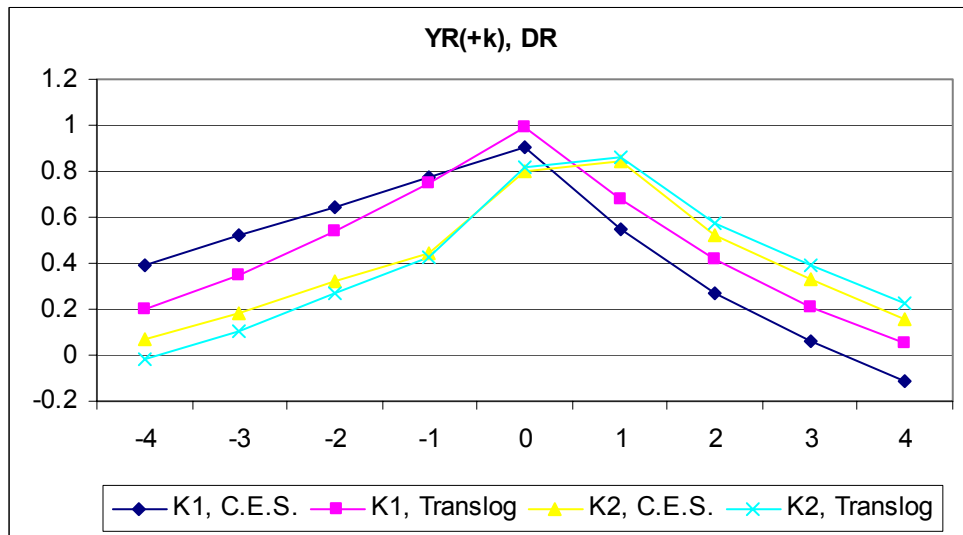
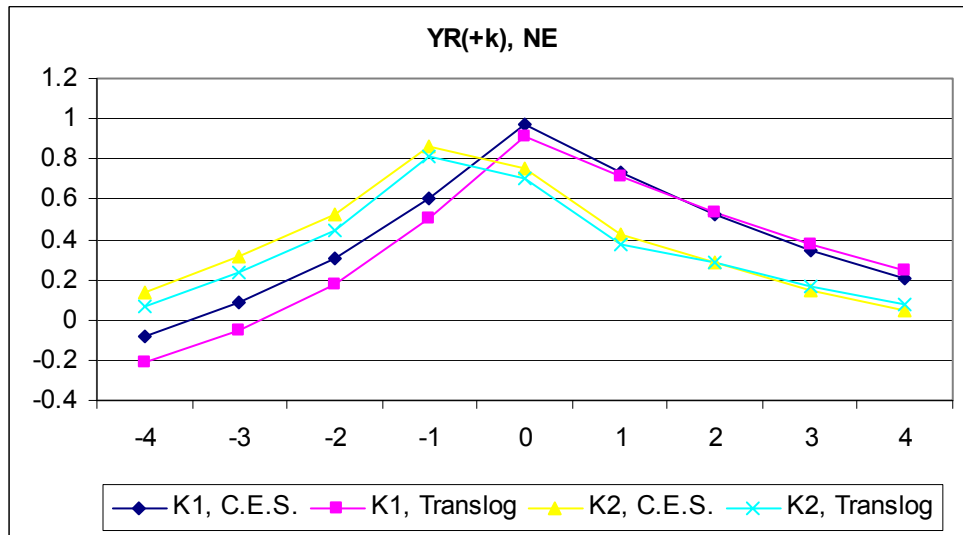


Figure 13. Model-Based Cross Correlations: GDP, Entry, and Real Profits, Model with Capital