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Embodied and disembodied technological change: the sectoral patterns of job-creation and job-destruction

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Abstract

This paper addresses, both theoretically and empirically, the sectoral patterns of job creation and job destruction in order to distinguish the alternative effects of embodied *vs* disembodied technological change operating into a vertically connected economy. Disembodied technological change turns out to positively affect employment dynamics in the "upstream'' sectors, while expansionary investment does so in the "downstream'' industries. Conversely, the replacement of obsolete capital vintages tends to exert a negative impact on labour demand, although this effect turns out to be statistically less robust.

Keywords: Innovation, disembodied and capital-embodied technological change, employment, job-creation, job-destruction, sectoral interdependencies.

JEL classification: O14, O31, O33

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1. Introduction

This work contributes to the evidence on the complex relationships between technology and employment dynamics. The question is there at least since the third edition (1821) of Ricardo's *Principles of Political Economy* (see Ricardo, 1821) and it recurrently emerges together with major technological and institutional transformations (see Noble 1986; Zuboff, 1988 and Knights and Willmott, 1990 on the social impact of ICTs), such as the present emergence of a new wave of automation driven by the pervasive diffusion of AI and robots (see Brynjolfsson and McAfee, 2014; Frey and Osborne, 2017; Acemoglu and Restrepo, 2017 Kenney and Zysman, 2019).

Indeed, almost three decades of economic theoretical and empirical literature have pointed out the multifaceted relationships between the adoption of technology and the ensuing effects upon employment (see Freeman, Clark and Soete, 1982, Freeman and Soete, 1994; Vivarelli, 1995; Pianta, 2005 and for recent surveys: Vivarelli, 2014; Calvino and Virgillito, 2018; Ugur, Awaworyi Churchill and Solomon, 2018). In general terms, the findings vary a lot depending on the analytical perspectives and the granularity of the observation. First, the levels of aggregation, whether firm, sectoral or macro-levels crucially matter. Second, so does the nature of the technological change, whether embodied (e.g. an investment in new machineries) or disembodied (via R&D expenditures). Third, the level of analysis has to take into account the balance between the direct labour-saving effect on the one hand, and the possible market "compensation mechanisms" on the other, also affected by the relatively balance between process *vs* product innovation.

Most of the extant literature addresses the job-creating/destroying effects of technological change at firm-level, from which the net job-creating effects emerge more straightforwardly when looking at very innovative firms, belonging to high-tech sectors, and when proxies of disembodied technical change (R&D and/or patents) are used in the econometric analysis (see Buerger, Broekel and Coad, 2010; Coad and Rao, 2011; Bogliacino, Piva and Vivarelli, 2012; Van Roy, Vertesy and Vivarelli, 2018). However, more controversial results emerge when looking at the sectoral level of aggregation (see Antonucci and Pianta, 2002; Bogliacino and Pianta, 2010; Aldieri and Vinci, 2018; 'and Hagsten, 2018, Dosi and Monhen, 2019). In fact, it should not be too surprising that, within the same markets of finite size, firms which are relatively more innovative, efficient and dynamic could grow in terms of market shares (and plausibly also in terms of employment) at the expenses of the less innovative firms. This is sometimes named in the current literature as the 'business stealing' effect (see Van Reenen, 1997, p.260), which in fact tends to capture the ubiquitous property of market selection among heterogeneous firms (Dosi et al., 2017). In all that, the positive employment effects of technological change at the micro-level may not map at all into sectoral dynamics and can even be reverted at the industry level (see Greenan and Guellec, 2000). In this context, labour shedding effects of productivity improvements due to process innovation likely result in sectoral job losses if they are not coupled with the introduction of product innovations. An archetypical case is agriculture. Over the last two centuries, at least, agriculture underwent a secular explosion in *process-innovations*, which were indeed *product innovations* for the upstream sectors discovering and introducing them. These go from ploughs to fertilisers, tractors, harvesting machines, new seeds and so on so forth. As well-known, the overall outcome has been an impressive growth of agricultural productivity and an equally impressive *fall* in agricultural employment. Hence, even in the most naive calculations of 'compensation effects' one ought to account for the balance between the labour saving impact in agriculture and the labour creating effect of the production and diffusion of tractors, harvesters, etc.

This is the type of theoretical contribution that we put forward in this contribution, trying to disentangle the sectoral patterns of job-creation/destruction distinguishing the diverse effects of disembodied and embodied technical change originating in different sectors. Rooted on three distinct but interrelated streams of literature, namely the input/output tradition from Leontief to Pasinetti (see Pasinetti, 1981), the agent-based modelling (see Dosi, Fagiolo and Roventini, 2010) and the evolutionary approach to innovation (see Nelson and Winter, 1982), this paper contributes to the ongoing debate about alternative effects of technological change upon employment growth.

In more detail, this paper considers a vertically connected two-sector economy, with an upstream macrosector performing R&D activity (locus of endogenous technical change) and a downstream one, whereby capital-goods bought from the upstream sector are employed for the production of a homogeneous consumption good. Therefore, product innovation of the upstream sector defines the process innovation of the downstream sector. However, unlike the upstream sector, in the downstream one only embodied technical change takes place, via the adoption of new vintages of equipment for both expansionary and replacement investment (scrapping).[1] The model entails - other things being equal - a job-creating effect in the upstream sector as it demands labour for both R&D activities and the production of new products (namely the new capital goods - machinery - to be adopted by the downstream sector as productivity enhancing process innovation). Conversely, the impact of embodied technical change in the downstream sector is more ambiguous: whenever expansionary investment might be eventually labour friendly, instead labour would be shed in the case of scrapping, when the obsolete vintages are replaced by the new more efficient ones.

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[1] The role of embodied technological change was initially emphasised by Salter (1960) and then analysed and tested both at a macro-level (Jorgenson, 1966; Hercowitz, 1998; Mukoyama, 2006) and at a micro one (see Conte and Vivarelli, 2014; Piva and Vivarelli, 2018).

Empirically, the model is explored by means of a cross-country and cross-sector panel analysis comprising 19 European countries and 41 industries over the period 1998-2016 (Section 4). Following a revised Pavitt's (1984) taxonomy (Bogliacino and Pianta 2010), we include in the upstream aggregate those industries which go under the heading of *Science-based* and *Specialised Supplier*, while the *Scale-Intensive, Information-Intensive* and *the Suppliers Dominated* sectors are included in the downstream aggregate. We then explore econometrically distinct specifications of the labour demand: consistently with the proposed model, in the upstream sector we investigate the role of R&D activity, while in the downstream sector the role of expansionary and replacement investment.

The structure of the paper reads as follow. Section 2 discusses the compensation mechanisms (or lack of them) which drive the relationships between technological change and employment, Section 3 presents a stylised two-sector model economy, while Section 4 discusses the empirical findings. Section 5 concludes.

2. Compensation mechanisms at work (or not)

The conflicting effects of technological change upon employment dynamics have been hotly debated since the in inception of Political Economy: see the conflicting views of Say, 1803; Ricardo, 1821 and Marx, 1867. Comprehensive analyses are in Freeman, Clark, and Soete (1982); Freeman and Soete (1987) and Vivarelli (1995) (see also Feldmann, 2013; Vivarelli 2013 and 2014). The core of the analysis is the classification of the possible market compensation mechanisms that can (in principle) counterbalance the initial labour saving impact of process innovation; in turn, this "compensation theory" is articulated on the basis of the alternative "pass-through" channels that trigger adjustments in prices, quantities and ensuing labour demand. The mechanisms, which might operate at different levels of aggregation - whether sectoral or economy-wide - can be classified into *Classical, Neoclassical, Keynesian and Schumpeterian* ones.

Classical mechanisms

- **New machines**. As the result of technological progress, new machines are introduced, possibly displacing labour. A "sectoral shift" of workers from the downstream machine-using industry towards the upstream machine-producing may counterbalance the initial detrimental effect on employment.

- **Decrease in prices**. The increase in productivity due to the introduction of new technologies induces a reduction in the average production costs. This effect - especially *in perfectly competitive markets* - induces a subsequent reduction in prices. Lower prices should translate into higher demand, and therefore higher employment.
- **New investments**. The accumulated extra-profits which emerge in non-perfectly competitive markets (where the elasticity between decreased unit costs and subsequent decreasing prices is less than one) may be invested by entrepreneurs in capital formation, expanding the productive capacity and hence the labour demand.

Neoclassical mechanism

- **Decrease in wages**. This mechanism acts in the labour market, where the initial workforce displacement leads to an excess of labour supply, hence to a subsequent reduction in wages. If a well-behaved production function exists, the consequent increase in labour demand is supposed to re-equilibrate the market and absorb the initial excess labour supply.

Keynesian mechanism

- **Increase in incomes**. Whenever workers are able to appropriate gains from the increase in productivity, technological progress can lead to an increase in wages and consumption. This induces higher demand, sparking an increase in employment via well-known Keynesian processes, and eventually compensating for the initial labour displacement.

Schumpeterian mechanism

- **New products**. As emphasised by Schumpeter (1912) in his seminal contribution, technological change cannot be reduced to the sole process innovation (potentially labour-saving). Indeed, the introduction of new products entails the rise of new branches of production and stimulates additional consumption. Enlarged production and higher consumption translates into higher demand and therefore higher employment.

It is important to note that the effectiveness of the aforementioned compensation mechanisms varies in time and across technologies, while many aspects intertwine, undermining the possibility of any *ex-ante* prediction about their efficacy.

So, for example, concerning the introduction of *new machines*, the process of mechanisation/automation may well spread across sectors. The structural change from agriculture to manufacturing, and from the latter to services, is a clear example of such patterns. However, in such dynamics the balance between the rates of labour-shedding in the sectors improving their processes of production, and the rates of labour creation in the sector offering new machines, new products and new services is hardly guaranteed. Moreover, labour-saving process innovation also affects the producers of capital goods (think of robots used in the construction of machineries) and this may severely limit the employment compensation within the upstream industries. Finally, if the introduction of new machines merely replaces those which are obsolete, no compensation arises (see Marx, 1867, vol. 1, ch.13; Clark, Freeman and Soete, 1987; Vivarelli, 1995). In fact, if among machine-producers new pieces of equipment entirely cannibalise older ones, such an industry would not benefit from any positive effect on employment.

Turning our attention to the compensation mechanism via *decrease in prices,* first of all - in order to fully operate - the induced demand expansion must counterbalance the reduction in aggregate demand associated with the labour dismissal due to technological change. Necessary conditions for its effectiveness include: [i] a significant price elasticity for the commodities that are affected by the price reduction; [ii] a high share of these commodities in consumers' consumption bundles; [iii] non-oligopolistic market structures allowing a cost/price elasticity close to one. The extent to which the amount and composition of aggregate demand is affected by price reductions therefore depends on whether the above conditions are fulfilled.

Similar considerations also apply to the *wage reduction channel*: indeed, decreasing wages may induce a higher demand for labour, *along* the labour demand curve (assuming the existence of a production function), but they also imply a decreasing aggregate demand and so a decreasing demand for labour (a *shift* of the labour demand to the left). Which of the two effects prevails is an open question. Moreover, this mechanism is strictly based on the assumption of perfect factor substitution; in this respect, a number of theoretical flaws can undermine the reliability of this assumption. Finally, technological change is not time-reversible: if a firm masters a given capital-intensive technique, it will hardly stop using it and substitute it with labour, merely because of a change in the relative prices of the production factors. Most often new technologies dominate older ones *irrespectively of relative prices*, especially in manufacturing industries (see Dosi and Nelson, 2010 and 2013).[2] In fact, knowledge and technological change are characterised by path-dependence, increasing-returns and irreversibility (in other words: 'history matters'; see Rosenberg, 1982; David 1985; Capone *et al.* 2019) and this further renders extremely unlikely a reverse in favour of a more labour-intensive (but inferior) technology just because of decreasing wages.

[2] In the presence of a theoretical isoquant that represents the negative relationship between capital and labour, a negative relationship between capital and labour productivity would also be expected. However, contrary to what is conventionally assumed, Hildenbrand (1981), Yu *et al.* (2015), Dosi *et al*. (2016) empirically trace a zero or even positive correlation between capital and labour productivity, providing evidence of the absence of any static factors substitution.

Severe limitations also affect the compensation mechanism *via new investments*. Even under some Ricardian assumption, in which all the profits are reinvested,[3] these investments could be directed to labour-saving machineries, breaking down the Keynesian channel that links more investment with more production, and thus more labour demand. Needless to say, the investment channel is also jeopardised by the increasing financialisation of business firms, which tend to invest profits more in financial assets rather than in capital formation.

The *income channel* is mostly effective under regimes of production and income distribution where unionised labour is able to exert heavy claims on incomes, reflected in constants, or even increasing wage shares (see Boyer, 1988). Currently, the increasingly fragmented labour force appears to be less and less able to lay collective claims, as a result of increasingly flexible industrial relations and weaker bargaining mechanisms. As a consequence, this mechanism seems to have lost momentum in the last decades.[4]

Finally, the *new products* channel is multi-faceted. Under the traditional Schumpeterian distinction between product and process innovation, the former is recognised to be labour-friendly while the latter as labour-displacing. However, labour-friendly nature of product innovation needs to be qualified. First, the intensity of its impact depends on the weight that new products have in the baskets of consumption and on the income elasticities of their demand. Second, those which are new products for those producing them might well represent efficiency enhancing processes for their users.[5] Third, in order to exert a compensating effect, new products should not exclusively replace obsolete ones. If new products just cannibalise the sales of old ones, the net result might be ambiguous.[6] Fourth, product innovators may face a demand increase via market expansion, while the market shares of non-innovators may be eroded since old products become obsolete. Finally, new products may be produced more efficiently, due to the widespread evidence on the complementarity between product and process innovation.

In a nutshell: if one does not believe in a number of very controversial assumptions, there is not much room for any easy and full compensation.

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3 Clearly, this is a strong pre-keynesian assumption: cumulated profits are in fact a necessary but not sufficient condition for investing (for instance, in case of gloomy demand expectations, extra-profits will be hoarded).

4 Indeed, we will drop it in the following theoretical and empirical analyses.

5 ICT industries are a good case to the point. Over several decades now they have been a major source of product innovation for the whole economy and indeed have displayed the highest rate of employment absorption (for a projection on the US Economy on the employment dynamics by major industries see Henderson, 2015). However, ICT also represents a major source of potentially labour saving process innovation for adopting industries. And on the consumption side, ICT products do not seem to have gained the same importance as drivers of demand of cars and other consumer durables in the post-WWII period.

6 According to Katsoulacos (1984), at the consumer level the “welfare effect” should be compared with the “substitution effect”. An example of a dominant substitution effect can be found in the music industry, where vinyl was displaced by the compact disc and the latter is now displayed by MP3 and other electronic supports.

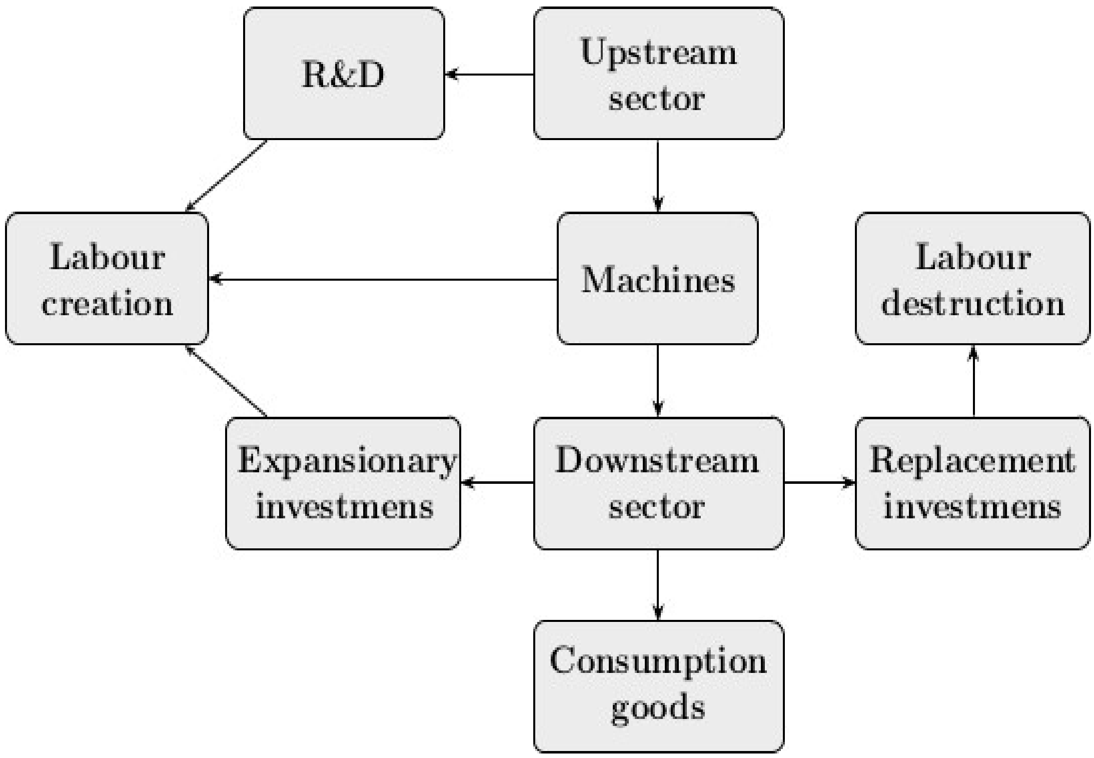
In contrast, a general *disequilibrium* perspective seems the most suitable to properly frame jointly the direct labour-saving impact of process innovation and the possible counterbalancing effects brought about by compensation mechanisms and product innovation. Indeed, only an account of the full thread of sectors linked by technological and demand flows - explicitly accounting for the distribution of diverse innovative opportunities and demand elasticities - would do justice to the complexities of the compensation question.

In this contribution, we fall short of such a very ambitious task. However, we present a model that accounts at least for some of the critical processes discussed above. In particular, a sectoral/partial disequilibrium perspective is put forward. The model has two main constituents. First, the production of new knowledge - by means of R&D activities - which eventually results into **new machines/products** produced by an upstream sector, and - second - the effects of **new investments** (split between expansionary and replacement ones), embodying the foregoing technological advancement and affecting the a downstream sector. In so doing, we are able to account for the different labour creating/labour displacing effects of technological change and to separately account for the different impacts attributable to the *production* (product innovation) *vs* the *adoption* (process innovation) of new technologies.

3. The model

The illustrative model which follows is a novel product/sector level adaptation, focusing on employment evolution, of the micro-to-macro-evolutionary model put forward by Dosi, Fagiolo, and Roventini (2010). The model describes a two-sector economy, wherein the upstream sector produces new machinery - for instance robots - and equipment (product-innovation) while the downstream sector is the adopter of the machines themselves (process-innovation). The vertical structure of the model directly highlights, 1) the labour friendly nature of product innovation in the upstream sector (that is the " new products" mechanism, see above; 2) the labour-saving nature of process innovation in the downstream sector; and 3) the role of the "new machines" mechanism captured by the increasing production of machines in the upstream sector. The model structure is summarised in the following Figure 1.

Figure 1: the model in a nutshell



3.1 The upstream sector

The sector produces a fixed bundle of Q products/machines which improve over time, defined as $q_t \in [1, \dots, Q]$. Each product q embodies a level of efficiency A_q which evolves according to a multiplicative stochastic process. The possibility of product improvements is affected by the sectoral level expenses in $R\&D$: the higher the $R\&D$ expenses, the higher will be the probability to have access to machine improvements:

$$A_{q,t+1} = (1 - e^{-\gamma R\&D_{1,t}})_q \left[A_{q,t}\left(1 + x_{q,t}^A\right)\right] \tag{1}$$

The first factor defines the "sectoral level of the lake" from which extracting product improvements, represented by multiple draws for each product q, accordingly to an exponential distribution. The second factor defines the intensity of the jump that each product does in terms of improvements, given by $x_{q,t}^A$, a random draw from a Beta distribution. The latter process entails that products are differentiated in terms of the degrees of innovativeness and thus efficiency they embody. The average level of productivity of the machines produced by the sector is defined as:

$$A_{1,t} = 1/q_t \sum A_{q,t} \quad (2)$$

The process of improvement of products is financed by $R\&D$ activity which is in turn affected by past product sales.[7] In particular, $R\&D$ reads as:

$$RD_{1,t} = \nu S_{1,t-1} \quad (3)$$

Sales are given by the sum of the expansionary and replacement investments which occur in the downstream sector.

$R\&D$ activity is performed by dedicated workers, whose demand reads as:

$$L_{1,t}^{R\&D} = \frac{\nu S_{1,t-1}}{w_{1,t}} \quad (4)$$

where w_1 refers to the exogenous sectoral wage level. In terms of what put forward in Section 2, eq. 4 introduces the mechanism "via decreasing wages" into the dynamics of the model.

Labour demand for production workers instead depends positively on the demand for machines and negatively on productivity:

$$L_{1,t}^{Q} = \frac{Q_{1,t}}{B_{1,t}} \quad (5)$$

where $B_{1,t}$ is defined as the productivity in producing machines at the sectoral level which evolves according to the same stochastic process defined in eq. 1 and 2. We conjecture that the expected realisation of the draw in $B_{1,t}$is higher than the one in $A_{1,t}$ (see Soete and Dosi, 1983). $Q_{1,t}$ is the overall bundle of machines ordered by sector 2.

The final labour demand is therefore the sum of $R\&D$ and production workers:

$$L_{1,t} = L_{1,t}^{R\&D} + L_{1,t}^{Q} \quad (6)$$

Given the monetary wage $w_{1,t}$, the unit cost of production in the up-stream sector is defined as:

$$c_{1,t} = \frac{w_{1,t}}{B_{1,t}} \quad (7)$$

With a fixed mark-up μ_1 pricing rule, the price $p_{1,t}$ is defined as:

$$p_{1,t} = (1 + \mu_1) c_{1,t} \quad (8)$$

In a nutshell, the dynamics of employment in the upstream aggregate is driven by the following chain of events:

[7] This is consistent with the "demand-pull" approach originally proposed by Schmookler (1962 and 1966) and empirically supported by various studies within the economics of innovation literature (see Scherer, 1982; Kleinknecht and Verspagen, 1990; Piva and Vivarelli, 2007).

$$\uparrow \Delta S_1 \Rightarrow \uparrow \Delta R\&D_1 \Rightarrow \uparrow \Delta L_1$$

$$\uparrow \Delta S_1 \Rightarrow \uparrow \Delta L_1^Q$$

Empirically, what described so far leads to the following predictions:

Implication 1: Disembodied technical change via R&D expenditures is expected to have a positive impact on employment growth.

Implication 2: In addition to R&D expenditures, employment in the upstream sector depends positively on output.

3.2 The downstream sector

The sectoral productive capacity of the downstream aggregate is given by the weighted average of the machine-level productivity generated by the upstream sector multiplied by the number of installed machines, implying that *the sequence of product innovations of sector 1 shapes process innovation of sector 2*:

$$K_{2,t} = \sum_q \sum_{k=t-\tau}^{t} A_{q,k}\, q_k \tag{9}$$

where $t - \tau$ is the oldest generation of vintages in use. The downstream sector does not undertake R&D, but it performs both *expansionary* and *replacement* investments. This is a way to take on board the compensation mechanism "via new investments" (accounting also for the critical issues discussed in Section 2). Analytically, if the desired capital stock K_2^d - computed as a function of the desired level of production $Q_{2,t}^d$ - is higher than the current capital stock, the sector invests $EI_{2,t}^d$ in order to expand its production capacity:

$$EI_{2,t}^d = K_{2,t}^d - K_{2,t} \tag{10}$$

In the downstream sector, the total desired labour demand $L_{2,t}^d$ in period t is determined by the ratio between the desired production $Q_{2,t}^d$, assumed to be formed via to adaptive expectations, and the average productivity of its current capital stock $K_{2,t}$:

$$L_{2,t}^d = \frac{Q_{2,t}^d}{K_{2,t}} \tag{11}$$

Scrapping $SI_{2,t}^d$ of a piece of equipment of vintage $t - \tau$ in favour of a new one of price $p_{1,t}$ occurs if:

$$p_{1,t} < \delta w_{2,t}\left(1/A_{q,t-\tau} - 1/A_{q,t}\right) \quad (12)$$

where $w_{2,t}$ is the current wage in Sector 2, $A_{q,t-\tau}$ is the productivity associated with vintage $t-\tau$ and $A_{q,\tau}$ is the one associated with current one, and δ is the payback period. Basically, this expression means that if cost savings stemming from scrapping will pay back the cost of the new equipment in less than δ periods, replacement will take place.[8] As far as the compensation mechanisms are concerned (see Section 2), Eq. 12 takes into account both the compensation "via decreasing prices" in sector 1 and a seemingly compensation "via decreasing wages" in sector 2.

Note that wages, although indirectly, exert an effect on labour demand as they impact on unit labour costs and indirectly on the scrapping decisions. At a first glance this looks like the compensation mechanism "via decrease in wages" discussed in Section 2; however, some qualifications are necessary in this respect. In fact, the model accounts for what erroneously, in a static framework, could be interpreted as a phenomenon of sheer substitution or of induced technical change along some meta-production function, whereby higher labour costs induce labour-saving movements along the production function itself (see the critical discussion put forward in Section 2). Indeed, in this model the possible statistical effects of wages upon replacement investments might just reveal accelerated/decelerated scrapping patterns. In order to see that, let us just rewrite the scrapping rule in terms of the dynamics of unit labour costs:

$$p_{1,t} < \delta w_{2,t-\tau}\left(1+g_{w,2}\right)^{(t-\tau)}\left[1/A_{q,t-\tau} - 1/A_{q,t}\right] \quad (13)$$

The expression in the square bracket, for our purpose, can be considered exogenous to sector 2 and just dependent on the dynamics of (exploited) opportunities in sector 1, and δ depends on institutional factors basically influencing the "short-sightedness" or patience of investors. Thus, the value of τ depends on the wage dynamics, $g_{w,2}$. In both sectors wages are determined by macroeconomic mechanisms which are exogenous to our partial disequilibrium model.

Total investment in buying new products is therefore:

$$I^{tot} = EI_{2,t} + SI_{2,t} \quad (14)$$

In the downstream sector, the dynamics of employment is therefore driven by the following chain of events:

$$\uparrow \Delta Q_2 \Rightarrow \uparrow \Delta EI_2 \Rightarrow \uparrow \Delta L_2$$

$$\uparrow \Delta A_1 \Rightarrow \uparrow \Delta SI_2 \Rightarrow \downarrow \Delta L_2$$

[8] Note that the foregoing assumption of machines produced by labour only is a simplifying one. Indeed, machines are produced also by means of machines, entailing (in principle) an underlying scrapping rule also in the upstream sector.

Empirically, the presented dynamics within the downstream aggregate leads to the following predictions.

Implication 3: Expansionary investments are expected to have a positive impact on employment growth.

Implication 4: Replacement investments are expected to have a negative impact on employment growth.

Implication 5: The net effect of embodied technical change on employment growth is a priori undetermined, and does not depend only on the nature of technical change as such but also on the general macroeconomic conditions with regard to aggregate demand, wage formation and the business climate affecting the investment decisions. In more detail, beyond investments, employment in the downstream sector depends positively on output and negatively on (sectoral) wages in so far as their growth accelerates the scrapping of older machines.

4. Empirical patterns

The five implications outlined above will be tested using sectoral STAN OECD and ANBERD OECD data covering 19 European countries over the period 1998-2016, as detailed in Table A1 of the Appendix.

Consistently with the model outlined above, a key preliminary issue is to characterise the upstream sectoral aggregate and its downstream counterpart. With this purpose in mind, we follow a refined Pavitt (1984) taxonomy, as in Bogliacino and Pianta (2010). In particular, we include in the upstream aggregate the "Science-based" and "Specialised Suppliers" sectors, which perform a large share of the total manufacturing R&D and tend to produce new products, including the overwhelming share of new generations of industrial equipment. These new equipment and machinery in turn are adopted by the downstream sector. The latter includes the "Scale and information intensive" and the "Supplier dominated" industries whose innovative activity crucially involves the adoption of embodied technological change. This sectoral classification is presented in Table A2.

The empirical specification will make use of the following variables from the STAN OECD database: employees, value added, labour costs, investments. In order to split the two components of investments highlighted by the proposed model, we rely on the following accounting strategy.

Whenever investments, proxied by Gross Fixed Capital Formation (GFCF),[9] are larger than the Consumption of Fixed Capital (CFCC), we assume that GFCF - *in primis* - replaces the deteriorated physical capital (CFCC). Therefore the CFCC amount represents the *replacement* component. The extra investment given by (GFCF – CFCC) represents the *expansionary* component.[10] Finally, from the ANBERD OECD dataset we extract the R&D (Business Enterprise R&D Expenditures) measure. Table A3 in the Appendix provides some descriptive statistics.

Let us start with a preliminary analysis of the simple correlations between employment growth and output growth disaggregated by upstream and downstream aggregates and by single sectors (Table 1). The relation is basically the complement in terms of employment of the "Verdoorn-Kaldor law" on the link between productivity growth and output growth, revealing widespread increasing returns (Kaldor, 1966). For similar estimates see Sylos Labini, 1984.

INSERT TABLE 1

Basically, the estimated correlations corroborate (or at the very least they do not contradict) a fundamental Keynesian proposition in the relation between labour demand and rates of economic activity. In fact, the relation between growth in value added and growth of employment turns out to be overall positive, albeit significant particularly in those downstream sectors of activity characterised by economies of scale. However, such estimates blackbox together Keynesian mechanisms of demand formation with technology-related processes of job-creation and job-destruction: in the following we shall precisely try to disentangle those different factors, testing the empirical implications of the model discussed in the previous section.

The estimated empirical specifications of employment (l) determinants read as:

$$l_{i,t} = \alpha l_{i,t-1} + \beta_1 y_{i,t} + \beta_2 w_{i,t} + \beta_3 R \wedge D_{i,t-1} + (\varepsilon_i + \nu_{i,t}) \qquad (15)$$

i = 1, … 177; t = 1998…2016

$$l_{i,t} = \alpha l_{i,t-1} + \beta_1 y_{i,t} + \beta_2 w_{i,t} + \beta_3 \mathrm{EI}_{i,t-1} + \beta_4 SI_{i,t-1} + (\varepsilon_i + \nu_{i,t}) \qquad (16)$$

i = 1, … 297; t = 1998…2016

[9] GFCF is defined as the acquisition (including purchases of new or second-hand assets) and creation of assets by producers for their own use, minus disposals of produced fixed assets. CFCC is the decline, during the course of the accounting period, in the current value of the stock of fixed assets owned and used by a producer as a result of physical deterioration, normal obsolescence or normal accidental damage. In both cases, data are compiled according to the 2008 System of National Accounts.

[10] Note that the OECD variable CFCC might not only capture the actual economic obsolescence of the machines inside the sector, but rather might be inflated by accounting principles/strategies and by legislations and tax procedures which favour super-depreciation. When CFCC resulted to be higher than GFCF, we set expansionary investments equal to 0 to avoid unreliable negative values.

As common in the literature (see Van Reenen, 1997; Lachenmaier and Rottmann, 2011; Bogliacino, Piva and Vivarelli, 2012) specifications (15) and (16) can be seen as dynamic labour demands augmented by proxies of disembodied (*R&D*) and embodied technological change (expansionary investments, *EI*, and scrapping, *SI*). In more detail, the inclusion of the lagged dependent variable ($l_{i,t-1}$) takes into account the viscosity and path-dependent nature of labour demand and the stickiness in hiring and firing procedures.[11] Value added (y) is capturing the revealed Keynesian correlation between output and employment (see above) and also relates to the compensation mechanism "via decrease in prices" discussed in Section 2. The cost of labour per employee (w)[12] is an important component of the demand for labour although not at all related with the interpretation of the neoclassical compensation mechanism "via decrease in wages", assuming some movements along industry level isoquants, but rather to the specific scrapping dynamics embedded in our model (see eq. 12). R&D expenditures represent the driver of the compensation mechanism "via new products", that in our model is working only in the upstream sectors supplying innovative equipment and machinery to the downstream ones. As far as the latter are concerned, embodied technological change occurs through both expansionary (*EI*) and replacing investment (scrapping *SI*), with the expectation of a positive estimated coefficient in the former case (compensation "via new investment") and a negative one in the latter (process innovation embodied in new capital vintages substituting less efficient ones). As common in the literature, the three technological variables are lagged since innovation may take some time to display its employment impact. Finally, ε is the idiosyncratic individual and time-invariant firm's fixed effect and ν the usual error term.

Specification (15) and (16) will be tested through three different methodologies, namely: Pooled Ordinary Least Squares (POLS) controlled for time effects; Fixed Effects (FE), in order to take into account country/sector unobservables; and Least Squares Dummy Variables Corrected (LSDVC), in order to deal with the endogeneity of the lagged dependent variable (see Kiviet, 1995; Judson and Owen, 1999; Bun and Kiviet, 2003).[13] Since all the variables are expressed in log, the estimated coefficients can be interpreted as elasticities.

[11] Indeed, the demand for labour is the standard domain of application of dynamic econometric methodologies such as GMM-DIF, GMM-SYS and the LSDVC estimator; see Arellano and Bond, 1991; Blundell and Bond, 1998; Kiviet, 1995).

[12] At the firm level, this is a better proxy of a company (dis)incentive rather than the sole wage component of the cost of labour.

[13] The LSDVC methodology is initialised by a dynamic panel estimate (in our case GMM-DIF) and then relies on a recursive correction of the bias of the FE estimator. Bruno (2005a and 2005b) extended the LSDVC methodology to unbalanced panels, such as that used in this study. By running Monte Carlo experiments, the author proved that the LSDVC estimator is to be preferred to the original LSDV estimator and both GMM-DIF and GMM-SYS estimators when the number of cross sectional observations is small (in our case n=474, then split into 177 upstream and 297

The results under alternative specifications are reported in Table 2 for the upstream and for the downstream aggregate.

INSERT TABLE 2

Let us discuss first the controls and then the variables related to technological change. First of all, the lagged employment is highly significant in all the six different estimates, with a magnitude ranging from 0.974 (POLS estimates tend to exaggerate the impact of the lagged dependent variable) to 0.673 (in contrast, FE tends to understate the estimate of the lagged dependent variable). Our LSDVC coefficients lay in between these two lower and upper boundaries in both the upstream and downstream case and this is reassuring about our methodological choice. Overall - and not surprising - labour demand is confirmed to be very persistent and autoregressive.

Consistently with the preliminary correlations displayed in Table 1, a positive and highly significant impact of value added is detected. However, it is interesting to notice that in our fully-fledged estimates the coefficients for the upstream sectors - once we control for the unobservable fixed effects through the FE and LSDVC estimates - turn out to be higher than those for the downstream ones. In other words, the employment/output elasticity results higher in the upstream aggregate, mainly characterised by R&D investments and product innovation, and lower in the downstream sectors, instead predominantly affected by embodied technological change and process innovation. This seems in line with what discussed in Section 2 and consistent with the model presented in Section 3: indeed, the different nature of technological change (labour-friendly *vs* labour-saving) in the two sectoral aggregates qualifies the Keynes-Kaldor link between output and employment which actually turns out to be possibly stronger in the upstream sectors.

The cost of labour per employee turns out to negatively affect the employment dynamics in all the six proposed estimations. According to our model (eq.12) this evidence - rather than supporting a potential substitutability of labour in favour of capital facing changes in the relative input prices - should be interpreted as a drive to labour shedding fuelled by a faster adoption of more efficient vintages of machines.

According to our interpretative framework (Sections 2 and 3), we expect a positive impact of disembodied technical change (R&D) on employment dynamics in the upstream sector, and in the downstream sector a positive impact of expansionary investment (EI) and a negative impact of replacing investment (SI).

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downstream) and the panel is severely unbalanced (in our case we deal with 5,116 available observations out of 9,006 potential ones). Since both conditions are verified in our dataset, we adopted Bruno's (2005a) estimator.

Indeed, according to our estimates, the role of disembodied technical change is unequivocally positive, so supporting the labour-friendly nature of new technologies in the upstream sector. However, the estimated employment elasticities are not too big, ranging from 0.3% to 1%, confirm previous evidence about a positive and significant, but rather small employment impact of R&D expenditures and product innovations (see Bogliacino, Piva and Vivarelli, 2012; Van Roy, Vertesy and Vivarelli, 2018; Barbieri, Piva and Vivarelli, 2019).

Accounting for the separate role of expansionary and replacement investment, we are able to identify a positive and very significant impact of the additional adoption of new machinery in the downstream sector, with a revealed elasticity of about 0.4%. On the other hand, in all the three estimates, replacement investment tends to exhibit a negative employment impact of about the same order of magnitude. However, the coefficient turns out to be (highly) significant only in the POLS estimates, while not significant at all in the other two. On the whole, our results strongly support the labour-friendly nature of the expansionary investment (albeit, again, the estimated elasticities are quite low), while the possible labour-saving impact of technological change embodied in scrapping is statistically less supported.

Summing up, the model predictions 1, 2, 3 and 5 are corroborated by our econometric estimates, while prediction 4 is only weakly supported.

5. Conclusions

This paper discusses the complex nexus existing between technological change and employment dynamics. In particular, we try to account for the distinct dynamics of an upstream and a downstream sectoral aggregate. Each aggregate is characterised by a different dynamics of technological change, which is assumed to be disembodied (R&D) in the upstream and embodied in the downstream sectors. In so doing, we are able to explore both the direct labour-saving impact of technological change (process innovation in the downstream sectors) and different counterbalancing labour-friendly effects (product innovations and different compensation mechanisms).

In line with our foregoing model implications, increasing value added involves increasing employment, but this link appears to be more robust in the upstream sectors where R&D investment and product innovation reinforces the employment/output elasticity.

Cost of labour turns out to negatively affect the demand for labour both in the upstream and the downstream sectors. However, contrary to the conventional wisdom, this evidence should be interpreted as a tendency towards labour-shedding driven by faster adoption of more efficient vintages of machinery.

Turning the attention to our main research questions, disembodied technical change (R&D) positively affects employment dynamics in the upstream sector, likewise expansionary embodied technical change in the downstream one. Finally, replacement of machines (scrapping) exerts a negative impact on labour demand, although this effect turns out to be statistically different according to the estimation techniques.

Table 1: employment growth / output (VA) growth correlations

UPSTREAM = 0.031		DOWNSTREAM = 0.038	
Manufacture of chemicals and chemical products (20)	0.030	Manufacture of food products (10)	-0.101
Manufacture of basic pharmaceutical products and pharmaceutical prep. (21)	0.021	Manufacture of beverages (11)	0.246*
Manufacture of computer, electronic and optical products (26)	0.105	Manufacture of tobacco products (12)	-0.232
Manufacture of electrical equipment (27)	0.040	Manufacture of textiles (13)	-0.334**
Manufacture of machinery and equipment n.e.c. (28)	0.029	Manufacture of wearing apparel (14)	0.060
Manufacture of other transport equipment (30)	-0.016	Manufacture of leather and related products (15)	0.210
Repair and installation of machinery and equipment (33)	0.084	Manufacture of wood and of products of wood and cork, except furniture (16)	0.371***
Telecommunications (61)	0.026	Manufacture of paper and paper products (17)	0.101
Computer programming, consultancy and related activities (62)	0.014	Printing and reproduction of recorded media (18)	0.208**
Real estate activities (68)	0.035	Manufacture of coke and refined petroleum products (19)	-0.028
Scientific research and development (72)	-0.001	Manufacture of rubber and plastic products (22)	0.283***
		Manufacture of other non-metallic mineral products (23)	0.495***
		Manufacture of basic metals (24)	0.175**
		Manufacture of fabricated metal products, except machinery and equipment (25)	0.676***
		Manufacture of motor vehicles, trailers and semi-trailers (29)	0.542***
		Manufacture of furniture + Other manufacturing (31-32)	0.247***
		Wholesale and retail trade, repair of motor vehicles and motorcycles (45)	0.349***
		Wholesale trade, except motor vehicles and motorcycles (46)	0.228***
		Retail trade, except motor vehicles and motorcycles (47)	0.226***
		Land transport and transport via pipelines (49)	0.161**
		Water transport (50)	-0.003
		Air transport (51)	0.140
		Warehousing and support activities for transportation (52)	0.450***
		Postal and courier activities (53)	0.398***
		Accommodation and food service activities (55-56)	0.247***
		Publishing activities (58)	0.352***
		Information service activities (63)	0.540***
		Financial service activities, except insurance and pension funding (64)	-0.239**
		Insurance, reinsurance and pension funding (65)	-0.056***
		Activities auxiliary to financial services and insurance activities (66)	0.396***
		Veterinary activities (75)	0.193
		Employment activities (78)	0.915***
		Travel agency, tour operator reservation services and related activities (79)	0.241***

Table 2: Dependent variable: Log(Employees)

	UPSTREAM			DOWNSTREAM		
	POLS	FE	LSDVC	POLS	FE	LSDVC
$Log(Employees)_{-1}$	0.974*** (0.004)	0.673*** (0.038)	0.734*** (0.018)	0.967*** (0.007)	0.796*** (0.052)	0.839*** (0.010)
Log(Value Added)	0.021*** (0.004)	0.192*** (0.026)	0.171*** (0.009)	0.047*** (0.007)	0.104*** (0.024)	0.092*** (0.006)
Log(Cost of labour per Employee)	-0.034*** (0.007)	-0.205*** (0.028)	-0.184*** (0.012)	-0.310*** (0.007)	-0.095*** (0.028)	-0.075*** (0.018)
$Log(R\&D)_{-1}$	0.003* (0.002)	0.010** (0.005)	0.008** (0.004)			
$Log(Consumption\ of\ Fixed\ Capital)_{-1}$				-0.018*** (0.002)	-0.003 (0.010)	-0.004 (0.004)
$Log(Expansionary\ Investments)_{-1}$				0.003*** (0.000)	0.004*** (0.001)	0.004*** (0.001)
Constant	0.038 (0.023)	0.408*** (0.098)		-0.004 (0.014)	0.324** (0.135)	
Wald time-dummies (p-value)	5.7*** (0.000)	4.5*** (0.000)	222.1*** (0.000)	12.7*** (0.000)	11.3*** (0.000)	275.5*** (0.000)
R^2 (overall)	0.99			0.99		
R^2 (within)		0.82			0.89	
Obs.	1,767			3,349		
N. of sectors	177			297		

Notes:
- Robust standard errors in brackets; * significance at 10%, ** 5%, *** 1 %.
- For time-dummies, Wald tests of joint significance are reported.

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APPENDIX

Table A1: Distribution of observations across countries

COUNTRY	SECTORS	OBSERVATIONS
AUSTRIA	41	525
BELGIUM	36	460
CZECH REPUBLIC	13	163
DENMARK	13	34
ESTONIA	14	32
FINLAND	13	409
FRANCE	13	72
GERMANY	35	488
HUNGARY	11	96
ITALY	36	503
NORWAY	13	132
POLAND	29	191
PORTUGAL	35	460
SLOVAKIA	41	492
SLOVENIA	38	531
SPAIN	13	124
SWEDEN	10	35
THE NETHERLANDS	40	174
UNITED KINGDOM	30	195
TOTAL	***474***	***5,116***

Table A2: Sectoral classification

UPSTREAM SECTORAL AGGREGATE: **Science-Based and Specialised Suppliers**	**2-digit NACE classification**
- Manufacture of chemicals and chemical products	20
- Manufacture of basic pharmaceutical products and pharmaceutical prep.	21
- Manufacture of computer, electronic and optical products	26
- Manufacture of electrical equipment	27
- Manufacture of machinery and equipment n.e.c.	28
- Manufacture of other transport equipment	30
- Repair and installation of machinery and equipment	33
- Telecommunications	61
- Computer programming, consultancy and related activities	62
- Real estate activities	68
- Scientific research and development	72
DOWNSTREAM SECTORAL AGGREGATE: **Scale and Information Intensive and Suppliers Dominated**	
- Manufacture of food products	10
- Manufacture of beverages	11
- Manufacture of tobacco products	12
- Manufacture of textiles	13
- Manufacture of wearing apparel	14
- Manufacture of leather and related products	15
- Manufacture of wood and of products of wood and cork, except furniture	16
- Manufacture of paper and paper products	17
- Printing and reproduction of recorded media	18
- Manufacture of coke and refined petroleum products	19
- Manufacture of rubber and plastic products	22

- Manufacture of other non-metallic mineral products	23
- Manufacture of basic metals	24
- Manufacture of fabricated metal products, except machinery and equipment	25
- Manufacture of motor vehicles, trailers and semi-trailers	29
- Manufacture of furniture + Other manufacturing	31-32
- Wholesale and retail trade, repair of motor vehicles and motorcycles	45
- Wholesale trade, except motor vehicles and motorcycles	46
- Retail trade, except motor vehicles and motorcycles	47
- Land transport and transport via pipelines	49
- Water transport	50
- Air transport	51
- Warehousing and support activities for transportation	52
- Postal and courier activities	53
- Accommodation and food service activities	55-56
- Publishing activities	58
- Information service activities	63
- Financial service activities, except insurance and pension funding	64
- Insurance, reinsurance and pension funding	65
- Activities auxiliary to financial services and insurance activities	66
- Veterinary activities	75
- Employment activities	78
- Travel agency, tour operator reservation services and related activities	79

Table A3: Descriptive statistics

		Employees	Value Added	Cost of Labour per Employee	R&D	Consumption of Fixed Capital	Expansionary Investments
UP	Mean	81.00	9,422.68	58.00	688.34		
	St.dev.	135.90	19,508.01	41.51	1,271.22		
DOWN	Mean	184.04	14,275.35	43.93		1,948.61	1,289.75
	St.dev.	397.61	53,491.72	41.08		9,239.55	6,452.03

Note:
- While the Employees are expressed in thousands of persons engaged, the monetary variables are expressed in millions (thousands in the case of Cost of labour per employee) of constant PPP 2010 US dollars.

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