Sector-specific Markup Fluctuations and the Business Cycle*

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Abstract

The counter-cyclicality in the relative price of equipment investment which is observed in the U.S. has been attributed to equipment-specific productivity shocks. Cross-country evidence indicates that a number of countries experience sizeable delays between a surge in equipment production and a fall in its relative price, which is difficult to reconcile with sector-specific shocks. I show that in the presence of sector specific, time-varying markups, relative price movements arise as a direct consequence of consumption smoothing, even if all shocks are aggregate, while barriers to firm entry lead to delays in relative price responses. A calibrated version of the model explains around one-third of the relative price fluctuations which are observed in the U.S., as well as the qualitative differences in the behaviour of this relative price across countries.

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1 Introduction

In a seminal paper, Greenwood, Hercowitz, and Krusell (2000) argue that the negative correlation which is observed in postwar U.S. data between equipment investment and its relative price is due to equipment-specific technology shocks, the idea being that positive shocks to the productivity of the equipment sector lead to falls in its price in terms of consumption goods. A look at cross-country evidence (figure 2 and 6 in appendix B) reveals that most countries in the OECD experience a delay of up to three years between a surge in equipment production and a fall in its relative price, which is difficult to reconcile with sector-specific technology shocks. This matters, because the observed fluctuations in the relative price of equipment in the U.S. have been interpreted as evidence in favour of the importance of technology shocks in the short-run, notably by Fisher (2006).

Models of imperfect competition provide an alternative channel for relative price movements, through sector-specific fluctuations in markups. Research indicates that price markups are inversely related to industry output (see section 2.2). Given that in U.S. data, equipment investment is much more variable than consumption, markups in the equipment-producing sector will react more strongly to aggregate shocks than markups in the consumption sector, leading to a countercyclical movement in the relative price of equipment.

I follow Jaimovich (2006) in assuming that the observed markup movements are due to pro-cyclical competitive pressure, through fluctuations in the number of firms. There is free entry; firms pay a fixed operating cost each period and compete à la Cournot. This leads to an increase in the number of firms, and a decrease in markups, during expansions.

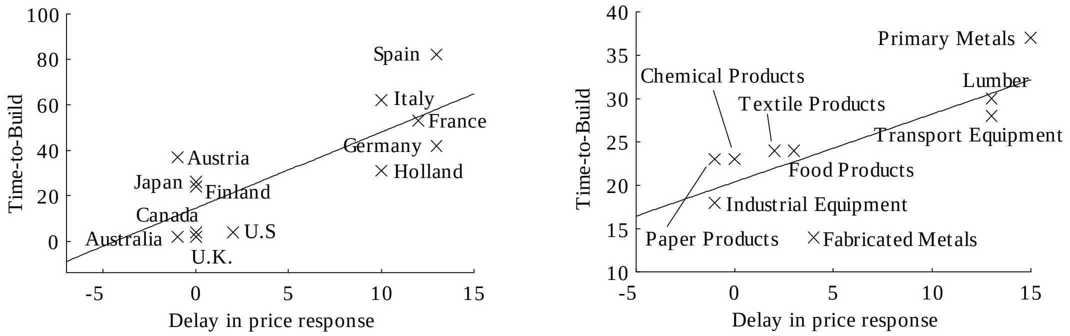
Relative price responses to a positive aggregate supply or demand shock will then be delayed in countries in which it takes more time to set up new firms. Indeed, I find a significant positive correlation between the time required to set up a firm as estimated by Djankov, La Porta, et al. (2002) and delays in the response of the relative price of equipment across countries (figure 1A). Also, for U.S. industries, the time required to build new plants in an industry, as estimated by Koeva (2000), is positively related to the delays in that industry's relative price response (figure 1B).

Note that the above reasoning could also be applied to the construction sector, which is even more volatile than the equipment-producing sector. However, the generally poor quality of price deflator estimates for the construction sector, as well as the long and variable time required to build structures (which implies further problems for the estimation of prices), speak in favour of focusing on equipment investment, at least for this paper. For simplicity, the model presented in this paper thus contains only one investment sector, and its behaviour will be compared

Figure 1: Time-to-Build and Delays in Relative Price Responses

A: Time Required to Set Up a Firm and Relative Price Response[a]

B: Time Required to Build a Plant and Relative Price Response[b]



[a]Lead time for a negative peak in the cross-correlation function between equipment investment and its price in terms of consumption goods, in months; number of business days it takes to obtain legal status to operate a firm, from Djankov, La Porta, et al. (2002).

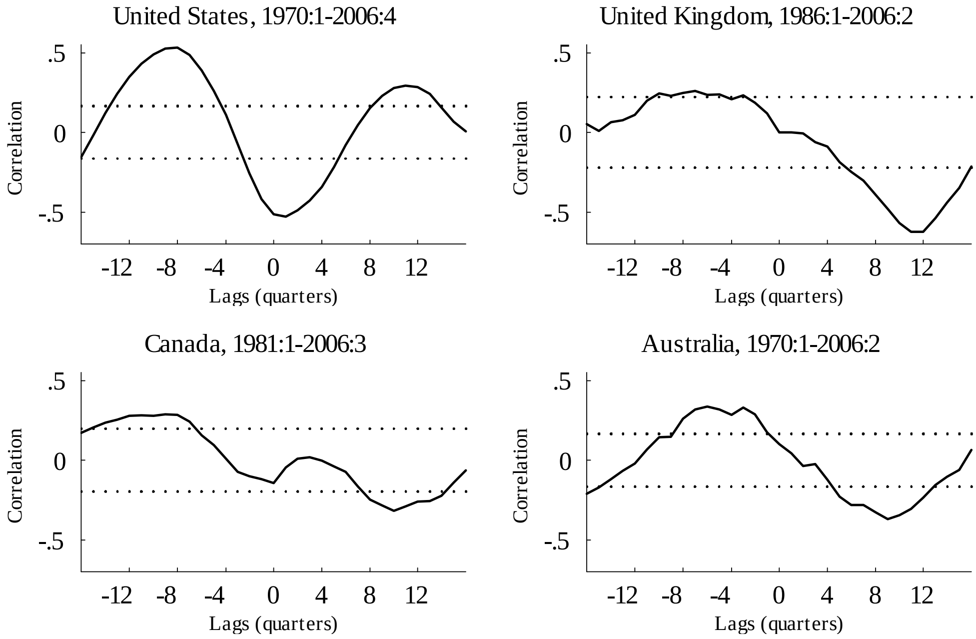
[b]Lead time for a negative peak in the cross-correlation function between industry output and its price in terms of non-durable goods, in months; estimate for the number of months needed to build a plant, from Koeva (2000).

to the behaviour of the equipment sector in the data. Explaining the short-run movements in the relative price of structures is an open challenge to business cycle theory and would certainly justify further research.

Within the framework under consideration, markup fluctuations also have an impact on the income shares of production factors. In the presence of delays to firm entry, incumbent firms earn windfall profits whenever they are hit by positive supply or demand shocks, leading to a fall in the labour income share. Ambler and Cardia (1998) show that this might explain why the labour share is counter-cyclical in most countries (figure 7 in appendix B). The model presented in this paper has a further implication: If the observed relative price movements are indeed induced by movements in markups, then the relative price of equipment should be negatively correlated with the labour share. A look at cross-country data confirms this to be the case for a majority of OECD countries (figure 3 and 8 in appendix B), which suggests a role for markups in bringing about relative price movements.

A well-known problem for many RBC models is their inability to replicate the high degree of sectoral co-movement in employment and output observed in the data, especially in the presence of relative price movements. Arguably, in order to correctly evaluate the impact of a given modelling framework on the movements in the relative price of equipment investment, the model under consideration should

Figure 2: Equipment Investment and its Relative Price[a]



[a]Cross-correlation between equipment investment at time t and its price in terms of consumption goods at various lags; all variables are logged and Hodrick-Prescott filtered prior to analysis. Dotted lines stand for 95 percent confidence intervals.

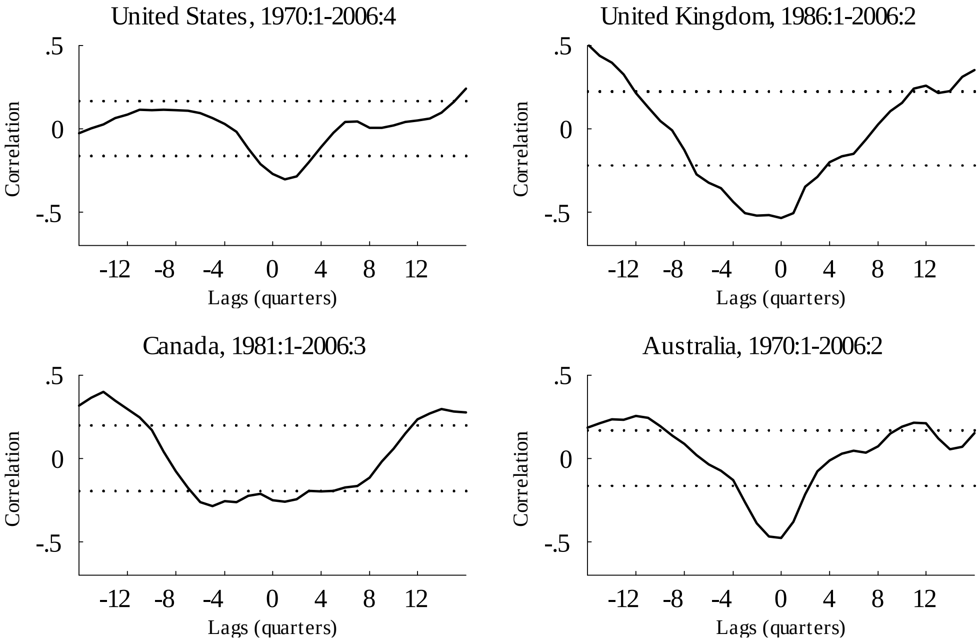
replicate the high amount of co-movement between the investment and consumption sectors. In the model presented in this paper, a lower degree of co-movement results in sectoral price markups moving in a less synchronised manner, which amplifies the movements in the relative price of investment.

Hornstein and Praschnik (1997) show that taking into account the pervasive use of materials in the U.S. economy generates an amount of co-movement between sectors which is broadly in line with the data. More particularly, what generates co-movement is the fact that a large part of the materials which are used in the investment sector are actually produced by industries in the consumption sector, so that an increase in investment directly translates into an increase in the production of consumption goods.

As emphasized by Jaimovich (2006), taking into account materials usage also amplifies markup variations, in that a decrease in the markup in any given industry leads to lower costs for materials for all other industries, which in turn leads to higher output, thereby further depressing markups.

Ferreira and Lloyd-Braga (2005) show that in models with counter-cyclical

Figure 3: The Relative Price of Equipment and the Labour Share[a]



[a]Cross-correlation between the relative price of equipment at time t and the labour share at various lags; all variables are logged and Hodrick-Prescott filtered prior to analysis. Dotted lines stand for 95 percent confidence intervals.

market power, indeterminacy and multiplicity of steady-states may arise with any positive market power. In order to keep this paper simple, I focus on local approximations around stable steady-states, thereby disregarding the above issue.

A version of the model economy calibrated to U.S. data with an entry delay for firms of one quarter replicates over one-third of the observed volatility of both the relative price of equipment and the labour share. The model implies a delay in the fall of the relative price of investment after a positive aggregate shock which corresponds to the delay to firm entry.

The remainder of the paper is organised as follows: section 2 looks at the empirical evidence; section 3 describes the model; section 4 deals with its calibration; section 5 looks at the results; and section 6 concludes.

2 Empirical Evidence

2.1 Cross-country Evidence

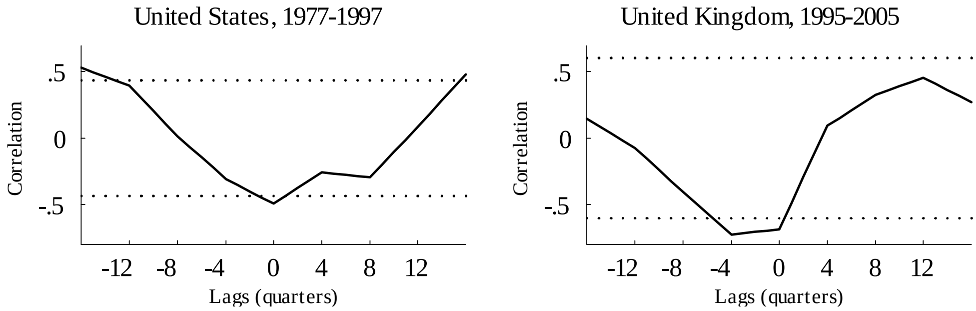
Fluctuations in the price of equipment investment in terms of consumption goods are large in most OECD countries. In a majority of countries, with some exceptions (Finland and the Netherlands), the relative price follows clear cyclical patterns, which however differ among countries: in the U.S., there is a contemporaneous negative correlation between equipment investment and its relative price, while other countries (Australia, Canada, Germany, Italy, and the U.K.) display a lag of up to three years between an increase in equipment production and a fall in its relative price (appendix B, figure 6). In the case of Italy and France, the contemporaneous correlation between the two variables is significantly positive. Also, the relative price of equipment is no less variable in countries in which it is not counter-cyclical.

If relative price movements are due to net firm entry, then one would expect the lag in the response of those relative prices across countries to be positively correlated to the time it takes to set up a firm in each country. Comparing lead times for relative price responses for the years 1995-2005 to estimates by Djankov, La Porta, et al. (2002) for the number of days required to obtain legal status to operate a firm in 1999 in various countries, I find a correlation of .8, significant at the 1% level (figure 1A).

However, the cross-country differences in relative price response delays are several orders of magnitudes larger than the differences in the time needed to set up new firms. A large part of this observed heterogeneity might then come from differences in the time required to build plants across countries. Given a lack of appropriate cross-country data, I look at evidence by Koeva (2000) for the time required to build plants across U.S. industries, which varies between 13 and 87 months. Comparing lead times for relative price responses across industries for the years 1997-2006 to the average time-to-build in each industry, I find a positive correlation of .76 which is significant at the 2% level (figure 1B). This time, the slope of the regression line between the two variables is .8, meaning that an increase in time-to-build of one month leads to an increase in the relative price response lag of slightly more than one month.

As has been pointed out before (see for example Bentolila and Saint-Paul, 2003), the labour share of income follows a broadly similar cyclical pattern across countries: output is negatively correlated with contemporaneous values of the labour share, and positively correlated with future values of that same variable; in other terms, the labour share lags output by between one quarter and two years. Among the countries in the sample, only Greece and Mexico do not follow this

Figure 4: The Relative Price of Equipment and the Number of Firms[a]



[a]Cross-correlation between the relative price of equipment at time t and the number of firms in the investment sector at various lags; all variables are logged and Hodrick-Prescott filtered prior to analysis. Dotted lines stand for 95 percent confidence intervals.

pattern (appendix B, figure 7).

The model presented in this paper predicts that the delay in the positive response of the labour share to an expansion in output should be the same as the delay in the negative response of the relative price of equipment. This is illustrated by the fact that for a majority of countries in the sample, there is a significant negative contemporaneous correlation between the relative price of equipment and the labour share (appendix B, figure 8).

An implication of the model is that the number of firms in the equipment investment sector should be negatively correlated with the relative price for that sector. Sector-specific data on the number of firms is generally limited. Notable exceptions are the U.S. and the U.K., for which ten, respectively twenty, years of data are available at the annual level for the investment sector. In both cases, the number of firms in the investment sector is significantly negatively correlated with the relative price of equipment investment (figure 4).

2.2 Net Entry and Price Markups

Since the seminal work on the cyclicality of the price markups charged by firms by Rotemberg and Woodford (1999), empirical evidence on the subject has progressively become more clear-cut. Looking at two-digit industries in the U.S., Galeotti and Schiantarelli (1998) and Bloch and Olive (2001) find that markups are countercyclical in most industries, while Oliveira Martins and Scarpetta (2002) confirms this finding for G5 countries. Jaimovich (2006) finds that estimates for the average level of markups range between around 15 and 30 percent in value-added data and between 5 and 15 percent in gross output data.

While time-series evidence on the correlation between the number of firms and the size of markups in a given sector is hard to come by, cross-section data is more readily available. Oliveira Martins, Scarpetta, and Pilat (1996) find that, for manufacturing sectors in the OECD, markups within a given sector tend to be lower for sectors with a high number of firms. In other terms, there appears to be a negative cross-sectional relationship between markups and the number of firms.

A crucial implication of the model is that the number of firms should be more variable in industries producing investment goods than in those producing consumption goods. Using annual data on the number of U.S. establishments for the years 1972-1988 provided by the County Business Survey, and weighing value-added industry output according to final use (consumption or investment), I find that the number of firms is almost twice as variable in investment-producing industries (with a standard deviation of 2.97 percent) than in consumption-producing ones (standard deviation of 1.93 percent).

3 A Two-sector Model with Endogenous Markups

The economy consists of two sectors, one producing consumption goods C and another producing investment goods I. Each sector contains a measure one of industries producing intermediate goods using capital, labour and materials as inputs. The monopolistic competition framework proposed by Gali and Zilibotti (1995) is adopted, in which each intermediate good is produced by an endogenous number of firms paying a fixed operating cost and competing à la Cournot. Fluctuations in macro-economic variables arise as a consequence of aggregate shocks to productivity. Time is discrete; time subscripts are omitted whenever there is no risk for confusion.

3.1 Preferences

The preferences of the representative agent are:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left[\log (C_t) + \kappa \log (N - L_t) \right], \tag{1}$$

where L_t denotes hours worked at time t, N denotes the endowment of hours, and β is the discount factor, with $\beta \in (0, 1)$.

3.2 Technology

Sectors producing final goods are indexed by $X \in \{C, I\}$, industries producing each intermediate good are indexed by $m \in (0, 1)$, and firms producing each of those intermediate goods are indexed by $n \in (1, ..., N_{xm})$, where N_{xm} is the number of firms producing the intermediate good m in sector X. Intermediate goods within each industry are homogeneous, as are final goods within each sector.

Firms producing final output in each sector X operate under perfect competition and use sector-specific intermediate goods Y_{xm} as inputs. The output of the representative final-output firm in each sector X is given by the constant elasticity of substitution function

$$Y_x = \left(\int_0^1 Y_{xm}^{\frac{\sigma-1}{\sigma}} dm \right)^{\frac{\sigma}{\sigma-1}},$$

where σ corresponds to the elasticity of substitution between any two intermediate goods, with $\sigma > 1$.

Firm n producing intermediate good m in sector X uses capital K_{xmn}, labour L_{xmn} and materials C^M_{xmn} and I^M_{xmn} as inputs, where C^M_{xmn} (I^M_{xmn}) denotes final goods produced by the consumption (investment) sector which are used as materials by sector X. The production technology faced by each firm is

$$Y_{cmn} = \left[K_{cmn}^{\alpha} \left(A L_{cmn} \right)^{1-\alpha} \right]^{1-\rho} \left[\left(C^M_{cmn} \right)^{\theta_c} \left(I^M_{cmn} \right)^{1-\theta_c} \right]^{\rho} \tag{2}$$

for consumption-producing firms and

$$Y_{imn} = \left[K_{imn}^{\alpha} \left(AQ L_{imn} \right)^{1-\alpha} \right]^{1-\rho} \left[\left(C^M_{imn} \right)^{\theta_i} \left(I^M_{imn} \right)^{1-\theta_i} \right]^{\rho} \tag{3}$$

for investment-producing ones, where $A_t = \exp(a_t)(1+\gamma_a)^t$ is aggregate productivity, with $\gamma_a \geq 0$ its growth rate and a_t a covariance stationary shock:

$$a_t = \varphi a_{t-1} + \varepsilon_t,\ \varepsilon_t \sim N\left(0, \sigma_\varepsilon^2\right), \tag{4}$$

with $0 < \varphi < 1$. Q is investment-specific productivity, and grows at a constant rate γ_q.

Each firm in the consumption (investment) sector pays a fixed operating cost of ϕ_c (ϕ_i) in terms of consumption (investment) goods. While there is a constant measure one of intermediate goods in each sector, the number of firms N_{xm} producing intermediate goods m in sector X is determined under free entry T periods in advance, with $T \geq 0$.

Final output in each sector is used for consumption C and investment I, as an input in both sectors, and for covering fixed costs:

$$
\begin{aligned}
Y_c &\geqq C + C_c^M + C_i^M + \phi_c \int_0^1 N_{cm} dm, && (5) \\
Y_i &\geqq I + I_c^M + I_i^M + \phi_i \int_0^1 N_{im} dm. && (6)
\end{aligned}
$$

Capital and labour are homogeneous and can be freely reallocated across sectors, industries and firms at any point in time. Aggregating across firms n, industries m and sectors X yields the following resource constraint for aggregate capital:

$$
K \geqq \int_0^1 \left(\sum_{n=1}^{N_{cm}} K_{cmn} \right) dm + \int_0^1 \left(\sum_{n=1}^{N_{im}} K_{imn} \right) dm = K_c + K_i. \tag{7}
$$

Similarly, the resource constraint for labour is

$$
L \geqq \int_0^1 \left(\sum_{n=1}^{N_{cm}} L_{cmn} \right) dm + \int_0^1 \left(\sum_{n=1}^{N_{im}} L_{imn} \right) dm = L_c + L_i. \tag{8}
$$

The law of motion for K_t is

$$
K_{t+1} = (1 - \delta) K_t + I_t, \tag{9}
$$

where δ stands for the physical depreciation rate of capital.

3.3 Competitive Equilibrium

The representative agent maximises his utility (1) subject to his budget constraint

$$
(1 + r_t) K_t P_{i,t} + w_t L_t - K_{t+1} P_{i,t} - C_t P_{c,t} \geqq 0,
$$

where r and w stand for the rental rates of capital and labour, while P_c and P_i denote the price of consumption and investment goods, respectively. The first order conditions with respect to K_t and L_t are

$$
\begin{aligned}
\frac{P_{i,t}}{C_t} &= \beta E_t \left[(1 + r_{t+1}) \frac{P_{i,t+1}}{C_{t+1}} \right], && (10) \\
\frac{w_t}{C_t} &= \frac{\kappa}{(N - L_t)}. && (11)
\end{aligned}
$$

The representative firm producing final goods in sector X chooses $\{Y_{xm}\}_{m=0}^1$ to maximise profits π_x given intermediate goods prices P_{xm}:

$$
\pi_x^* = \max_{\{Y_{xm}\}_{m=0}^1} \left[\left(\int_0^1 Y_{xm}^{\frac{\sigma-1}{\sigma}} dm \right)^{\frac{\sigma}{\sigma-1}} P_x - \int_0^1 Y_{xm} P_{xm} dm \right]. \tag{12}
$$

The first order condition for Y_{xm} yields the usual demand function for each intermediate good m in sector X:

$$P_{xm} = \left(\frac{Y_x}{Y_{xm}}\right)^{1/\sigma} P_x. \tag{13}$$

Firms within each intermediate-goods sector compete à la Cournot. A given firm n producing the intermediate good Y_{xmn} chooses its factor inputs K_{xmn} and L_{xmn} and its materials inputs C^M_{xnm} and I^M_{xmn} to maximise expected profits given factor prices r and w, taking as given other firms' decisions:

$$\pi^*_{xmn} = \max_{\substack{K_{xmn}, L_{xmn}, \\ C^M_{xmn}, I^M_{xmn}}} \left[Y_{xmn}P_{xm} - (r+\delta)\, P_i K_{xmn} - wL_{xmn} - C^M_{xmn} - P_i I^M_{xmn} - \phi_x\right], \tag{14}$$

where Y_{xmn} is given by equation (2) for the consumption sector and by equation (3) for the investment sector, and P_{xm} is given by the demand for good $Y_{xm} = \sum_n Y_{xmn}$ in equation (13). The first order conditions for K_{xmn} and L_{xmn} satisfy

$$\begin{aligned} P_i\,(r+\delta) &= \left(1 - \frac{Y_{xmn}}{\sigma Y_{xm}}\right) \alpha\,(1-\rho)\, \frac{Y_{xmn}}{K_{xmn}} P_{xmn}, && (15) \\ w &= \left(1 - \frac{Y_{xmn}}{\sigma Y_{xm}}\right) (1-\alpha)\,(1-\rho)\, \frac{Y_{xmn}}{L_{xmn}} P_{xmn}, && (16) \end{aligned}$$

while the two pairs of first order conditions for materials C^M_{xnm} and I^M_{xmn} satisfy

$$\begin{aligned} P_c &= \left(1 - \frac{Y_{xmn}}{\sigma Y_{xm}}\right) \theta_x \rho \frac{Y_{xmn}}{C^M_{xmn}} P_{xmn}, && (17) \\ P_i &= \left(1 - \frac{Y_{xmn}}{\sigma Y_{xm}}\right) (1-\theta_x)\, \rho \frac{Y_{xmn}}{I^M_{xmn}} P_{xmn}, && (18) \end{aligned}$$

for $X = \{C, I\}$.

Considering only symmetric equilibria in which the number of firms is the same in all industries within each sector, and integrating over all intermediate goods in each sector, yields the factor price equations for each sector x:

$$\begin{aligned} P_i\,(r+\delta) &= \left(1 - \frac{1}{\sigma N_x}\right) \alpha\,(1-\rho)\, \frac{Y_x}{K_x} P_x, && (19) \\ w &= \left(1 - \frac{1}{\sigma N_x}\right) (1-\alpha)\,(1-\rho)\, \frac{Y_x}{L_x} P_x, && (20) \\ P_c &= \left(1 - \frac{1}{\sigma N_x}\right) \theta_x \rho \frac{Y_x}{C^M_x} P_x, && (21) \\ P_i &= \left(1 - \frac{1}{\sigma N_x}\right) (1-\theta_x)\, \rho \frac{Y_x}{I^M_x} P_x. && (22) \end{aligned}$$

I define μ_x as the sector-specific wedge between marginal productivity and actual factor prices, which results from less-than-perfect competition:

$$\mu_x = \frac{1}{\sigma N_x}. \tag{23}$$

This wedge disappears as N_x, the number of firms, goes to infinity. The ratio of price over marginal cost is then given by $\frac{1}{1-\mu_x}$; however, for simplicity, I will refer to μ_x as the markup for sector X.

Under free entry, the number of firms in each sector which are due to operate at time $t+T$ adjusts at each point in time to ensure that expected profits T periods ahead, which are given by equation (14), are zero in all sectors:

$$E_t\left(\pi^*_{xmn,t+T}\right) = 0, \forall x, m, n. \tag{24}$$

Ignoring integer constraints for the number of firms and aggregating equation (24) over all intermediate goods yields the aggregate zero profit condition for each sector:

$$N_{x,t} = \frac{\mu_x Y_x}{\phi_x}. \tag{25}$$

Plugging the above expression into equation (23) yields the markup as a function of expected output T periods ahead:

$$\mu_{x,t} = \sqrt{\frac{\phi_{x,t}}{\sigma E_{t-T}\left(Y_{x,t}\right)}}. \tag{26}$$

Equation (26) implies that the markup in a given sector is negatively correlated with expected output in that same sector.

Equations (19) through (22) yield the following expression for the relative price of investment:

$$\frac{P_{i,t}}{P_{c,t}} = \left(Q_t^{-1}\frac{1-\mu_{c,t}}{1-\mu_{i,t}}\Omega\right)^{\frac{1}{1-(\theta_c-\theta_i)\rho}}, \tag{27}$$

where

$$\Omega = \left[\frac{\left(1-\theta_c\right)^{1-\theta_c}\theta_c^{\theta_c}}{\left(1-\theta_i\right)^{1-\theta_i}\theta_i^{\theta i}}\right]^{\rho}$$

is a constant term which equals one if $\theta_c = \theta_i$. Given that investment-specific productivity Q_t follows a deterministic trend, the above expression implies that all movements in the relative price of investment are due to sector-specific markup fluctuations; equation (27) implies a negative correlation between the markup in any given sector and its relative price. In the presence of co-movement between the production of consumption and investment goods, fluctuations in μ_i will dominate

Table 1: Parameterisation

Parameter	Chosen value	Parameter	Chosen value
α	32%	γ_q	.51%
β	.989	ρ	.49
δ	1.56%	θ_c	.79
κ	1.74	θ_i	.74
φ	.95	Φ	15%
γ_a	.48%	σ_ε	1.23%

as long as investment is more volatile than consumption, leading to a negative correlation between aggregate output and the relative price of investment. Through the determination of markups in equation (26), delays in the creation of new firms lead to delays in the response of the relative price in (27).

An equilibrium for this model is defined as a sequence

$$\{X_t\}_{t=0}^{\infty} \text{ for } X = \left\{C, I, K, K_c, K_i, L, L_c, L_i, C_c^M, C_i^M, I_c^M, I_i^M, A, P_i, N_c, N_i, w, r\right\}$$

which satisfies the first order conditions for the households' problem (10) and (11), the four pairs of factor price equations given by equations (19) through (22), the law of motions for capital (9) and for aggregate productivity (4), the resource constraints for consumption (5), investment (6), capital (7), and labour (8), and the expression for the number of firms in each sector (25); P_c is normalised to one.

Given that this problem does not have a closed-form solution, a second-order approximation is obtained by using a methodology proposed and implemented by Collard and Juillard (2001).

4 Calibration

In this section, I select parameter values such that the model economy's stochastic steady state displays a number of features which are observed over the long run in U.S. data. This benchmark calibration is then used to replicate the qualitative behaviour of the relative price of equipment investment for both the U.S. and the U.K., by varying the parameter governing the delay to firm entry.

The length of one time period in the model is set to one quarter. Total net output in the model is denoted Y_t and is obtained by chain-weighting consumption and investment.

The steady-state growth rates of A, γ_a, and Q, γ_q, the discount rate β, the utility function parameter κ, the physical depreciation rate of capital δ and the technology parameter α are set to match average quarterly values for aggregate U.S. data for the time period 1955:1-2000:4. The average per capita growth rate for the consumption (investment) sector is .37% (.88%). The average ratio of investment expenditures to total output is 22%; the quarterly depreciation rate imputed by NIPA is 1.56%, and the average capital income share is 32%. Finally, the average fraction of time spent working is set to one third.

The technology parameters ρ, θ_c and θ_i are set to match certain features of the input-output structure for the U.S. economy: ρ is set to match the ratio of materials usage over total output observed in U.S. data, which is 49%. Likewise, θ_c (θ_i) is set to match the proportion of materials used to make consumption (investment) goods which were produced by the consumption sector, which corresponds to 79% (74%). The data which is used for this exercise is the benchmark two-digit SIC input-output use table prepared by NIPA for the year 1997.

The variance of the aggregate shock σ_ε is set to match the volatility of (logged and Hodrick-Prescott filtered) aggregate output in U.S. data; the parameter determining the persistence of productivity shocks, φ, is set to .95.

The parameters which still need to be calibrated are the elasticity of substitution between intermediary goods, σ, and the fixed operating costs, ϕ_x, for $x \in \{C, I\}$. Note that, since ϕ_x and σ always appear together in the model, it is not possible nor indeed necessary to estimate them separately. Instead, the relevant variables for calibration are given by the average markup for each sector, μ_x. ϕ_x and σ are set such that average markups are the same in both sectors. Notice that, since the consumption sector is much larger than the investment sector, and that both sectors have a measure one of industries, setting the markups in both sector to a common value implies that fixed costs will be much higher in the consumption sector. However, one could equivalently set the number of industries in each sector such that the size of industries be the same in both sectors; in that case, identical fixed costs across sectors will imply identical markups. Given that materials are used as inputs in the production process, the relevant markup is that over gross output. Based on the discussion in section 2, plausible values for this markup, which corresponds to

$$\Phi = \frac{Y_x}{Y_x - \phi_x N_x} - 1 = \frac{\mu_x}{1 - \mu_x},$$

lie between 5% and 15%. For the benchmark case, Φ is set to 15%. The last parameter which needs to be determined is the delay to firm entry. T is set to one quarter to replicate the contemporaneous correlation between equipment investment and its relative price which is observed in the U.S., and to ten quarters to replicate the behaviour of the relative price in economies like the U.K., Canada, and Australia, in which there is a delay of up to twelve quarters between a surge in equipment investment and a fall in its relative price. The chosen parameter values are listed in table 1.

5 Results

Figure 5 illustrates the cross-correlations between a number of variables both for the model and the data, and table 2 contains statistics characterising the behaviour of the U.S. economy over the sample period, along with the corresponding statistics for the model.

The first (second) column of graphs in figure 5 contains the simulated cross-corelation functions for the calibrated model with the delay to firm entry, T, set to one (ten) quarters, as well as the empirical cross-correlations for U.S. (U.K.) data.

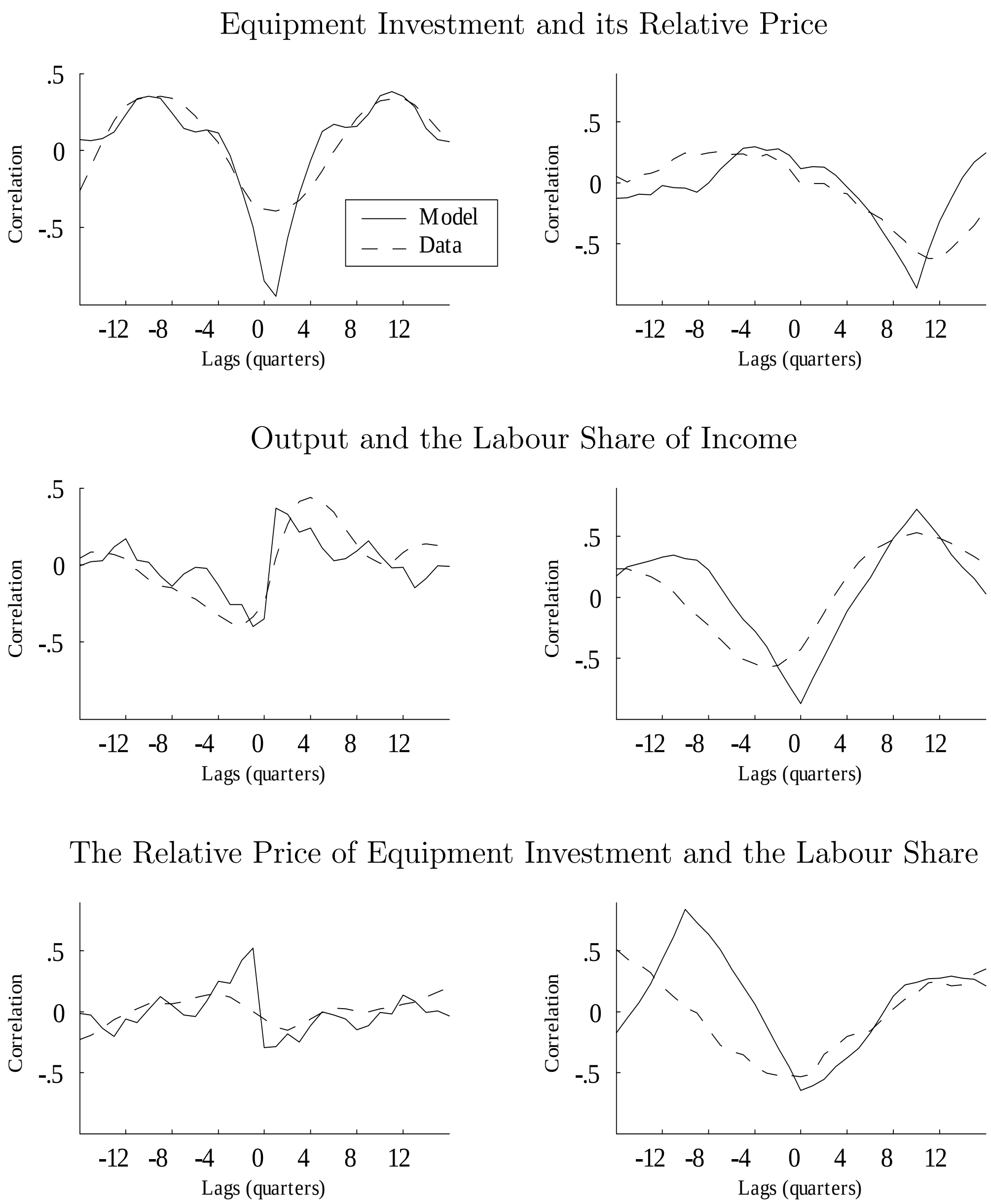
The model replicates both the contemporaneous negative correlation between equipment investment (which corresponds to total investment in the model) and its relative price observed in U.S. data, and the lagged contemporaneous correlation between the two variables observed in a number of OECD countries (figure 6).

As explained in the introduction, the counter-cyclicality in the relative price of investment in the model is due to the fact that investment is more variable than consumption; given that markups are sector-specific, this implies that the counter-cyclical variations in markups will be stronger in the former sector, leading to counter-cyclical variations in its relative price. Since there is a delay to firm entry, positive productivity shocks will lead to windfall profits for firms, so that the labour share of income will be negatively contemporaneously correlated with output. The labour share will then rise again at the same time as the number of firms increases and markups (and thus the relative price of investment) decrease, so that the relative price and the labour share will be negatively correlated. As a result, the delay in the positive response in the labour share is longer for higher values of T.

Table 2 contains a set of standard business cycle statistics for the U.S. and the U.K., as well as for the calibrated model. Column (c) contains the simulation results under perfect competition, that is, when markups are set to zero in both sectors. Because of the induced movements in the relative price of investment, introducing markups (column d and e) results in a higher volatility of investment and output. Comparing the benchmark case of $T = 1$ (column d) with the statistics for U.S. data, the model does not perform significantly worse than the standard RBC model in reproducing standard business cycle statistics for the U.S. (column a), and in addition explains around one-third of the fluctuations in both the relative

Figure 5: Simulated and Empirical Cross-Correlations[a]

$T = 1$; U.S. Data $T = 10$; U.K. Data



[a]The first (second) column contains the cross-correlation functions between the stated variables for the model with T=1 (T=10), and for U.S. (U.K.) data.

Table 2: Business Cycle Statistics[a]

	Data		$\Phi = 0$	$\Phi = 15\%$	
	U.S.	U.K.		T=1	T=10
Statistic[b]	(a)	(b)	(c)	(d)	(e)
σ_y	2.11	1.13	1.60	2.11	1.81
σ_c	0.81	1.36	0.54	0.61	0.73
σ_i	7.24	5.25	5.80	8.31	6.04
σ_l	1.57	–	0.78	1.06	0.53
σ_{p_i}	1.06	2.17	0	0.31	0.12
σ_λ	0.66	1.19	0	0.22	0.39
σ_{n_c}	1.93	–	–	0.58	0.52
σ_{n_i}	2.97	–	–	2.51	1.29
$\rho(c,i)$	66	67	83	64	90

[a]Results for the model are based on 500 replications of sample size 184. The dataset is described in the appendix.

[b]σ_x denotes the standard deviation of variable x, $\rho(x,y)$ denotes the correlation between x and variable y, where x and y are logged and Hodrick-Prescott filtered prior to analysis. Both statistics are reported in percentage terms.

price of investment and the labour share. Both in the data and in the model, the volatility in the number of firms is much higher in the investment sector than in the consumption sector, although the difference between the two is higher in the model.

The amplitude of the relative price movements which are induced by the model diminishes for $T = 10$ (column e), while the amplitude of the induced movements in the labour share increases. This implies that countries which experience long delays between surges in equipment investment and decreases in its relative price should display less volatility in this relative price, and more volatility in the labour share. While the latter is true enough, the former is not: in countries with large delays in the response of the relative price, like the U.K. (column b) relative prices tend to be highly volatile, often more so than in the U.S. An explanation for this phenomenon is that countries with long delays to firm entry may have higher average markups, which would again increase the volatility of relative prices.

Finally, for the benchmark case, the model generates a contemporaneous correlation between consumption and investment of close to fifty percent, which is somewhat less than what we observe in U.S. data. Co-movement is more pronounced for the case of perfect competition, as well as for a longer delay to firm entry. Also, although the amount of sectoral co-movement is very similar for the U.S. and the U.K., it is much higher for larger values of T; this again suggests that markups in the U.K. may be larger than in the U.S.

6 Conclusion

Cross-country evidence reveals that the negative contemporaneous correlation which is observed for the U.S. between equipment investment and its relative price is not observed for most other OECD countries. Instead, many countries experience a delay of up to three years between increases in equipment investment and decreases in its relative price.

While this evidence is difficult to reconcile with investment-specific supply shocks, which are the currently favoured explanation for relative price movements (see Greenwood, Hercowitz, and Krusell, 2000), it is compatible with imperfect-competition induced relative price movements. More precisely, countries in which it takes more time to set up a firm might experience delays in markup movements, and thus also in relative price movements.

The model can explain both the simultaneous output expansion and decrease in the relative price of equipment investment observed in the U.S. and some other countries, and the long delay between these two movements observed for most OECD countries, by introducing delays to firm entry. Also, the model replicates the counter-cyclical labour share of income movements observed in most OECD countries, as well as the fact that the labour share tends to be negatively correlated with the relative price of equipment investment.

For an average price markup over gross production of 15%, the model is shown to generate about one-third of the observed variability in both relative price of investment and the labour share of income for the U.S.

Given that the counter-cyclicality of the relative price of equipment investment in the U.S. has been used as evidence for the importance of productivity shocks (see Fisher, 2006), the question whether these relative price movements are caused by sector-specific productivity shocks or by alternative mechanisms such as the one proposed in this paper has an importance of its own. Cross-country evidence indicates that for most OECD countries except the U.S., sector-specific shocks seem to be at odds with the data.

A Data

The sample of countries for which cross-correlations are computed includes all OECD members for which at least twenty years of quarterly data are available for the relevant macroeconomic variables, as well as those countries for which at least thirty years of yearly data are available. The sample of countries with quarterly data consists of Australia, Canada, Germany, Finland, France, Italy, Holland, the U.K. and the U.S.; the sample with annual data consists of Austria, Spain, Greece, Ireland, Japan, Korea, Mexico, Sweden and the U.S. (the latter to provide comparability between the results for quarterly and yearly data). The data used in the calibration exercise is described in section 4.

The aggregate data for each country consist of seasonally adjusted quarterly or annual time series from the OECD, both in nominal and real (chained) terms (CQRSA and LNBQRSA for quarterly data, and CARSA and LNBARSA for annual data). Output in the model is matched up with the corresponding series for gross domestic product, and consumption is matched up with the series for private final consumption expenditure. Equipment investment is obtained by substracting investment in housing and other buildings and construction from total gross fixed investment. When real series are added or substracted from one another they are chain-weighted; see Whelan (2002) regarding substraction operations between chained real series.

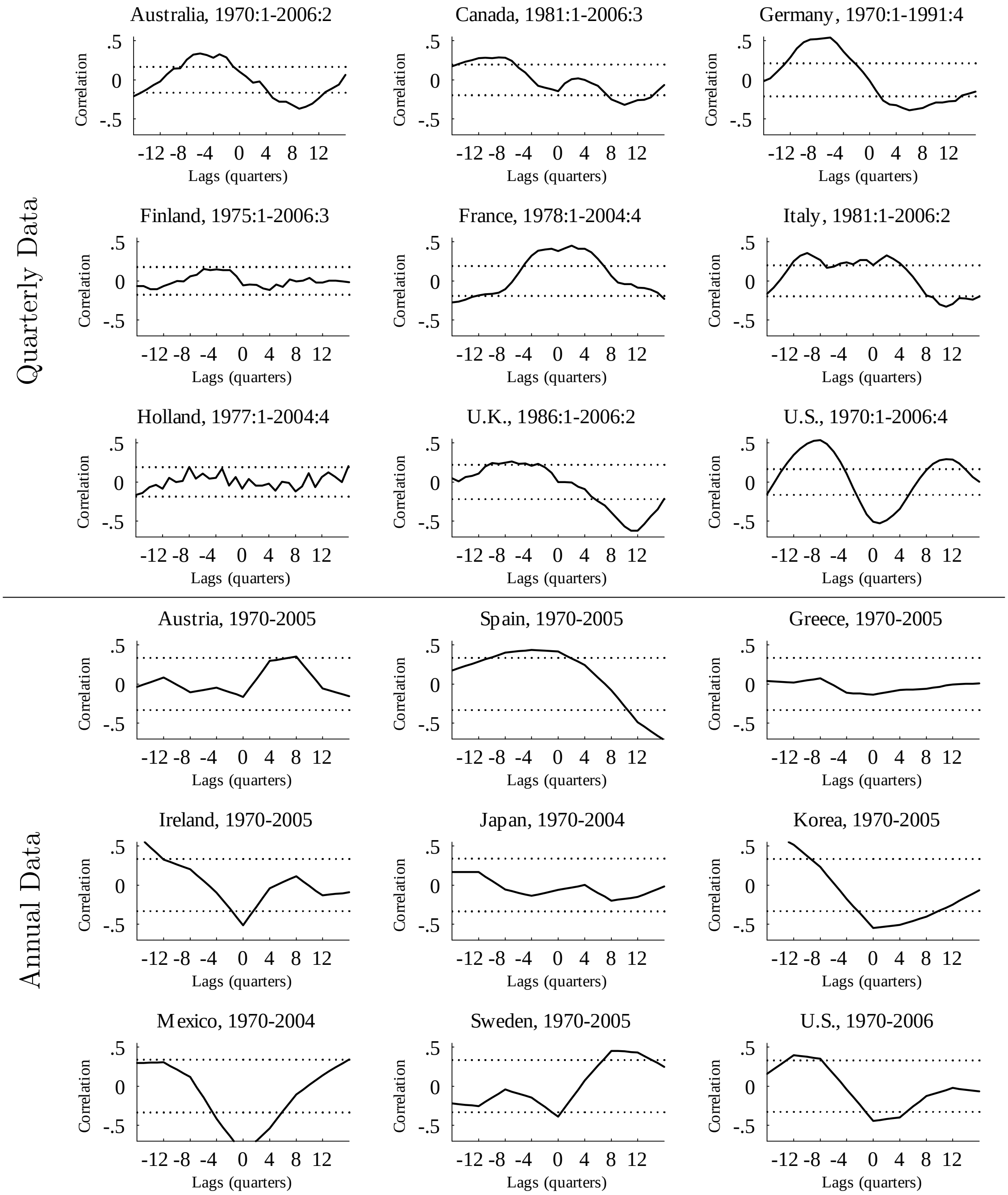
The relative price of equipment investment is defined as the price of one real unit of equipment divided by the price of one real unit of consumption. The labour share is defined as the ratio of the compensation of employees over gross domestic product, so that all ambiguous income is attributed to capital; this allows to calculate labour shares for a large number of countries in a consistent way. While this method leads to an underestimation of the labour share, it does not appear to affect its cyclical properties, at least for U.S. data, as discussed by Rios-Rull and Santaeulalia-Llopis (2006).

Prior to computing cross-correlations, all variables are Hodrick-Prescott filtered, with a parameter λ of 1600 for quarterly data and of 100 for yearly data.

The data used to make figure 1B consists of the monthly manufacturing output by industry (table 2BU) and the corresponding price deflators from NIPA (tables 2BU and 2BUI). I omit those industries for which Koeva's (2000) dataset contains less than three observations.

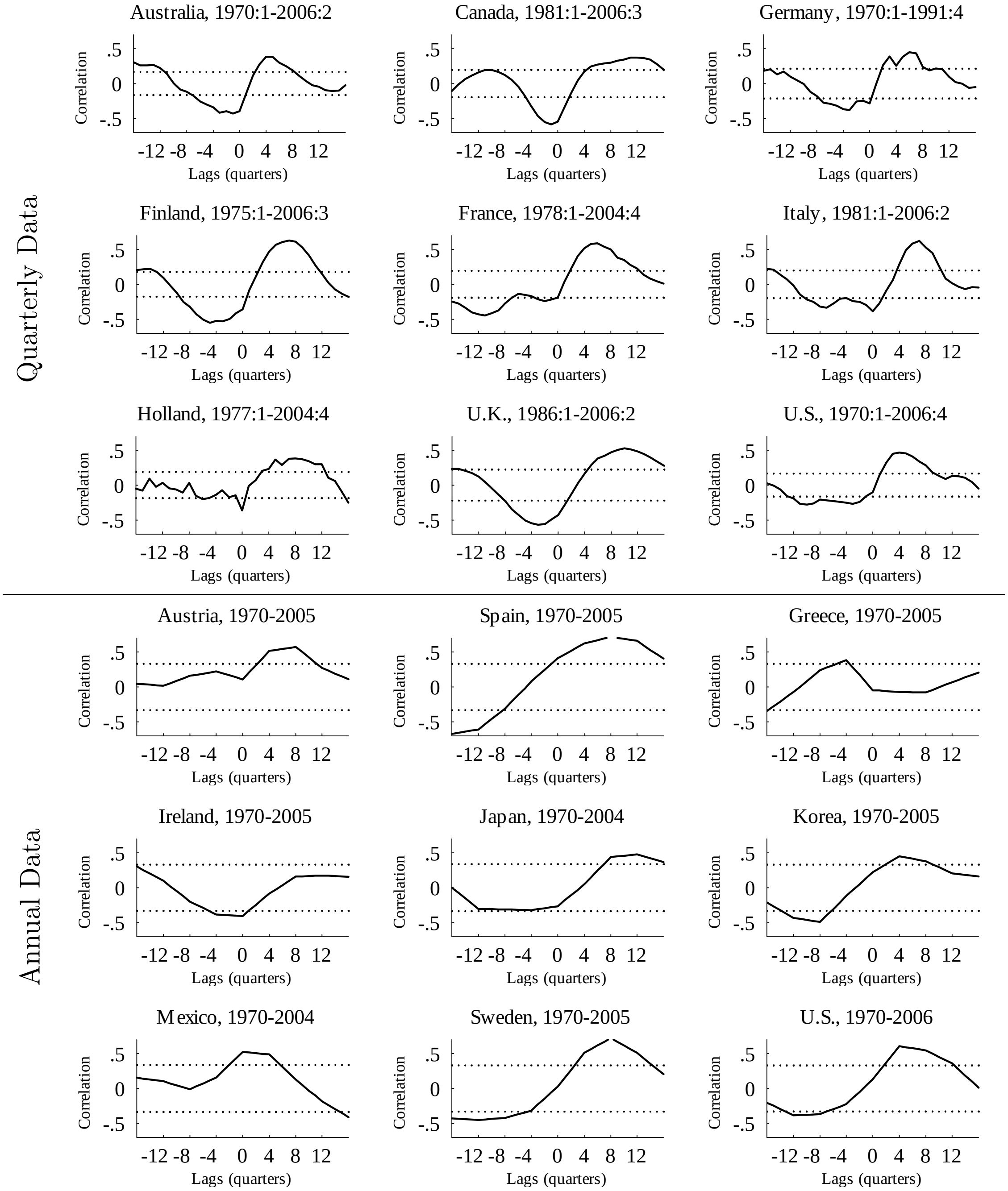
B Additional Figures

Figure 6: Equipment Investment and its Relative Price[a]



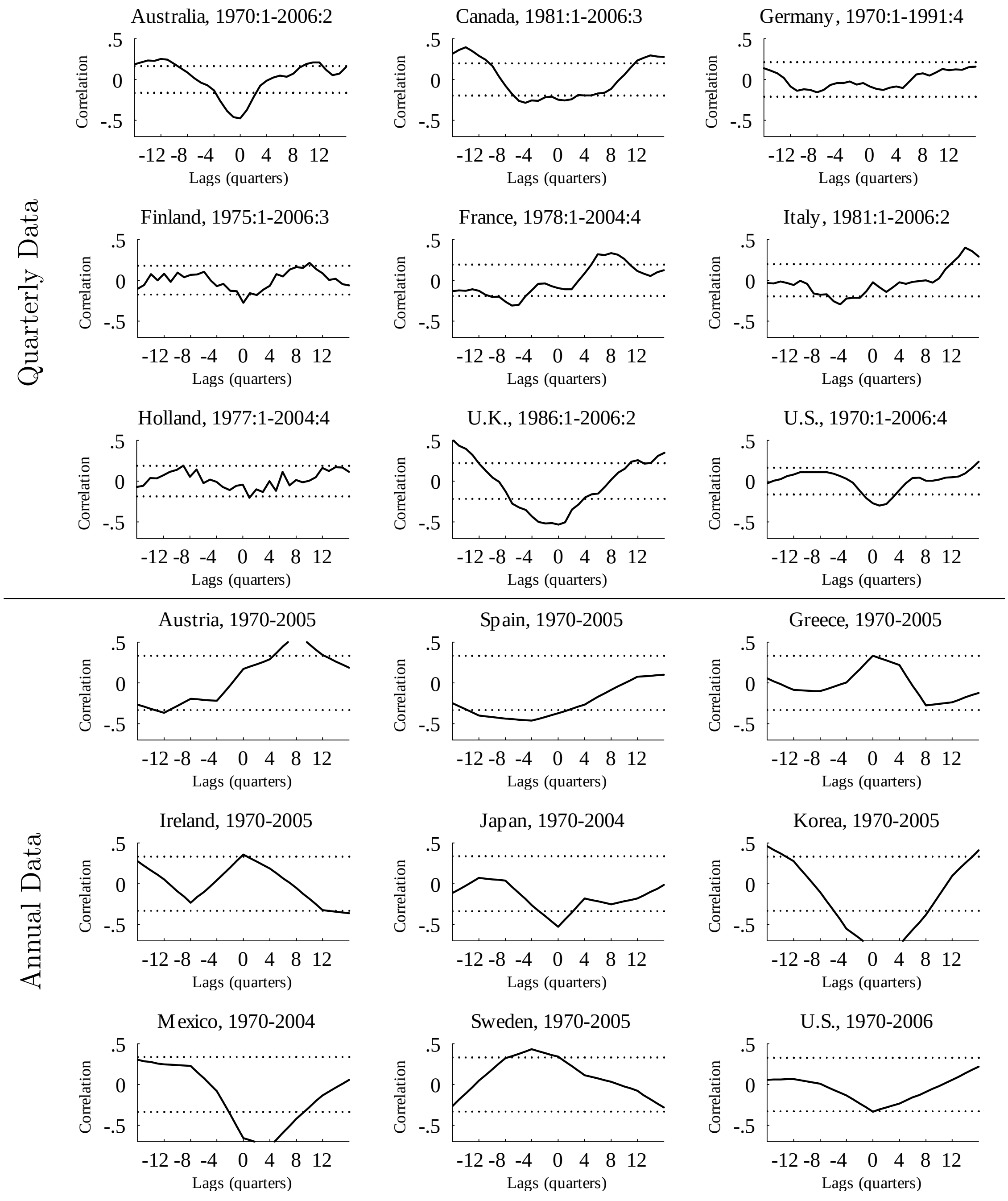
[a]Cross-correlation between equipment investment at time t and its price in terms of consumption goods at various lags.

Figure 7: Output and the Labour Share[a]



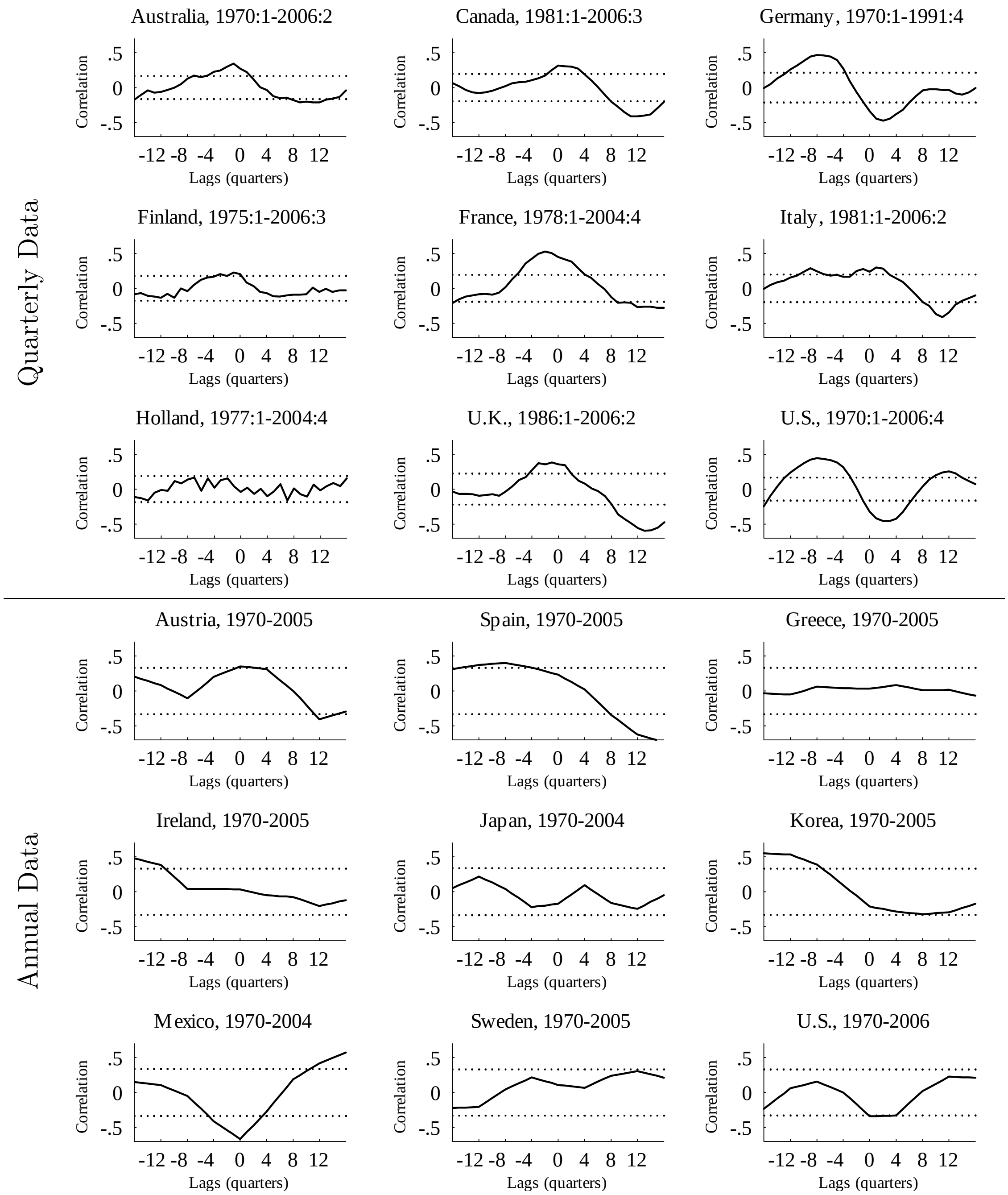
[a]Cross-correlation between output at time t and the labour share of income at various lags.

Figure 8: The Relative Price of Equipment and the Labour Share[a]



[a]Cross-correlation between the relative price of equipment at time t and the labour share of income at various lags.

Figure 9: Output and the Relative Price of Equipment[a]



[a]Cross-correlation between output at time t and the relative price of equipment at various lags.

References

Ambler, S., and E. Cardia (1998): “The Cyclical Behaviour of Wages and Profits under Imperfect Competition,” *The Canadian Journal of Economics*, 31(1), 148–164.

Bentolila, S., and G. Saint-Paul (2003): “Explaining Movements in the Labor Share,” *Contributions to Macroeconomics*, 3(1), 1103–1133.

Bloch, H., and M. Olive (2001): “Pricing over the Cycle,” *Review of Industrial Organization*, 19(1), 99–108.

Collard, F., and M. Juillard (2001): “A Higher-Order Taylor Expansion Approach to Simulation of Stochastic Forward-Looking Models with an Application to a Nonlinear Phillips Curve Model,” *Computational Economics*, 17(2), 125–139.

Djankov, S., R. La Porta, et al. (2002): “The Regulation of Entry,” *The Quarterly Journal of Economics*, 117(1), 1–37.

Ferreira, R. D. S., and T. Lloyd-Braga (2005): “Non-linear endogenous fluctuations with free entry and variable markups,” *Journal of Economic Dynamics and Control*, 29(5), 847–871.

Fisher, J. (2006): “The Dynamic Effects of Neutral and Investment-Specific Technology Shocks,” *Journal of Political Economy*, 114(3).

Galeotti, M., and F. Schiantarelli (1998): “The Cyclicality of Markups in a Model with Adjustment Costs: Econometric Evidence for US Industry,” *Oxford Bulletin of Economics and Statistics*, 60(2), 121–142.

Gali, J., and F. Zilibotti (1995): “Endogenous Growth and Poverty Traps in a Cournotian Model,” *Annales d’Economie et de Statistique*, 37/38(3), 197–214.

Greenwood, J., Z. Hercowitz, and P. Krusell (2000): “The Role of Investment-Specific Technological Change in the Business Cycle,” *European Economic Review*, 44(1), 91–115.

Hornstein, A., and J. Praschnik (1997): “Intermediate inputs and sectoral comovement in the business cycle,” *Journal of Monetary Economics*, 40(3), 573–595.

Jaimovich, N. (2006): “Firm Dynamics, Markup Variations, and the Business Cycle,” *Mimeo.*

Koeva, P. (2000): “The Facts About Time-to-Build,” *IMF Working Paper*, 00/138.

Oliveira Martins, J., and S. Scarpetta (2002): “Estimation of the Cyclical Behaviour of Markups: a Technical Note,” *OECD Economic Studies*, 34(1), 173–188.

Oliveira Martins, J., S. Scarpetta, and D. Pilat (1996): “Mark-up Pricing, Market Structure and the Business Cycle,” *OECD Economic Studies*, 27(1996), 11.

Rios-Rull, J.-V., and R. Santaeulalia-Llopis (2006): “Redistributive Shocks and Productivity Shocks,” .

Rotemberg, J., and M. Woodford (1999): “The Cyclical Behavior of Prices and Costs,” in *Handbook of Macroeconomics*, ed. by J. Taylor, and M. Woodford, vol. 1B. Amsterdam: North-Holland.

Whelan, K. (2002): “A Guide to U.S. Chain Aggregated NIPA Data,” *Review of Income and Wealth*, 48(2), 217–33.