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Biased Technical Change, Intermediate Goods and Total Factor Productivity[*]

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Abstract

Biased technical change can be defined as changes that affect the elasticity of output with respect to inputs. In this paper, I analyze the effect of biased technical change on total factor productivity (TFP). I construct an input-output economy in which firms produce gross output using capital, labor and intermediate goods. In equilibrium, biased technical change appears as an explicit part of TFP in the value added aggregate production function, where the latter is obtained through the aggregation of individual firms optimal decisions. A larger elasticity of gross output with respect to intermediates implies a smaller TFP level. I use the model to quantify the impact of biased technical change for measured TFP growth in Italy. The exercise shows that biased technical change can account for the productivity slowdown observed in Italy from 1994 to 2004.

Keywords: Total Factor Productivity Growth, Intermediate Goods, Productivity Slowdown.
JEL Classification: E01, E25, O47.

1 Introduction

Intermediate goods represent an important production input in most sectors of industrialized economies.[1] In the U.S., for a given amount of nominal value added, roughly an equivalent amount of intermediate goods is delivered to intermediate demand. Despite this fact, growth and business cycle models usually consider capital and labor as the only inputs. This procedure is justified by the double nature of intermediate goods which are both input and output in production and cancel out in aggregate accounting relationships.[2] The supply side of the economy is then represented by an aggregate value added production function in capital and labor inputs. Nevertheless, intermediate goods represent an important factor in the determination of capital and labor productivity in aggregate value added (TFP hereafter). This is clearly shown in the business cycle literature, where the link between intermediate goods and TFP is analyzed, among others, by Long and Plosser (1983) and Horvath (2000). In these papers, sectorial shocks spread through an input-output structure and give rise to aggregate TFP fluctuations.

This paper focuses on the interaction between intermediate goods and TFP growth. In particular, I present a theory of TFP with intermediate goods in the production process and

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[1] An intermediate good is represented by any input entering a production process which cannot be described as capital or labor and that depreciates completely during the same production process. Then, they include raw materials, energy, components, finished goods and services. That is, intermediate goods are classified by use, as in the input-output tables, and not by type of good.

[2] Jorgenson, Gollop and Fraumeni (1987, p. 6), describe their value-added measure in the following way: "*Aggregate output is a function of quantities of sectorial value-added and sums of each type of capital and labor input over all sectors. Deliveries to intermediate demand by all sectors are precisely offset by receipts of intermediate input, so that transactions in intermediate goods do not appear at the aggregate level.*"

biased technical change.[3] I define biased technical change as Young (2004, p. 917): "one broad definition of biased technical changes is changes that directly affect factor elasticities". Positive (negative) biased technical change implies a decrease (increase) in the elasticity of gross output with respect to intermediates where gross output production is performed at the firm level using capital, labor and intermediate goods. In order to understand the link between biased technical change and aggregate TFP, suppose that aggregate capital and labor inputs are given. When the production technology of each firm is highly intensive in intermediate goods, the demand for intermediates is high and a large part of the available aggregate capital and labor is used to produce intermediate goods themselves, the remaining part being used to produce value added. When positive biased technical change occurs, it reduces the intensity by which intermediate goods are used in the production process. It follows that each firm tends to use less intermediates, the amount of capital and labor used to produce intermediate goods decreases so that more capital and labor are devoted to produce value added. As a result, the economy produces more value added with a given amount of capital and labor, and measured TFP increases.

Following this intuition, I construct a model of gross output production that formalizes the source and the use of intermediate goods. There is a continuum of firms in the economy, each producing gross output with a constant returns to scale Cobb-Douglas production

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[3]For recent papers that build theories of TFP see, among others, Parente and Prescott (1999), Herrendorf and Teixeira (2005), Castro, Clementi and MacDonald (2006), Lagos (2006), Guner, Ventura and Xu (forthcoming) and Restuccia and Rogerson (2007).

function in capital, labor and intermediate goods. In addition to the standard neutral technical change in capital and labor, I allow for biased technical change that affects the elasticity of output with respect to inputs. Given the Cobb-Douglas assumption for the production function, the share of each input in gross production is equal to the elasticity of output with respect to that input in equilibrium.

Intermediate goods in production are represented by a Dixit-Stiglitz aggregator of all other goods produced in the economy. This modelling strategy implies that each firm produces a good which is both final and intermediate. This is consistent with input-output tables, in which most goods are both consumed (or invested) and used in the production of other goods in the economy. Assuming symmetry across firms in the Dixit-Stiglitz aggregator, it is possible to derive an expression in which aggregate value added depends on a Cobb-Douglas aggregator of capital and labor, as in a standard neoclassical production function. The difference with standard models (with capital and labor as the only inputs) is that now value added depends on the parameter governing the elasticity of output with respect to intermediate goods in the production function of the single firm. In particular, TFP in the model becomes the product of two components: one is the usual neutral technological parameter while the other is a function of the elasticity of output with respect to intermediate goods. Thus, TFP growth is also given by two components, one due to neutral productivity change and the other to biased technical change. In particular, when positive (negative) biased technical change occurs, aggregate TFP increases (decreases).

The mechanism driving this result works as follows. TFP is given by the difference between real gross output and intermediate goods, divided by the amount of capital and labor used. The first term, real gross output over capital and labor, represents capital and labor productivity in gross output. When the elasticity of output with respect to intermediate goods decreases, given constant returns to scale, the production process becomes more intensive in capital and labor. It follows that an additional unit of capital or labor, fixed the amount of the other inputs, gives now a higher level of output. Thus, capital and labor productivity in gross output production increases. The second term, intermediate goods over capital and labor, represents the relative utilization of intermediates with respect to capital and labor. Given prices, when the elasticity of output with respect to intermediates decreases, this ratio decreases. Thus, both terms contribute to increase (decrease) TFP when positive (negative) biased technical change occurs. Standard models, that abstract from the use of intermediate goods in production, disregard the effect due to biased technical change and attribute the entire TFP growth to neutral technical change.

By affecting TFP, biased technical change also influences the equilibrium values of the model's variables. To study this effect, I analyze the steady state of a planner problem in a simplified version of the model with fixed labor supply and a representative firm. The results show that the higher the elasticity of output with respect to intermediate goods, the lower are TFP, per capita gross output, capital and consumption in the steady state.

In order to quantify the importance of biased technical change for TFP growth, I then

use data for Italy from the EU KLEMS Database, March 2007.[4] In the data, I capture

biased technical change by measuring the variation in the share of intermediate goods in

gross production, which is equal to the elasticity of output with respect to intermediates in

the model's equilibrium. In the period going from 1994 to 2004 Italy experiences a slowdown

in the growth rate of aggregate TFP. During that period the growth in the Solow residual

is virtually zero. Using the model proposed in the paper I show that the slowdown can

be attributed to a substantial amount of negative biased technical change occurred in Italy

during that period.

This paper is related to the literature that combines general equilibrium models and

input-output structures. As mentioned above, Long and Plosser (1983) and Horvath (2000)

construct similar models to study how sectorial productivity shocks aggregate and create

business cycle fluctuations. Bruno (1984) shows that an increase in the price of intermediate

goods used in a given sector is equivalent to a Hicks-neutral negative technological shock in

the value added production function of that sector. He points out that the increase in the

price of raw materials can account for the productivity slowdown occurred in the U.S. man-

ufacturing sector in the seventies. Ciccone (2002) analyzes the effect of industrialization on

aggregate output and TFP. In his model, new technologies are more intensive in intermediate

goods. When an increase in productivity occurs in sectors producing intermediate goods,

the final producer benefits from that increase and becomes more productive himself. It fol-

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[4]The dataset is freely downloadable at http://www.euklems.net/

lows that industrialization provides a TFP increase in this model. Jones (2007) shows that the share of intermediate goods can provide a multiplier on the productivity level which is able to explain cross-country differences in the level of TFP. Both Ciccone (2002) and Jones (2007) exploit the multiplier effect due to intermediate goods described in Hulten (1978).

In contrast to Ciccone (2002) and Jones (2007), this paper shows that the share of intermediate goods does not necessarily generate a multiplier on productivity growth. When neutral technological change is embedded in capital and labor only, and not in intermediate goods, there is no multiplier associated with the share of intermediate goods. As discussed in Jorgenson, Gollop and Fraumeni (1987) growth in the quality of inputs is found for capital and labor but not for intermediates. This is the view taken in this paper. It follows that in the model presented here, when there is no biased technical change (when the share of intermediate goods is fixed over time), the share of intermediate goods provides only a level effect on TFP, inversely related to the level of the share and fixed over time.

The remaining of the paper is organized as follows: section 2 presents the model; section 3 applies the model to the case of Italy; section 4 concludes.

2   The Model

There is a continuum of goods in the economy, indexed by $i \in [0, 1]$. Each good can be either consumed, invested in the production of new capital, or used as an intermediate in the production of the other goods.

2.1 Household

An infinitely lived representative household makes decisions on consumption, labor services and capital accumulation. Labor services are sold and capital services are rented to firms. The household solves

$$\max_{C_t, n_t} \sum_{t=0}^{\infty} \beta^t [\log C_t + \eta \log(1 - n_t)] \tag{1}$$

subject to

$$P_t C_t + P_t I_t = w_t n_t + r_t k_t,$$

and

$$I_t = k_{t+1} - (1 - \delta) k_t,$$

where C_t is the consumption index, n_t is the amount of labor services, k_t is the capital stock, I_t is investment, w_t, r_t and P_t are the wage rate, the rental rate of capital and the price of consumption and investment in terms of a given numeraire, $\delta \in (0, 1)$ is the depreciation rate, $\beta \in (0, 1)$ is the subjective discount factor and $\eta > 0$ is the weight of labor in the utility function. Consumption and investment are both Dixit-Stiglitz aggregators of the goods in the economy given by

$$C_t = \left[\int_0^1 c_{it}^\gamma di \right]^{\frac{1}{\gamma}}, \tag{2}$$

and

$$I_t = \left[\int_0^1 \iota_{it}^\gamma di \right]^{\frac{1}{\gamma}}, \tag{3}$$

where $\gamma < 1$ governs the elasticity of substitution among different goods, and c_{it} and ι_{it} are the household's demands for good i as a consumption and as an investment good. Given the price of each good, from (2) and (3) there is always a well-defined bundle of individual goods that the household optimally purchases to obtain one unit of C_t or I_t.[5] The corresponding price for this bundle, P_t, is given by

$$P_t = \left[\int_0^1 p_i^{-\frac{\gamma}{1-\gamma}} di \right]^{-\frac{1-\gamma}{\gamma}}. \tag{4}$$

The first order conditions for the household problem deliver the following relations

$$\frac{\beta}{C_{t+1}} \left[\frac{r_{t+1}}{P_{t+1}} + (1 - \delta) \right] = \frac{1}{C_t}, \tag{5}$$

and

$$\frac{\eta C_t}{1 - n_t} = \frac{w_t}{P_t}. \tag{6}$$

Equation (5) is the standard Euler equation. It equates the value of one unit of investment priced at the marginal utility today, $1/C_t$, to the return on investment, $[r_{t+1}/P_{t+1} + (1 - \delta)]$, priced at the marginal utility tomorrow, $1/C_{t+1}$, and discounted by β. Equation (6) simply equates the marginal rate of substitution between labor and consumption to the wage rate in consumption terms.

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[5] The optimal bundle purchased to obtain one unit of C is found by solving the expenditure minimization problem

$$\min_{c_i} \left[\int_0^1 p_i c_i di \right],$$

$$s.\ t.\ \left[\int_0^1 c_i^\gamma di \right]^{\frac{1}{\gamma}} \geq C.$$

A similar problem is solved to find the optimal bundle purchased to obtain one unit of I. The price index in (4) is then obtained as the Lagrange multiplier of the minimization problem.

2.2   Firms

Each atomless firm i produces gross output y_i buying intermediate goods from other firms, renting capital K_i and buying labor N_i from households according to the following production function

$$y_i = \left[A \left(K_i \right)^\alpha \left(N_i \right)^{1-\alpha} \right]^{1-\theta} \left(M_i \right)^\theta , \tag{7}$$

where M_i is an aggregator of intermediate goods and $\alpha \in (0, 1)$.[6] Technological change in (7) is driven by two factors: A, which is the neutral technological change parameter embedded in capital and labor, and θ, which represents the biased technological change parameter. Thus, both A and θ are assumed to change over time, with $\theta \in (0, 1)$ always.

Each firm solves

$$\max_{K_i, N_i, m_j^i} \left\{ p_i \left[A \left(K_i \right)^\alpha \left(N_i \right)^{1-\alpha} \right]^{1-\theta} \left(M_i \right)^\theta - r K_i - w N_i - \int_0^1 p_j m_j^i dj \right\}, \tag{8}$$

where p_i is the price of output in terms of the numeraire and r and w are as previously defined. As the problem of the firm is static, time subscripts are avoided in the current subsection to save notation. The set of intermediate goods coincides with the set of goods produced in the economy. Thus, m_j^i, $j \in [0, 1]$, is the amount of intermediate good demanded by firm i from firm j and p_j is the corresponding price. It follows that p_j is the price of output of firm j. The aggregator of intermediate goods entering the production function (7),

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[6] As found in Jorgenson, Gollop and Fraumeni (1987), p. 202, Table 6.8, "*growth in input* (intermediates) *quality is not an important source of growth in intermediate goods*" while "*growth in capital input quality is an important but not predominant source of growth in capital input*" and finally "*growth in the quality of hours worked is a very important source of growth in labor input*". According to these findings neutral technical change in (7) is embedded in capital and labor only.

M_i, is defined as a Dixit-Stiglitz aggregator of individual intermediate goods

$$M_i = \left[\int_0^1 \left(m_j^i \right)^\gamma dj \right]^{\frac{1}{\gamma}}. \tag{9}$$

Given (9), the price index of intermediate inputs M_i is

$$p^m = \left[\int_0^1 p_j^{-\frac{\gamma}{1-\gamma}} dj \right]^{-\frac{1-\gamma}{\gamma}} = P,$$

where P is the price index of consumption and investment indices given by (4). The Dixit-Stiglitz aggregator implies that, given an amount M_i that firm i is willing to use in the production process, there is an optimal combination of the m_j^i's that minimizes the cost $\int_0^1 p_j m_j^i dj$. As the firm always chooses to minimize its cost, I can rewrite (8) as

$$\max_{K_i, N_i, M_i} \left\{ p_i \left[A \left(K_i \right)^\alpha \left(N_i \right)^{1-\alpha} \right]^{1-\theta} \left(M_i \right)^\theta - rK_i - wN_i - PM_i \right\}, \tag{10}$$

where P represents the minimum cost of purchasing one unit of M_i.[7]

At an optimum, given the Cobb-Douglas form of the production function (7),

$$\frac{PM_i^*}{p_i y_i^*} = \theta. \tag{11}$$

Thus, at an optimal solution, $M_i^* = \theta p_i y_i^* / P$, and (7) implies that gross output y_i^* is given by

$$y_i^* = \left[A \left(K_i^* \right)^\alpha \left(N_i^* \right)^{1-\alpha} \right]^{1-\theta} \left(\theta \frac{p_i y_i^*}{P} \right)^\theta,$$

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[7]Note that the assumption of Dixit-Stiglitz aggregators usually implies that firms have some degree of monopoly power. Here I don't allow for monopoly power so that each firm i must be interpreted as the representative firm of a sector in which each profit maximizing producer takes the price of output as given.

and solving for y_i^*, I obtain

$$y_i^* = \theta^{\frac{\theta}{1-\theta}} \left(\frac{p_i}{P}\right)^{\frac{\theta}{1-\theta}} A\left(K_i^*\right)^\alpha \left(N_i^*\right)^{1-\alpha}, \tag{12}$$

where K_i^* and N_i^* are capital and labor at the optimal solution. The maximization problem

(10) is the same for all firms, i. e.,

$$K_i^* = K^*, \ N_i^* = N^*, \ M_i^* = M^*, \ \forall \ i.$$

As all firms set the same price in equilibrium, $p_i = p = P \ \forall \ i$, and (12) can be written as

$$y^* = \theta^{\frac{\theta}{1-\theta}} A\left(K^*\right)^\alpha \left(N^*\right)^{1-\alpha}, \tag{13}$$

where y^* is the quantity of gross output produced by each firm in equilibrium. Each firm's

gross output is a function of capital, labor and the neutral and biased technological change

parameters, A and θ.

Aggregate gross output is defined as a Dixit-Stiglitz aggregator of individual gross outputs

$$Y = \left[\int_0^1 y_i^\gamma \, di\right]^{\frac{1}{\gamma}},$$

and when all firms produce the same quantity y^*, as in the symmetric equilibrium above this

becomes

$$Y = \left[\int_0^1 (y^*)^\gamma \, di\right]^{\frac{1}{\gamma}} = y^*. \tag{14}$$

As a result, aggregate gross output coincides with individual gross output.[8] The correspond-

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[8] The elasticity of substitution in the Dixit-Stiglitz aggregators of consumption, investment, intermediate goods and gross output is chosen to be the same for exposition purposes. A different elasticity for each aggregator would not influence the results of the model.

ing price index for Y is

$$P^Y = \left[\int_0^1 p_i^{-\frac{\gamma}{1-\gamma}} di \right]^{-\frac{1-\gamma}{\gamma}} = P.$$

Real value added is given by the difference between real gross output and real intermediate goods $V = Y - M$. Given (11), (13) and (14), V can be written as

$$V = (1-\theta)\theta^{\frac{\theta}{1-\theta}} A \left(K^*\right)^\alpha \left(N^*\right)^{1-\alpha}. \tag{15}$$

The amount of value added is determined by the amount of capital and labor used in the production process and the levels of neutral and biased technical change parameters, A and θ. In a standard growth accounting exercise TFP is given by

$$TFP = \frac{V}{\left(K^*\right)^\alpha \left(N^*\right)^{1-\alpha}}, \tag{16}$$

which depends both on neutral and biased technical change. In particular, from (15)

$$TFP = AB \tag{17}$$

where $B = (1-\theta)\theta^{\frac{\theta}{1-\theta}}$ is a decreasing function of θ. This is plotted in figure 1. It follows that TFP in the model depends negatively on the level of θ. In equilibrium, θ is equal to the share of intermediate goods in gross output production. In many industrialized countries, this share lies between 0.6 and 0.4.[9] Note that a change in θ from 0.6 to 0.4 implies an increase in B, and consequently in TFP, of 75%.

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[9]Using the EU KLEMS Database, March 2007, it is possible to show that this is true for Australia, Austria, Belgium, Denmark, Finland, France, Germany (West Germany until 1991), Japan, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, U.K. and U.S., during the 1970-2004 period.
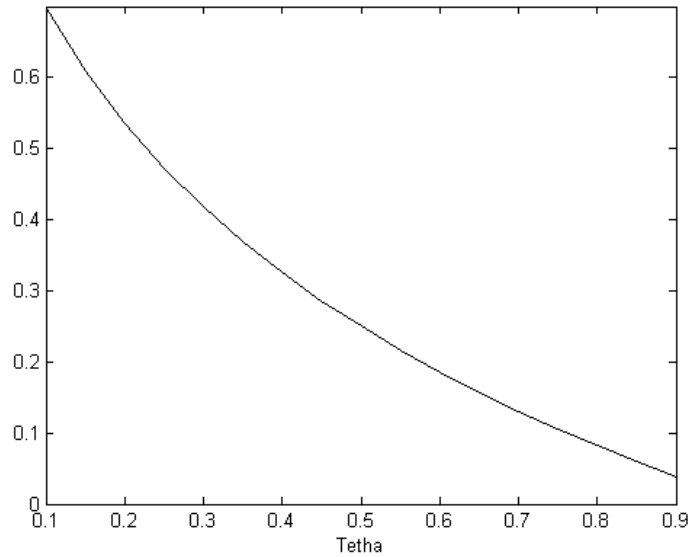
Figure 1: The function B.

As θ changes, there are two effects on TFP. Too see this, note that TFP can be written as

$$TFP = \frac{Y}{(K^*)^\alpha (N^*)^{1-\alpha}} - \frac{M}{(K^*)^\alpha (N^*)^{1-\alpha}}. \tag{18}$$

By using the first order condition for intermediate goods from the firm's problem (10), $\theta p_i \left[A (K_i)^\alpha (N_i)^{1-\alpha} \right]^{1-\theta} (M_i)^{\theta-1} = P$, it is possible to show that $Y/[(K^*)^\alpha (N^*)^{1-\alpha}]$ is always equal to $A\theta^{\frac{\theta}{1-\theta}}$ in equilibrium, with this function decreasing in θ. Thus, when θ declines with positive biased technical change, the production function (7) implies that capital and labor become more productive in gross output, as the elasticity of output with respect to these inputs increases. That is, with the amount of all inputs fixed, an additional unit of capital or labor implies an increase in output greater than that obtained with a smaller θ. This is why a decline in θ increases the first term in (18).

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When θ decreases there is also an effect on the second term in (18), which represents the relative utilization of intermediates and capital and labor. Given prices, the maximization problem (10) induces the firm to use less intermediates and more capital and labor. Using again the first order condition with respect to intermediate goods it can be shown that the second term in (18) is always equal to $A\theta^{\frac{1}{1-\theta}}$, which is increasing in θ. Thus, the two effects, on capital and labor productivity in gross output and on the relative utilization of the inputs move in the same direction so that a decrease (increase) in θ increases (decreases) capital and labor productivity in value added. The sum of the two effects is then $A\theta^{\frac{\theta}{1-\theta}} - A\theta^{\frac{1}{1-\theta}} = A(1-\theta)\theta^{\frac{\theta}{1-\theta}} = AB$.

Finally, note that TFP is linear in A in (17). The result is in contrast with the standard view, which suggests that an increase in productivity in one sector spreads to other sectors through the input-output matrix, creating a multiplier effect on aggregate TFP.[10] This happens because in the model presented here neutral technical change A is embedded in capital and labor only, and not in intermediate goods. It follows that the multiplier effect on aggregate TFP is canceled out by the negative effect that a larger θ has on neutral productivity A in the production function (7). Indeed, Jorgenson, Gollop ad Fraumeni (1987) find that growth in the inputs quality occurs only in capital and labor and not in intermediate goods.

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[10]See Hulten (1978), Jones (2007) and Gabaix (2008).

2.3 Market Clearing

Given the assumption of symmetry across firms, the household sells an equal amount of labor and rents an equal amount of capital to each firm. Market clearing in the labor market requires

$$n_t = \int_0^1 n_{it} di = \int_0^1 n_t di = \int_0^1 N_{it} di = \int_0^1 N_t di = N_t. \tag{19}$$

A similar condition holds for the capital stock

$$k_t = \int_0^1 k_{it} dh = \int_0^1 k_t di = \int_0^1 K_{it} di = \int_0^1 K_t di = K_t. \tag{20}$$

In the goods market the supply side must satisfy

$$Y_t = V_t + M_t, \tag{21}$$

i.e., gross output must be equal to the sum of value added and intermediate goods.[11] On the demand side

$$Y_t = C_t + I_t + M_t, \tag{22}$$

i.e., gross output is the sum of consumption, investment and intermediate goods demands. Equations (21) and (22) imply that

$$V_t = C_t + I_t, \tag{23}$$

which is the usual accounting relationship that equates, in the absence of government expenditure, value added to consumption plus investment.

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[11] As the price of gross output, value added and intermediates is the same, (21) holds both in nominal and in real terms.

2.4   Steady State

In this section I study the impact of biased technical change on steady state variables. To compare the steady state with that of a standard one sector growth model with exogenous labor supply I simplify the analysis and consider a representative firm and fix labor supply to one. The equilibrium is equivalent to that of the economy described in the previous subsections, once labor is excluded from the utility function and exogenously fixed.[12] The production function in (7) becomes, in per capita terms $y = A^{1-\theta}k^{\alpha(1-\theta)}m^{\theta}$, where y now describes per capita gross output of the representative firm. The planner solves

$$\max_{c_t} \sum_{t=0}^{\infty} \beta^t \log c_t,$$

subject to

$$c_t + k_{t+1} - (1-\delta)k_t + m_t = A_t^{1-\theta_t}k_t^{\alpha(1-\theta_t)}m_t^{\theta_t},$$

where all variables, consumption c_t, capital k_t and intermediate goods m_t are in per capita terms. As above, δ is the depreciation rate and β the subjective discount factor while A_t and θ_t represent neutral and biased technical change. The steady state per capita capital of this economy is

$$k^* = \left[\frac{(1-\theta)\theta^{\frac{\theta}{1-\theta}}\alpha A}{(1/\beta) - 1 + \delta} \right]^{\frac{1}{1-\alpha}}. \tag{24}$$

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[12] Assuming a representative firm simplifies the algebra of the model presented in the previous subsections, and permits to reach the same value added expression as in (15). With this modelling strategy, however, the source of intermediates becomes unclear. A possible interpretation of the representative firm is the following. In a first stage of production the firm uses capital and labor to produce intermediate goods. In a second stage, these intermediates are combined with capital and labor to produce value added. The per capita value added production function can be represented by $v = A^{1-\theta}k^{\alpha(1-\theta)}m^{\theta} - m$ where all variables are in per capita terms.
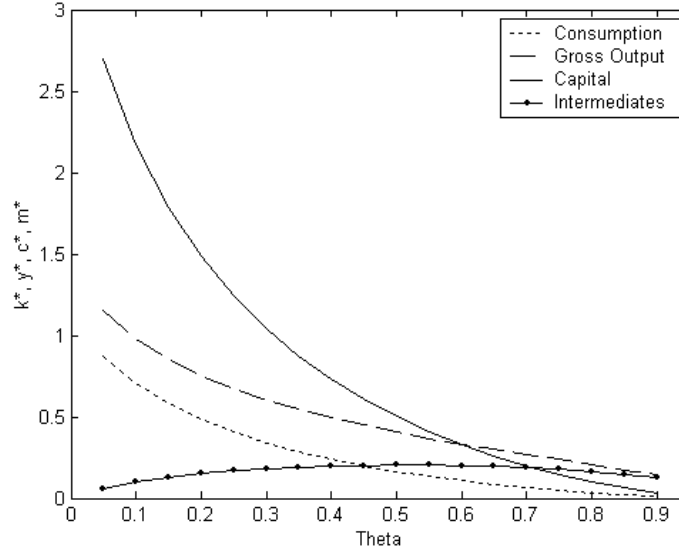
Figure 2: Steady state values of per capita consumption, capital, gross output and intermediate goods for different values of the biased technical change parameter θ.

Details of the calculations are reported in Appendix A. With respect to the standard one sector growth model, steady state per capita capital depends also on $B = (1 - \theta)\theta^{\frac{\theta}{1-\theta}}$. It follows that the higher θ, the lower k^*. Figure 2 reports the steady state value of consumption, gross output, intermediate goods and capital, all in per capita terms, for different values of θ and $A = 1$, $\delta = 0.08$, $\alpha = 0.3$ and $\beta = 0.96$. All series are decreasing in θ except intermediate goods. Thus, when negative biased technical change increases the intensity of intermediate goods in production, the steady state value of consumption decreases. Steady state TFP is measured by $(c + \delta k)/k^\alpha$, that is, value added divided by the Cobb-Douglas aggregator of capital and labor, and it is reported in Figure 3.[13] Steady state productivity decreases with the level of θ.

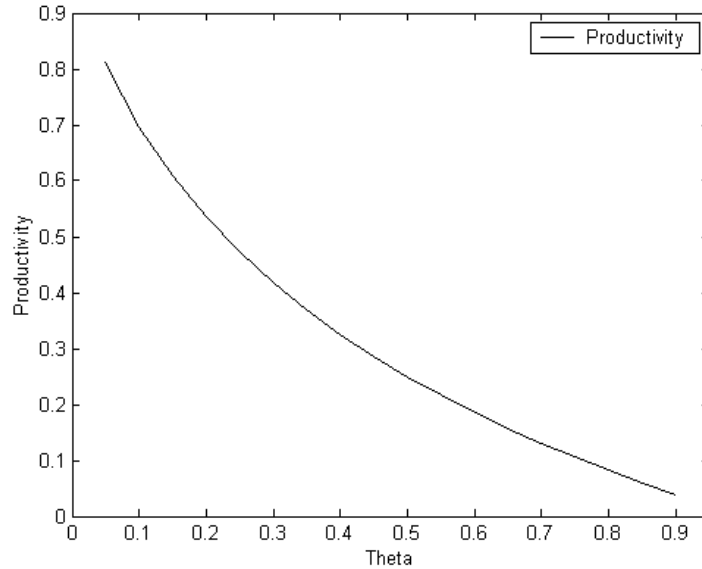[13] Recall that $N = 1$, so $k^\alpha = K^\alpha N^{1-\alpha}$.

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Figure 3: TFP $(c + \delta k)/k^\alpha$ for different values of the biased technical change parameter θ.

The steady state analysis confirms that biased technical change affects the equilibrium in the same qualitative fashion as neutral technical change. It follows that this sort of technical change could be used to generate exogenous growth in a growth model with intermediate goods.

3 The Case of Italy

Figure 4 plots TFP (the Solow residual), the relative price and the relative quantity of intermediate goods with respect to gross output and the share of intermediate goods in gross output in Italy for the 1970-2004 period. The top-right panel shows that the relative price of intermediates is constant in the long run, with an increase in the period going from the mid-seventies to the mid-eighties due to the price of energy inputs. During the mid-eighties
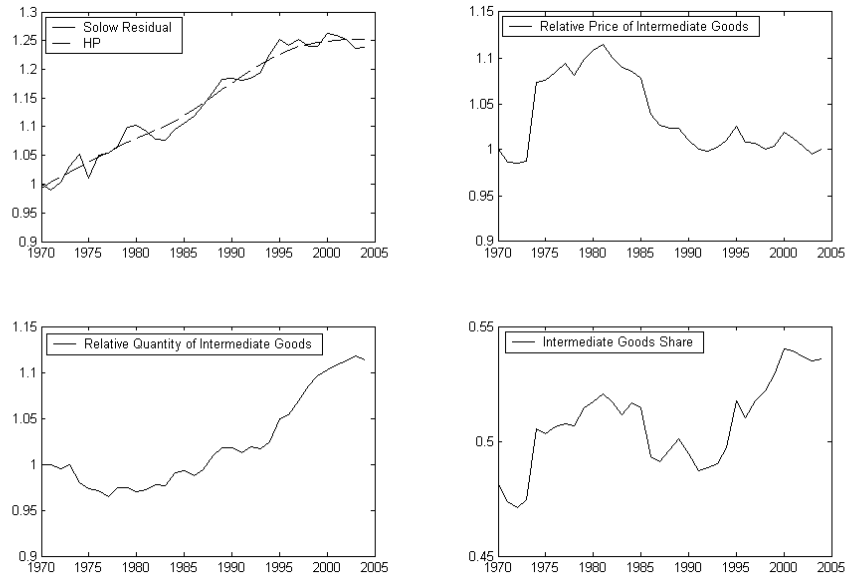
Figure 4: The first panel displays the Solow residual and its HP trend; the second panel displays the relative price of intermediate goods with respect to output: the third panel reports the relative quantity of intermediate goods with respect to output; the fourth panel reports the share of intermediate goods in gross output. All series are computed from the Italian dataset of the EU KLEMS Database, March 2007.

the relative price of intermediates returns to the level observed before the oil shocks and remains constant until the end of the sample. The bottom-left panel shows that the relative quantity of intermediate goods grows by 2.4% from the 1970 to 1994 and by 8.7% from 1994 to 2004. The top-left panel shows that around 1994 Italy also experiences a marked productivity slowdown: the average yearly growth rate of the Solow residual is 0.85% during the 1970-1994 period and becomes 0.1% between 1994 and 2004.

Together, these data suggest that the slowdown observed in measured TFP might be due to negative biased technical change. To quantify this effect, I use the model presented in

section 2 to compute the average yearly growth rate of neutral technical change A, from the data. Using the empirical counterpart of formula (17), this is given by

$$\mu_A = \mu_{TFP} - \mu_B. \tag{25}$$

where μ_{TFP} is the yearly average growth rate of TFP and μ_B the yearly average growth rate of B. Both μ_{TFP} and μ_B can be computed directly from the data and μ_A is then obtained from (25). Table 1 reports μ_{TFP}, μ_B and μ_A for different sub-samples.

Table 1			
Growth Rates	1970-2004	1970-1994	1994-2004
μ_{TFP}	0.63%	0.85%	0.09%
μ_B	-0.45%	-0.19%	-1.09%
μ_A	1.08%	1.04%	1.18%

The growth rate μ_B is calculated using the share of intermediate goods in gross output as the empirical counterpart for the model's θ. The bottom-right panel of Figure 4 shows how θ evolves in the data between 1970 and 2004. For the whole sample, θ increases from 0.48 to 0.54, resulting in an average yearly decline in B of 0.45%. The increase in θ is particularly steep in the 1994-2004 sub-period when it changes from 0.5 to 0.54, implying an average yearly decline in B of 1.09%, compared to 0.19% of the 1970-1994 period.

The growth rate of TFP, μ_{TFP}, is calculated as in a standard growth accounting procedure using data for capital, labor and value added.[14] Its yearly average is virtually zero during the last ten years of the sample. A standard model in capital and labor would attribute this to a slowdown in neutral technical change. Instead, when neutral technical change growth is

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[14]See Appendix B for details of the calculations of μ_{TFP} and μ_B.

calculated using (25), its growth pattern does not change much across subsamples. According to the model, neutral technical change growth is 1.08% per year over the entire sample, 1.04% in the 1970-1994 sub-sample and 1.18% in the 1994-2004 period. The slowdown in the observed Solow residual can be accounted for by a change in the production technology that affects the utilization intensity of intermediate goods in the production process. Thus, the quantitative results confirm that biased technical change can represent an important source of TFP growth. The forces driving the changes in the relative utilization of intermediate goods in production, which in this paper has been modelled as exogenous biased technical change, represents a new channel to investigate to explain TFP growth.

Note that the model presented in section 2 delivers, by construction, a relative price of intermediate goods with respect to gross output equal to one. This assumption is not more restrictive than considering the same price for consumption, investment and output in the standard one sector growth model. In the data, however, the relative price of intermediates in a given country is not always constant. For this reason, the Italian dataset is suitable to quantify the relevance of biased technical change for TFP determination, as it provides a case in which the relative price of intermediates is constant and the relative quantity of intermediates increases, suggesting a pure change in the technology used to produce gross output. For other countries both the relative quantity and the relative price of intermediates change at the same time. In those cases, a change in the utilization of intermediate goods can be due in part to substitutability among factors following the change in price and in

part to biased technical change. To disentangle the two effects, a richer model, in which the variations in the price of intermediates are also explained, is needed.

To conclude this section, it is worth mentioning that the share of intermediate goods in gross output can be also interpreted as a measure of the amount of "offshoring" performed by the firms in the economy. Indeed, when firms decide to delegate the production of some intermediate goods to external production units (that is, firms offshore a part of the production process), the share of intermediate goods in gross output observed in the data increases. However, as pointed out in the offshoring literature, this decision can be interpreted as technical change in the production of final goods.[15] This view is consistent with the model presented here, where the change in the share of intermediate goods follows from a (biased) change in technology. The incentive to offshore can be high for the single firm but it can imply a reduction in aggregate TFP. In Italy, for instance, firms have an incentive to remain small because of the labor legislation.[16] It follows that a firm might find more profitable to buy intermediates from an external firm, which is less efficient, than to produce the intermediate itself at a higher level of efficiency.

4 Conclusions

This paper provides a theoretical framework showing how biased technical change can affect TFP growth together with neutral technical change. A simple input-output model is used

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[15] See for instance Baldwin and Robert-Nicoud (2006).

[16] Firms with more than fifteen employees face an employment protection legislation more restrictive than firms with fifteen or less employees. See Guner, Ventura and Xu (forthcoming) for details.

to make this point. When biased technical change lowers the elasticity of gross output with respect to intermediate goods in a Cobb-Douglas production function, the production process becomes more intensive in capital and labor and less in intermediate goods. Thus, the contribution of capital and labor to value added increases and, in turn, TFP. In the model, this effect shows up trough a function that depends only on the elasticity of output with respect to intermediates. It follows that the effect of biased technical change on TFP can be measured using data on the share of intermediate goods in gross production, which is equal to the elasticity of output with respect to intermediates in the model's equilibrium. Using the EU KLEMS Database, March 2007, biased technical change is showed to be able to account for the productivity slowdown observed in Italy in the last decade.

The model also shows that intermediate goods does not always provide a multiplier effect on aggregate TFP, as showed in Hulten's (1978) early contribution. In the model presented, the higher the share of intermediate goods, the lower aggregate TFP level. This result follows from the fact that neutral technical change is embedded in capital and labor only, and not in intermediate goods. Thus, when the technology is more intensive in intermediate goods, the contribution of neutral technical change is dampened and the multiplier effect on aggregate TFP disappears.

This paper attempts to take a step further in the understanding of the determinants of TFP growth. It shows that standard models, that adopt a value added aggregate production function in capital and labor, might miss important effects on TFP due to changes in the

gross output technology at the firm level. Thus, a crucial point in the analysis of TFP should be to measure to what extent technologies at the firm level are becoming more or less intensive in intermediate goods. As countries specialize in different products, the results might be quite heterogenous, suggesting a possible source of TFP growth differences.

The results encountered pose new questions that ought to be answered to construct a theory of TFP. Among these questions are the following: what is driving biased technical change in contrast to neutral technical change? Are there cases in which biased technical change is the driving force in TFP growth? Is the pattern of biased technical change the same across countries? I try to answer these questions in ongoing research.

Appendix A: The Planner's Problem

The planner solves

$$\max_{c_t} \sum_{t=0}^{\infty} \beta^t [\log c_t],$$

subject to

$$c_t + k_{t+1} - (1-\delta)k_t + m_t = A_t^{1-\theta_t} k_t^{\alpha(1-\theta_t)} m_t^{\theta_t}.$$

Optimality conditions for this problem are

$$\frac{c_{t+1}}{\beta c_t} = \left[\alpha \left(1 - \theta_{t+1}\right) A_{t+1}^{1-\theta_{t+1}} k_{t+1}^{\alpha(1-\theta_{t+1})-1} m_{t+1}^{\theta_{t+1}} + (1-\delta) \right], \qquad (26)$$

and

$$\theta_t A_t^{1-\theta_t} k_t^{\alpha(1-\theta_t)} m_t^{\theta_t - 1} = 1. \qquad (27)$$

In steady state, $\theta_t = \theta$, $A_t = A$, $k_t = k$, $m_t = m$, and $c_t = c$, $\forall\ t$. To obtain the steady state capital per capita, equation (24), solve (27) for m, use it in (26) and solve for k. Then, use again (27) to obtain steady state per capita intermediates

$$m^* = \theta^{\frac{1}{1-\theta}} A \left[\frac{(1-\theta)\theta^{\frac{\theta}{1-\theta}} \alpha A}{(1/\beta) - 1 + \delta} \right]^{\frac{\alpha}{1-\alpha}},$$

and the production function $A_t k_t^{\alpha(1-\theta_t)} m_t^{\theta_t}$ to find the steady state per capita production

$$y^* = \theta^{\frac{\theta}{1-\theta}} A \left[\frac{(1-\theta)\theta^{\frac{\theta}{1-\theta}} \alpha A}{(1/\beta) - 1 + \delta} \right]^{\frac{\alpha}{1-\alpha}}.$$

Steady state per capita consumption is then

$$c^* = y^* - m^* - \delta k^*.$$

Appendix B: Data and Methodology

The series for TFP is constructed as the residual from a Cobb-Douglas production function

$$TFP_t = \frac{V_t}{K_t^\alpha N_t^{1-\alpha}}, \tag{28}$$

where V_t is real value added (real GDP) and K_t and N_t are capital and labor series. All series are obtained from the KLEMS dataset for Italy. The parameter α is the average capital share of nominal value added. To construct the series for real value added I follow the U.S. National Product and Income Accounts (NIPA) that recommend to use chain-weighted Fisher indices.[17] Real value added is a chain-weighted Fisher quantity index in which the base year is given by the previous year. As the product of the quantity and price Fisher indices is equal to the nominal value of the series, this procedure is equivalent to deflating nominal value added by the chain-weighted Fisher price index. The formula for real value added is then

$$V_t = [V_t^{Las} V_t^{Paa}]^{0.5}, \tag{29}$$

where V_t^{Las} is the Laspeyres chain-weighted quantity index and V_t^{Paa} is the Paasche chain-weighted quantity index, given by

$$V_t^{Las} = \frac{\sum_{i=1}^{I} p_{i,t-1} y_{i,t} - \sum_{i=1}^{I} p_{i,t-1}^m m_{i,t}}{\sum_{i=1}^{I} p_{i,t-1} y_{i,t-1} - \sum_{i=1}^{I} p_{i,t-1}^m m_{i,t-1}},$$

and

$$V_t^{Paa} = \frac{\sum_{i=1}^{I} p_{i,t} y_{i,t} - \sum_{i=1}^{I} p_{i,t}^m m_{i,t}}{\sum_{i=1}^{I} p_{i,t} y_{i,t-1} - \sum_{i=1}^{I} p_{i,t}^m m_{i,t-1}},$$

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[17]See Bureau of Economic Analysis (2006) for details.

where $I = 26$ is the number of sectors, y_i and m_i are gross output and intermediate goods in sector i and p_i and p_i^m are the corresponding prices.[18] Gross output prices p_i are basic prices, which include the subsidies on products received by the producer while intermediate goods prices p_i^m are purchaser's prices.

The series for aggregate labor services is available in the KLEMS dataset. This is constructed in the following way. Series for labor services in each sector are constructed using the methodology described in Jorgenson, Gollop and Fraumeni (1987). These series are available in the KLEMS dataset and reflect the amount of labor services instead of the total number of hours worked. Growth of labor services in a given sector j is given by

$$\Delta \ln N_{jt} = \sum_{i=1}^{N_j^n} \bar{\chi}_{jit}^n \Delta \ln N_{jit}, \tag{30}$$

where $\bar{\chi}_{jit}^n = \frac{\chi_{jit}^n + \chi_{jit-1}^n}{2}$, $\chi_{jit}^n = p_{jit}^n N_{jit} / \left(\sum_{i=1}^{N_{jn}} p_{jit}^n N_{jit} \right)$ is the share of labor of type i in total labor compensation of sector j, N_{jit} is the total number of hours of type i labor in sector j and p_{jit}^n the corresponding price and Δ indicates the annual change in the variable. Finally N_j^n is the total number of different types of labor in sector j. Equation (30) implies that labor services are given by a Tornqvist index of the various types of labor. Thus, this index takes into account quality improvement in measuring labor. The aggregate labor series used in (28) is then computed as

$$\Delta \ln N_t = \sum_{j=1}^{I} \bar{\chi}_{jt}^n \Delta \ln N_{jt}, \tag{31}$$

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[18]The number of sectors considered, 26, represents the higher level of disaggregation permitted in the KLEMS dataset for Italy.

where each $\Delta \ln N_{jt}$ is obtained from (30), $\bar{\chi}_{jt}^n$ represents the last two periods average of the labor share of sector j in aggregate labor compensation and I is the number of sectors considered.

The series for aggregate capital services is also available in the KLEMS dataset. This is constructed as follows. For each sector, the series for each capital asset is constructed using the *perpetual inventory method*. In particular, the stock of capital of asset i at t is given by

$$K_{it} = \sum_{\tau=1}^{\infty} (1 - \delta_i)^\tau I_{i,t-\tau}, \tag{32}$$

where $I_{i,t-\tau}$ is investment in that asset at time $t - \tau$ and δ_i is a constant asset specific depreciation rate. Aggregation across types of asset in a generic sector j is done in a fashion similar to that of labor

$$\Delta \ln K_{jt} = \sum_{i=1}^{N_j^k} \bar{\chi}_{jit}^k \Delta \ln K_{jit}, \tag{33}$$

where $\bar{\chi}_{jit}^k = \frac{\chi_{jit}^k + \chi_{jit-1}^k}{2}$, $\chi_{jit}^k = p_{jit}^k K_{jit} / \left(\sum_{i=1}^{N_k} p_{jit}^k K_{jit} \right)$ is the share of capital of type i in total capital compensation of sector j, K_{jit} is the amount of capital of type i in sector j and p_{jit}^k is the corresponding price. Finally N_j^k is the total number of different types of capital in sector j. The aggregate capital series used in (28) is then computed as

$$\Delta \ln K_t = \sum_{j=1}^{I} \bar{\chi}_{jt}^k \Delta \ln K_{jt} \tag{34}$$

where each $\Delta \ln K_{jt}$ is obtained from (33), $\bar{\chi}_{jt}^k$ represents the last two periods average of the capital share of sector j in aggregate capital compensation and I is the number of sectors

considered.[19]

The average yearly growth rate of TFP_t, μ_{TFP} is obtained from the growth factor over the period considered, $1 + x_{TFP}$, as

$$\mu_{TFP} = (1 + x_{TFP})^{1/(T-1)} - 1, \tag{35}$$

where T is the length of the period.

The aggregate intermediate goods share in gross output is calculated as

$$IGS_t = \frac{\sum_{i=1}^{I} p_{i,t}^m m_{i,t}}{\sum_{i=1}^{I} p_{i,t} y_{i,t}}, \tag{36}$$

where $I = 26$ is the number of sectors, y_i and m_i are gross output and intermediate goods in sector i and p_i and p_i^m are the corresponding prices. Gross output prices p_i are basic prices, which include the subsidies on products received by the producer while intermediate goods prices p_i^m are purchaser's prices. The series is plotted in figure 4.

I construct the series for B_t using IGS_t (which is the empirical counterpart of θ_t),

$$B_t = (1 - IGS_t)IGS_t^{\frac{IGS_t}{1 - IGS_t}}. \tag{37}$$

The average yearly growth rate μ_B is then found using the formula

$$\mu_B = (1 + x_B)^{1/(T-1)} - 1, \tag{38}$$

where $1 + x_B$ is the growth factor of B_t over the sample period and T is the number of years.

The average yearly growth rate μ_A is then found from (25).

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[19]For further details on the methodology used to construct the KLEMS dataset refer to "EU KLEMS Growth and Productivity Accounts, Version 1.0, PART I Methodology".

The series for the relative quantity of intermediate goods over gross output is obtained by constructing chain-weighted Fisher quantity indices of intermediate goods and gross output and taking the ratio of the two series. The formulas for the indices of gross output and intermediates are

$$Y_t = [Y_t^{Las} Y_t^{Paa}]^{0.5}, \tag{39}$$

$$M_t = [M_t^{Las} M_t^{Paa}]^{0.5}, \tag{40}$$

where Y_t^{Las} is the Laspeyres chain-weighted quantity index and Y_t^{Paa} is the Paasche chain-weighted quantity index for gross output and M_t^{Las} and M_t^{Paa} the corresponding series for intermediates given by

$$Y_t^{Las} = \frac{\sum_{i=1}^{I} p_{i,t-1} y_{i,t}}{\sum_{i=1}^{I} p_{i,t-1} y_{i,t-1}},$$

$$Y_t^{Paa} = \frac{\sum_{i=1}^{I} p_{i,t} y_{i,t}}{\sum_{i=1}^{I} p_{i,t} y_{i,t-1}},$$

$$M_t^{Las} = \frac{\sum_{i=1}^{I} p_{i,t-1}^m m_{i,t}}{\sum_{i=1}^{I} p_{i,t-1}^m m_{i,t-1}},$$

and

$$M_t^{Paa} = \frac{\sum_{i=1}^{I} p_{i,t}^m m_{i,t}}{\sum_{i=1}^{I} p_{i,t}^m m_{i,t-1}},$$

where $I = 26$ is once again the number of sectors, y_i and m_i are gross output and intermediate goods in sector i and p_i and p_i^m are the corresponding prices. As for value added, gross output prices p_i are basic prices, which include the subsidies on products received by the producer while intermediate goods prices p_i^m are purchaser's prices. The relative quantity of intermediate goods reported in figure 4 is the ratio of (40) and (39). To find the price indices

of intermediate goods and gross output it is sufficient to divide the nominal amount at the aggregate level by the chain-weighted quantity index (39) and (40). To find the relative price of intermediate goods with respect to gross output I take the ratio of the series so obtained. This is the series reported in figure 4.

References

[1] Baldwin, R. and Robert-Nicoud, F., (2006), "Offshoring and globalisation: What is new about the new paradigm?", available via: http://www.econ.hit-u.ac.jp/~coe-res/fdi2006/papers/baldwin.pdf.

[2] Bruno, M., (1984), "Raw Materials, Profits and the Productivity Slowdown", *Quarterly Journal of Economics*, Vol.99, No. 1, pp. 1-30.

[3] Bureau of Economic Analysis (2006), "A Guide to the National Income and Product Accounts of the United States," http://www.bea.gov/bea/an/nipaguid.pdf.

[4] Castro, R., Clementi, G. L., and MacDonald, G., (2006), "Legal Institutions, Sectoral Heterogeneity, and Economic Development", SSRN working paper http://ssrn.com/abstract=869755.

[5] Ciccone, A., (2002), "Input Chains and Industrialization", *Review of Economic Studies* 69, pp. 565-587.

[6] EU KLEMS Growth and Productivity Accounts, Version 1.0, PART I Methodology, http://www.euklems.net/.

[7] Gabaix, X., (2008), "The Granular Origins of Aggregate Fluctuations". Available at SSRN: http://ssrn.com/abstract=1111765.

[8] Guner, N., Ventura, G. and Xu, Y., "Macroeconomic Implications of Size Dependent Policies", *Review of Economic Dynamics*, forthcoming.

[9] Herrendorf, B. and Teixeira, A., (2005), "How Barriers to International Trade Affect TFP", *Review of Economic Dynamics*, Vol. 8, No. 4, pp. 866-876.

[10] Horvath, M., (2000), "Sectoral Shocks and Aggregate Fluctuations", *Journal of Monetary Economics* 45, pp. 69-106.

[11] Hulten, C.R., (1978), "Growth Accounting with Intermediate Goods", *Review of Economic Studies*, Vol 45, No.3, pp. 511-518.

[12] Jones, C. I., (2007), "Intermediate Goods and Weak Links: A Theory of Economic Development", mimeo.

[13] Jorgenson, D. W., Gollop, F. M. and Fraumeni B. M. (1987), "Productivity and U.S. Economic Growth", Harvard University Press, Cambridge, MA.

[14] Lagos, R., (2006), "A Model of TFP", *Review of Economic Studies* 73, 983–1007.

[15] Long, J. and Plosser, C., (1983), "Real business cycles", *Journal of Political Economy* 91, pp. 39-69.

[16] Parente, S. and Prescott, E. C., (1999), "Monopoly Rights: A Barrier to Riches", *American Economic Review*, Vol. 89, No. 5, pp. 1216-1233.

[17] Restuccia, D. and Rogerson, R., (2007), "Policy Distortions and Aggregate Productivity with Heterogeneous Plants", NBER Working Paper No. 13018.

[18] Young, A.,T., (2004), Labor's share fluctuations, biased technical change, and the business cycle, Review of Economic Dynamics 7 pp. 916–931.