

# Biased Technical Change, Intermediate Goods and Total Factor Productivity\*

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## Abstract

In this paper, I show that the intensity through which intermediate goods are used in the production process affects aggregate total factor productivity (TFP). To do this, I construct an input-output model economy in which firms produce gross output by means of a production function in capital, labor and intermediate goods. This production function is subject, together with the standard neutral technical change, to *intermediates-biased technical change*. Positive (negative) intermediates-biased technical change implies a decline (increase) in the elasticity of gross output with respect to intermediate goods. In equilibrium, this elasticity appears as an explicit part of TFP in the value added aggregate production function. In particular, when the elasticity of gross output with respect to intermediates increases, aggregate TFP declines. I use the model to quantify the impact of intermediates-biased technical change for measured TFP growth in Italy. The exercise shows that intermediates-biased technical change can account for the productivity slowdown observed in Italy from 1994 to 2004.

**JEL Classification:** E01, E25, O47.

**Keywords:** Total Factor Productivity, Growth, Biased Technical Change, Intermediate Goods.

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# 1 Introduction

Intermediate goods represent an important production input in most sectors of industrialized economies. In the U.S., for a given amount of nominal GDP, roughly an equivalent amount of intermediate goods is delivered to intermediate demand.<sup>1</sup> Despite this fact, growth and business cycle models usually consider capital and labor as the only inputs. In these models, the supply side of the economy is represented by an aggregate value added production function in capital and labor inputs. This procedure is justified by the double nature of intermediate goods which are both output and input in production and cancel out in aggregate accounting relationships.<sup>2</sup> Important exceptions to this practice in the real business cycle literature are Long and Plosser (1983) and Horvath (2000), who show how sectorial shocks can spread through an input-output structure and give rise to aggregate total factor productivity (TFP) fluctuations. These models point out that the linkages among sectors, represented by intermediate goods, contribute to determine aggregate TFP movements. Despite these results and the current debate on the sources of aggregate TFP growth, few attempts have been made to study the relationship between intermediate goods utilization and aggregate TFP growth.<sup>3</sup>

In this paper, I show that standard measures of aggregate TFP depend on the amount of intermediate goods per-unit of gross output used in production. For this purpose, I construct an input-output model economy in which firms produce gross output by means of a production function in capital, labor and intermediate goods. This production function is

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<sup>1</sup>Intermediate goods include raw materials, energy, components, finished goods and services. They are classified by use, as in the input-output tables, and not by type of good.

<sup>2</sup>Jorgenson, Gollop and Fraumeni (1987, p. 6), for instance, describe aggregate value added as follows: "*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.*"

<sup>3</sup>Among these attempts see Ciccone (2002) and Jones (2007), which are discussed below in the text. For recent papers that build theories of TFP see, among others, Parente and Prescott (1999), Boldrin and Levine (2001, 2007), Herrendorf and Teixeira (2005), Castro, Clementi and MacDonald (2006), Lagos (2006), Restuccia and Rogerson (2008) and Guner, Ventura and Xu (2008).

subject, together with the standard capital and labor augmenting *neutral technical change*, to a particular type of biased technical change, called *intermediates-biased technical change*. In this paper, positive (negative) intermediates-biased technical change implies a decline (increase) in the elasticity of gross output with respect to intermediate goods.<sup>4</sup> In turn, this implies a decline (increase) in the amount of intermediate goods used to produce one unit of gross output in equilibrium. The main result is that the elasticity of gross output with respect to intermediate goods appears as an explicit part of TFP in the aggregate value added production function of the economy. *Ceteris paribus*, a decline in the elasticity of gross output with respect to intermediate goods affects the aggregate value added production function in the same fashion as positive neutral technical change which, in standard models, is the only source of TFP growth. In a typical growth accounting exercise, this implies that what is measured as aggregate TFP growth is the sum of two components, one generated by the standard neutral technical change and the other by the intermediates-biased technical change.

The mechanism driving the result works as follows. By definition, measured TFP is given by the difference between the joint productivity of capital and labor in gross output and the relative utilization of intermediate goods with respect to capital and labor in production. The decline in the elasticity of gross output with respect to intermediate goods due to positive intermediates-biased technical change has two effects on measured TFP. First, it increases the joint productivity of capital and labor in gross output. Second, it makes the production process become more intensive in capital and labor and less in intermediate goods. This implies that the relative utilization of intermediate goods with respect to capital and labor declines. As a result, both effects generated by positive intermediates-biased technical change contribute to increase measured TFP.

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<sup>4</sup>I define biased technical change as in Young (2004, p. 917): "one broad definition of biased technical changes is changes that directly affect factor elasticities".

This paper contributes to the TFP literature by identifying a direct and measurable effect of intermediate goods utilization in the production process on measured TFP. In some cases, this effect can be large. To show this, I use data for Italy from the EU KLEMS Database, March 2007.<sup>5</sup> Italy provides an ideal environment to measure intermediates-biased technical change because the price of intermediate goods relative to that of gross output displays no long run trend. Thus, any change in the relative utilization of intermediate goods in gross output can be attributed to intermediates-biased technical change. In the period from 1994 to 2004 Italy experiences a slowdown in the growth rate of measured 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 intermediates-biased technical change during that period.

The remaining of the paper is organized as follows: section 2 discusses the related literature; section 3 presents the model; section 4 provides the quantitative example; section 5 concludes.

## 2 Related Literature

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

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<sup>5</sup>The dataset is freely downloadable at <http://www.euklems.net/>

on aggregate output and TFP. In his model, new technologies adopted with industrialization are more intensive in intermediate goods. When an increase in productivity occurs in sectors producing intermediate goods, final producers benefit from that increase and become more productive themselves. The increase in the productivity of the final producers is proportional to the intensity of intermediate goods in the production process. As new technologies are more intensive in intermediate goods, it follows that industrialization provides a TFP increase. 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 first 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 the productivity level. When neutral technical change is embodied in capital and labor only, and not in intermediate goods, there is no multiplier associated with the share of intermediate goods. It follows that in the model presented here, when there is no intermediates-biased technical change (that is, 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.

This paper also relates to the large literature on biased technical change. The literature on skill-biased technical change is mainly concerned with explaining the rise in the wage premium of skilled workers relative to the unskilled and the contemporaneous increase in the supply of skilled workers. As noted in Acemoglu (2002), these two facts would not have happened at the same time without a substantial amount of skill-biased technical change during the same period. Hornstein and Krusell (1996) and Greenwood and Yorukoglu (1997) argue that the introduction of new technologies (such as skill-biased technologies) can have an impact a negative effect on TFP growth, as workers take time to learn how to use the

new machines. Acemoglu (1998) suggests that maximum TFP growth is attained when there is a balanced effort in developing both skill-biased and unskill-biased technologies. When the skill-biased technical change process is too sustained, few resources are devoted to the development of unskilled-bias technologies. It follows that, due to decreasing returns on each type of technology, aggregate TFP growth falls. In the investment-specific technical change literature, Greenwood, Hercowitz and Krusell (1997) separate the source of TFP growth due to the standard Hicks-neutral technical progress from that deriving from the introduction of new and more efficient capital goods. They find that investment-specific technical change contributes for 58% to post-war growth in the U.S. Compared to these contributions, this paper studies the effect of a new type of biased technical change, namely intermediates-biased technical change, on TFP growth.

### 3 The Model

#### 3.1 Household

There is an infinitely lived representative household, endowed with one unit of labor services each period. Every period, given the current capital stock owned, the household makes optimal decisions on the amount of labor services to sell to firms, on how much to consume and on how much to invest in capital. The formal problem is

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

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 consumption,  $n_t$  is the amount of labor services sold to firms,  $k_t$  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 of the capital stock,  $\beta \in (0, 1)$  is the subjective discount factor and  $\eta > 0$  is a preference parameter that measures the importance of leisure relative to consumption.

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

$$\frac{\beta}{C_{t+1}} \left[ \frac{r_{t+1}}{p_{t+1}} + (1 - \delta) \right] = \frac{1}{C_t}, \quad (2)$$

and

$$\frac{\eta C_t}{1 - n_t} = \frac{w_t}{p_t}. \quad (3)$$

Equation (2) 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  $\beta$ . Equation (3) simply equates the marginal rate of substitution between labor and consumption to the wage rate in consumption terms.

### 3.2 Firms

There is a continuum of firms in the economy, indexed by  $i \in [0, 1]$ . Each firm produces a good that can be either consumed, invested to build capital stock, or used as an intermediate good in the production of the other goods in the economy. All goods are perfect substitutes as consumption goods, as investment goods and as intermediate goods. Each atomless firm  $i$  produces gross output  $Y_i$  using intermediate goods purchased from other firms,  $M_i$ , capital rented from the household,  $K_i$ , and labor services purchased from the household,  $N_i$ , according to the following production function

$$Y_i = [AK_i^\alpha N_i^{1-\alpha}]^{1-\theta} M_i^\theta, \quad (4)$$

where  $\alpha \in (0, 1)$ . I allow for two types of technical change in (4): one is the *neutral technical change*, embodied in capital and labor, and driven by changes in  $A$ ; the second is

the *intermediates-biased technical change*, driven by changes in  $\theta$ . Both  $A$  and  $\theta$  are assumed to exogenously change over time, with  $\theta \in (0, 1)$  always.

Firm  $i$  in this economy solves

$$\max_{K_i, N_i, M_i} \left\{ p \left[ AK_i^\alpha N_i^{1-\alpha} \right]^{1-\theta} M_i^\theta - rK_i - wN_i - pM_i \right\}, \quad (5)$$

where  $p$  is the price of gross output in terms of the numeraire. As the problem of the firm is static, I avoid time subscripts to save notation. For each firm, the set of available intermediate goods is represented by the set of all other goods in the economy. As all firms in the economy produce gross output using a common technology, all goods in the economy display the same price in equilibrium. It follows that the price of intermediate goods is equal to the price of gross output,  $p$ , so that each firm is indifferent in deciding from which other firm (or firms) to purchase the amount of intermediate goods  $M_i$ .

Given the Cobb-Douglas form of the production function (4), the first order condition of (5) with respect to intermediate goods delivers the following condition

$$\frac{M_i}{Y_i} = \theta. \quad (6)$$

Equation (6) highlights the direct relationship between the intermediates-biased technical change variable  $\theta$  and the utilization of intermediate goods per unit of output. When  $\theta$  increases (decreases) because of negative (positive) intermediates-biased technical change, the production process becomes more (less) intensive in intermediate goods.

Using (6) to substitute for  $M_i$  in (4), I obtain

$$Y_i = \theta^{\frac{\theta}{1-\theta}} AK_i^\alpha N_i^{1-\alpha}. \quad (7)$$

In equilibrium, each firm's gross output is a function of capital, labor and the neutral and intermediates-biased technical change variables,  $A$  and  $\theta$ . Aggregate intermediate goods  $M$  and aggregate gross output  $Y$  can then be found by integrating (6) and (7) over the  $[0, 1]$

interval. After defining  $K = \int_0^1 K_i di$  and  $N = \int_0^1 N_i di$  as the total amounts of capital and labor used in production in the economy, and observing that in equilibrium the capital/labor ratio is the same for all firms (so that  $\frac{K_i}{N_i} = \frac{K}{N}$  for all  $i$ ), aggregate gross output is given by  $Y = \theta^{\frac{\theta}{1-\theta}} AK^\alpha N^{1-\alpha}$  and aggregate intermediate goods are given by  $M = \theta Y$ .

Real value added is given by the difference between gross output and intermediate goods  $V = Y - M$ . Given aggregate gross output and intermediate goods,  $V$  can be written as

$$V = (1 - \theta)\theta^{\frac{\theta}{1-\theta}} AK^\alpha N^{1-\alpha}. \quad (8)$$

The amount of real value added is determined by the amount of capital and labor used in the production process and the levels of neutral and intermediates-biased technical change variables,  $A$  and  $\theta$ . In a standard growth accounting exercise, measured TFP is given by

$$TFP = \frac{V}{K^\alpha N^{1-\alpha}}. \quad (9)$$

Thus, measured TFP depends both on neutral and intermediates-biased technical change. In particular, from (8)

$$TFP = AB, \quad (10)$$

where  $B = (1 - \theta)\theta^{\frac{\theta}{1-\theta}}$  is a decreasing function of  $\theta$ . This is plotted in figure 1. It follows that the model displays a negative relationship between measured TFP and the level of  $\theta$ .<sup>6</sup> In equilibrium,  $\theta$  is equal to the share of intermediate goods in gross output production. In many industrialized countries, this share lies between 0.4 and 0.6. Note that a change in  $\theta$  from 0.6 to 0.4 implies an increase in  $B$ , and consequently in measured TFP, of 75%. Table 1 reports the average  $\theta$  over the 1970-2004 period for a set of countries in the KLEMS dataset and the corresponding value for  $B$ . The U.S. display the smallest value of  $\theta$ , 0.44, while Belgium displays the largest, 0.57. These values imply that the function  $B$  is 40% larger in

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<sup>6</sup>To avoid confusion with the neutral technical change variable  $A$ , which coincides with TFP in standard models, I will refer to (10) as "measured TFP" through the rest of the paper.

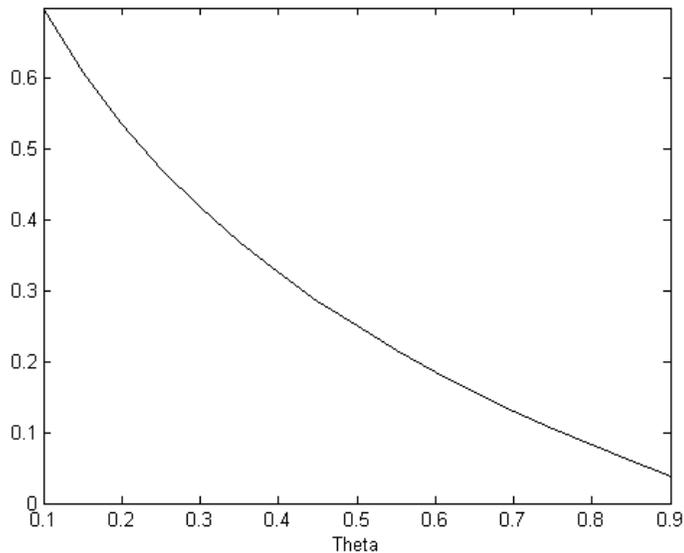


Figure 1: The function  $B$ .

the U.S. with respect to Belgium, 0.29 versus 0.21. Thus, if measured TFP were determined by the function  $B$  alone, the U.S. would be the most productive country and Belgium the least productive. This suggests that measured TFP levels across countries might display large differences even when neutral technical change  $A$  is the same.

As  $\theta$  changes, there are two effects on measured TFP. To see this, note that measured TFP can be written as

$$TFP = \frac{Y}{K^\alpha N^{1-\alpha}} - \frac{M}{K^\alpha N^{1-\alpha}}. \quad (11)$$

The first term on the right hand side of (11) represents capital and labor joint productivity in gross output. By using the expression for aggregate gross output,  $Y = \theta^{\frac{\theta}{1-\theta}} AK^\alpha N^{1-\alpha}$ , it follows that  $Y/[K^\alpha N^{1-\alpha}]$  is always equal to  $A\theta^{\frac{\theta}{1-\theta}}$  in equilibrium, with this function decreasing in  $\theta$ . Thus, when  $\theta$  declines with positive intermediates-biased technical change, the production function (4) implies that capital and labor become more productive in gross output. This, in turn, implies that the aggregate (gross) production possibility of the economy, given aggregate capital and labor, is larger when the production technology is less intensive

<b>Table 1</b>		
	$\theta$	$B$
Austria	0.47	0.27
Belgium	0.57	0.21
Denmark	0.48	0.26
Finland	0.52	0.24
France	0.51	0.25
Germany	0.48	0.26
Ireland	0.54	0.22
Italy	0.51	0.24
Japan	0.50	0.25
Netherlands	0.51	0.24
Portugal	0.54	0.22
Spain	0.52	0.24
Sweden	0.52	0.24
UK	0.54	0.23
US	0.44	0.29

$\theta$  is the average share of intermediate goods in gross output for the period 1970-2004 (Denmark 1970-2005, Finland 1975-2004, Japan 1973-2004, Portugal 1977-2004. Data for Germany include only West-Germany until 1990). Source: KLEMS Database, March 2007.

in intermediate goods.

When  $\theta$  decreases there is also an effect on the second term on the right hand side of (11), which represents the relative utilization of intermediates with respect to capital and labor. When  $\theta$  decreases, the weight of intermediates in the production function (4) decreases, while the weight of capital and labor increases. Other conditions equal, the firm is willing to use more capital and labor and less intermediate goods in the production process. Thus, the second ratio on the right hand side of (11) decreases when  $\theta$  becomes smaller. Using the expressions for aggregate gross output and aggregate intermediate goods, it can be shown that the second ratio on the right hand side of (11) is always equal to  $A\theta^{\frac{1}{1-\theta}}$ , which is increasing in  $\theta$ .

Thus, the two effects, on capital and labor joint productivity in gross output and on the relative utilization of the inputs move in the same direction so that a decrease in  $\theta$  increases capital and labor joint productivity (measured TFP) in value added. The sum of the two

effects is  $A\theta^{\frac{\theta}{1-\theta}} - A\theta^{\frac{1}{1-\theta}} = A(1-\theta)\theta^{\frac{\theta}{1-\theta}} = AB$ .

Finally, note that measured TFP is linear in  $A$  in (10). 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 measured TFP.<sup>7</sup> The difference results from the way  $A$  enters into the production function. In the model presented here neutral technical change  $A$  is embodied in capital and labor only, and not in intermediate goods, so that gross output TFP at the firm level is given by  $A^{1-\theta}$ . Hulten (1978), Jones (2007) and Gabaix (2008), instead, assume that neutral technical change is embodied in capital, labor and intermediate goods. The resulting gross output TFP at the firm level is given by  $A > A^{1-\theta}$ . In both models, aggregate measured TFP depends on firm level TFP raised to the power  $1/(1-\theta)$ , that is  $A^{1/(1-\theta)}$  and  $A$  respectively. Thus, when neutral technical change  $A$  is embodied in capital and labor only, aggregate measured TFP is linear in  $A$ . Only when neutral technical change is assumed to be embodied also into intermediate goods a multiplier effect  $1/(1-\theta)$  appears on  $A$  in aggregate measured TFP. Indeed, Jorgenson, Gollop and Fraumeni (1987) find that growth in the inputs quality occurs only in capital and labor and not in intermediate goods. These empirical results drive the use of a capital and labor neutral technical change in the production function (4).<sup>8</sup>

### 3.3 Market Clearing

Market clearing in the capital and labor markets requires that the amounts of capital and labor supplied by the household be equal to total capital and labor used in the production process

$$k_t = K_t \text{ and } n_t = N_t. \tag{12}$$

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<sup>7</sup>See Hulten (1978), Ciccone (2002), Jones (2007) and Gabaix (2008).

<sup>8</sup>Jorgenson, Gollop and Fraumeni (1987), p. 202, Table 6.8, write "*growth in input (intermediates) quality is not an important source of growth in intermediate goods*", "*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*".

In the goods market, the supply side must satisfy

$$Y_t = V_t + M_t, \tag{13}$$

i.e., gross output must be equal to the sum of value added and intermediate goods.<sup>9</sup> On the demand side the following holds

$$Y_t = C_t + I_t + M_t, \tag{14}$$

i.e., gross output is the sum of consumption, investment and intermediate goods demands.

Equations (13) and (14) imply that

$$V_t = C_t + I_t, \tag{15}$$

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

### 3.4 Steady State

By affecting measured TFP, intermediates-biased technical change influences the equilibrium values of the model's variables. In this section, I analyze how  $\theta$  influences the steady state values of the model. The steady state can be solved in closed form, so it provides explicit relationships between the model's variables and  $\theta$ . To derive the steady state, I state a planner problem in a version of the model with fixed labor supply and a representative firm. The available amount of labor services is one each period. The equilibrium of this problem is equivalent to that of the economy described in the previous subsections, once labor is excluded from the utility function and exogenously fixed to one.<sup>10</sup> The production function

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<sup>9</sup>As the price of gross output, value added and intermediates is the same, (13) holds both in nominal and in real terms.

<sup>10</sup>Although the result is the same as in the case with a continuum of identical firms, in the model with the representative firm the source of intermediates becomes unclear. Thus, for exposition purposes, the model with a continuum of firms was preferred in the previous subsections. 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.

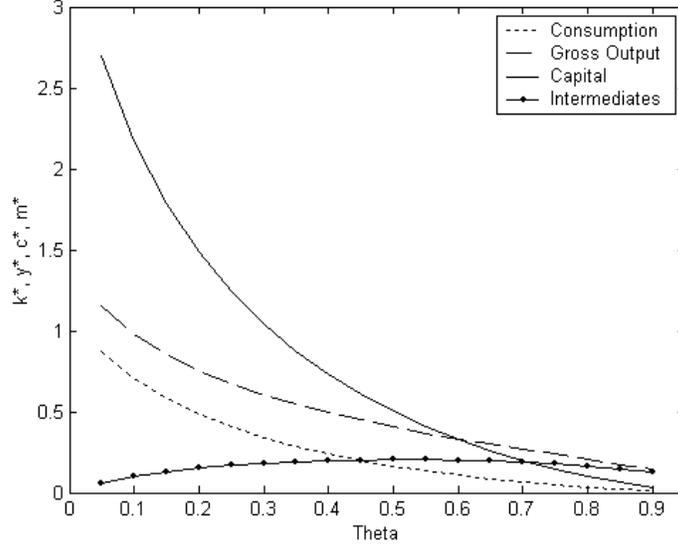


Figure 2: Steady state values of per capita consumption, capital, gross output and intermediate goods for different values of the biased technical change variable  $\theta$ .

in (4) becomes, in per capita terms  $y = A^{1-\theta} k^{\alpha(1-\theta)} m^\theta$ , where  $y$  is the 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

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

where all variables, consumption  $c_t$ , capital  $k_t$  and intermediate goods  $m_t$  are in per capita terms. As before,  $\delta$  is the depreciation rate and  $\beta$  the subjective discount factor while  $A_t$  and  $\theta_t$  represent the neutral and the intermediates-biased technical change variables. For given  $A$  and  $\theta$ , a steady state for this economy can be found. The steady state per capita capital of this economy is

$$k^* = \left[ \frac{(1 - \theta)\theta^{\frac{\theta}{1-\theta}} \alpha A}{(1/\beta) - 1 + \delta} \right]^{\frac{1}{1-\alpha}}. \quad (16)$$

Details of the calculations are reported in Appendix A. With respect to the standard one

sector growth model, the steady state per capita capital depends also on  $B = (1 - \theta)\theta^{\frac{\theta}{1-\theta}}$ . It follows that the higher  $\theta$ , the lower  $k^*$ . Figure 2 reports the steady state consumption, gross output, intermediate goods and capital, all in per capita terms, as functions of  $\theta$  and with  $A = 1$ ,  $\delta = 0.08$ ,  $\alpha = 0.3$  and  $\beta = 0.96$ . All functions are decreasing in  $\theta$  except for the intermediate goods one. Thus, when negative intermediates-biased technical change increases the intensity of intermediate goods in production, the steady state values of gross output, capital and consumption decrease.

The non-monotone pattern of steady state intermediates observed in figure 2 is the result of two opposite effects. First, when  $\theta$  increases, the technology becomes more intensive in intermediate goods, so that the optimal amount of this input tends to increase in equilibrium. Second, when  $\theta$  increases, steady state output declines because measured TFP is smaller and the amount of intermediate goods needed for production in equilibrium declines. The two effects compete to determine the optimal amount of intermediates in steady state. For  $\theta < 0.5$  the first effect dominates when  $\theta$  increases while for  $\theta > 0.5$  the opposite holds true.

The steady state analysis confirms that intermediates-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.<sup>11</sup>

## 4 A Quantitative Example

Given the theory proposed in the previous section, the question becomes to what extent, quantitatively, can intermediates-biased technical change affect measured TFP growth. Note that the model 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

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<sup>11</sup>Note, however, that biased technical change cannot be a source of unbounded growth. The reason lies in the fact that  $\theta$  is always between zero and one.

the same price for consumption, investment and output in the standard one sector growth model. In most countries, however, the relative price of intermediates is not constant over time. When this is the case, changes in the utilization of intermediate goods per unit of output are due in part to substitution among factors following changes in the relative price and in part to intermediates-biased technical change. To disentangle the two effects, a richer model, in which variations in the relative price of intermediates are also explained, is needed. For this reason, the case of Italy represents a suitable example to quantify the relevance of intermediates-biased technical change on measured TFP growth in the context of the model presented in this paper. In Italy, the relative price of intermediates is constant in the long run while the relative quantity of intermediates with respect to gross output increases, suggesting a pure negative intermediates-biased technical change in the gross output production function.

Figure 3 plots measured 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 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 intermediates-biased technical change. To quantify this effect, I use the model

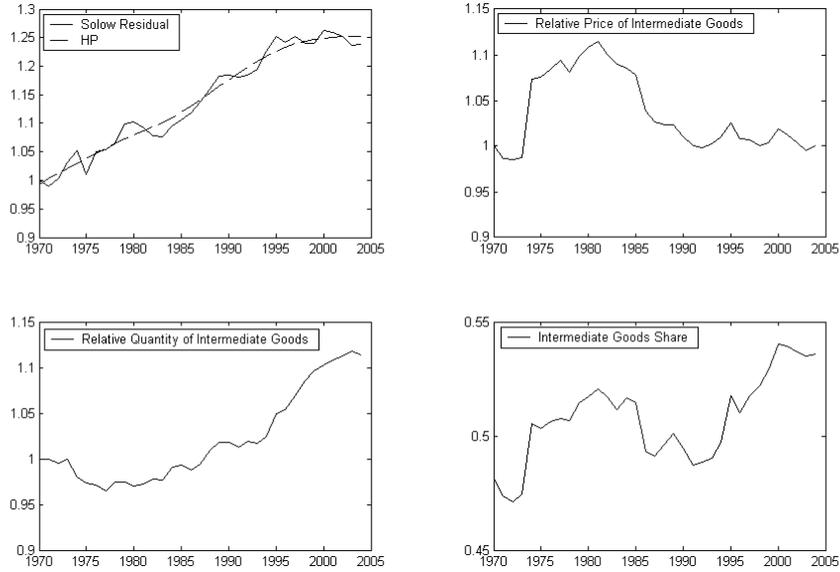


Figure 3: The first panel displays the Solow residual and its HP trend; the second panel displays the relative price of intermediate goods with respect to output; the third panel reports the relative quantity of intermediate goods with respect to output; the fourth panel reports the share of intermediate goods in gross output. All series are computed from the Italian dataset of the EU KLEMS Database, March 2007.

presented in section 3 to compute the average yearly growth rate of neutral technical change  $A$ , from the data. Using the empirical counterpart of formula (10), this is given by

$$\mu_A = \mu_{TFP} - \mu_B. \quad (17)$$

where  $\mu_{TFP}$  is the yearly average growth rate of measured TFP and  $\mu_B$  the yearly average growth rate of  $B$ . Both  $\mu_{TFP}$  and  $\mu_B$  can be computed directly from the data and  $\mu_A$  is then obtained from (17). Table 2 reports  $\mu_{TFP}$ ,  $\mu_B$  and  $\mu_A$  for different sub-samples.

Table 2			
Growth Rates	1970-2004	1970-1994	1994-2004
$\mu_{TFP}$	0.63%	0.85%	0.09%
$\mu_B$	-0.45%	-0.19%	-1.09%
$\mu_A$	1.08%	1.04%	1.18%

The growth rate  $\mu_B$  is calculated using the share of intermediate goods in gross output as the empirical counterpart for the model's  $\theta$ . The bottom-right panel of figure 3 shows how  $\theta$  evolves in the data between 1970 and 2004. For the whole sample,  $\theta$  increases from 0.48 to 0.54, resulting in an average yearly decline in  $B$  of 0.45%. The increase in  $\theta$  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 measured TFP,  $\mu_{TFP}$ , is calculated as in a standard growth accounting procedure using data for capital, labor and value added.<sup>12</sup> 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 calculated using (17), 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.<sup>13</sup> 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. The quantitative results confirm that intermediates-biased technical change can represent an important source of measured 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 intermediates-biased technical change, represent a new channel to investigate to explain measured TFP growth.

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” per-

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<sup>12</sup>See Appendix B for details of the calculations of  $\mu_{TFP}$  and  $\mu_B$ .

<sup>13</sup>Note that the increase in the relative price of intermediates occurred between the mid-seventies and the mid-eighties does not affect the quantitative results in Table 2. In fact, this relative price is the same in 1970 and in 1994. This implies that, regardless of the movements in the relative price between 1970 and 1994, the change in the relative quantity of intermediates over gross output observed in 1994 relative to 1970 is due only to intermediates-biased technical change.

formed 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.<sup>14</sup> 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 measured TFP. In Italy, for instance, firms have an incentive to remain small because of the labor legislation.<sup>15</sup> It follows that a firm might find more profitable to buy intermediates from a less efficient external firm than to produce the intermediate itself at a higher level of efficiency.

## 5 Conclusions

This paper provides a theoretical framework that shows how intermediates-biased technical change can affect measured TFP growth together with neutral technical change. A simple input-output model is used to make this point. *Ceteris paribus*, when positive intermediates-biased technical change lowers the elasticity of gross output with respect to intermediate goods, the production process becomes more intensive in capital and labor and less in intermediate goods and measured aggregate TFP increases. In the model, this effect shows up through a function that depends only on the elasticity of output with respect to intermediates that explicitly appears in the TFP definition of the aggregate value added production function. It follows that the effect of intermediates-biased technical change on measured

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<sup>14</sup>See for instance Baldwin and Robert-Nicoud (2006). Grossman and Rossi-Hansberg (2008), instead, propose a model of "trading tasks" in which a reduction in the cost of offshoring results in an increase in domestic productivity. In their model, when the cost of offshoring decreases, imported intermediate goods (tasks performed abroad) increase. The savings in cost that domestic firms experience, because of the smaller cost of offshoring, have the same effect as an increase in domestic productivity.

<sup>15</sup>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 (2008) for details.

TFP can be computed using data on the share of intermediate goods in gross production, which is equal to the elasticity of gross output with respect to intermediates in equilibrium. A growth accounting exercise shows that intermediates-biased technical change can account for the productivity slowdown observed in Italy from 1994 to 2004.

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 the aggregate TFP level. This result follows from the fact that neutral technical change is embodied in capital and labor only, and not in intermediate goods.

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, miss an important effect on TFP due to changes in the gross output technology at the firm level. Thus, aggregate TFP growth measures should take into account to what extent technologies at the firm level are becoming more or less intensive in intermediate goods. This dimension represents a possible source of TFP growth differences across countries.

## Appendix A: The Planner's Problem

The planner solves

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

subject to

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

First order conditions for this problem deliver the following relationships

$$\frac{c_{t+1}}{\beta c_t} = \left[ \alpha (1 - \theta_{t+1}) A_{t+1}^{1-\theta_{t+1}} k_{t+1}^{\alpha(1-\theta_{t+1})-1} m_{t+1}^{\theta_{t+1}} + (1 - \delta) \right], \quad (18)$$

and

$$\theta_t A_t^{1-\theta_t} k_t^{\alpha(1-\theta_t)} m_t^{\theta_t-1} = 1. \quad (19)$$

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 (16), solve (19) for  $m$ , use it in (18) and solve for  $k$ . Then, use again (19) 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  $A_t^{1-\theta_t} k_t^{\alpha(1-\theta_t)} m_t^{\theta_t}$  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

$$TFP_t = \frac{V_t}{K_t^\alpha N_t^{1-\alpha}}, \quad (20)$$

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  $\alpha$  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.<sup>16</sup> 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

$$V_t = [V_t^{Las} V_t^{Paa}]^{0.5}, \quad (21)$$

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

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

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.<sup>17</sup> 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 reflect

<sup>16</sup>See Bureau of Economic Analysis (2006) for details.

<sup>17</sup>The number of sectors considered, 26, represents the higher level of disaggregation permitted in the KLEMS dataset for Italy.

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

$$\Delta \ln N_{jt} = \sum_{i=1}^{N_j^n} \bar{\chi}_{jit}^n \Delta \ln N_{jit}, \quad (22)$$

where  $\bar{\chi}_{jit}^n = \frac{\chi_{jit}^n + \chi_{jit-1}^n}{2}$ ,  $\chi_{jit}^n = p_{jit}^n N_{jit} / \left( \sum_{i=1}^{N_j^n} p_{jit}^n N_{jit} \right)$  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  $\Delta$  indicates the annual change in the variable. Finally  $N_j^n$  is the total number of different types of labor in sector  $j$ . Equation (22) 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 (20) is then computed as

$$\Delta \ln N_t = \sum_{j=1}^I \bar{\chi}_{jt}^n \Delta \ln N_{jt}, \quad (23)$$

where each  $\Delta \ln N_{jt}$  is obtained from (22),  $\bar{\chi}_{jt}^n$  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

$$K_{it} = \sum_{\tau=1}^{\infty} (1 - \delta_i)^\tau I_{i,t-\tau}, \quad (24)$$

where  $I_{i,t-\tau}$  is investment in that asset at time  $t - \tau$  and  $\delta_i$  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

$$\Delta \ln K_{jt} = \sum_{i=1}^{N_j^k} \bar{\chi}_{jit}^k \Delta \ln K_{jit}, \quad (25)$$

where  $\bar{\chi}_{jit}^k = \frac{\chi_{jit}^k + \chi_{jit-1}^k}{2}$ ,  $\chi_{jit}^k = p_{jit}^k K_{jit} / \left( \sum_{i=1}^{N_j^k} p_{jit}^k K_{jit} \right)$  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 (20) is then computed as

$$\Delta \ln K_t = \sum_{j=1}^I \bar{\chi}_{jt}^k \Delta \ln K_{jt} \quad (26)$$

where each  $\Delta \ln K_{jt}$  is obtained from (25),  $\bar{\chi}_{jt}^k$  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.<sup>18</sup>

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

$$\mu_{TFP} = (1 + x_{TFP})^{1/(T-1)} - 1, \quad (27)$$

where  $T$  is the number of years.

The aggregate intermediate goods share in gross output is calculated as

$$IGS_t = \frac{\sum_{i=1}^I p_{i,t}^m m_{i,t}}{\sum_{i=1}^I p_{i,t} y_{i,t}}, \quad (28)$$

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 the fourth panel of figure 3.

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

$$B_t = (1 - IGS_t) IGS_t^{\frac{IGS_t}{1-IGS_t}}. \quad (29)$$

The average yearly growth rate  $\mu_B$  is then found using the formula

$$\mu_B = (1 + x_B)^{1/(T-1)} - 1, \quad (30)$$

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<sup>18</sup>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".

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  $\mu_A$  is then found from (17).

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

$$Y_t = [Y_t^{Las} Y_t^{Paa}]^{0.5}, \quad (31)$$

$$M_t = [M_t^{Las} M_t^{Paa}]^{0.5}, \quad (32)$$

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 the third panel of figure 3 is the ratio of (32) and (31). 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 (31) and (32).

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 the second panel of figure 3.

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