University of Cambridge

MANUFACTURING DEVELOPMENT
Structural Change and Production Capabilities Dynamics

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This dissertation is submitted for the degree of Doctor of Philosophy

DECLARATION

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text.

This dissertation does not exceed the word limit for the Degree Committee of Human, Social and Political Sciences.

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Abstract

Over the last three decades the political economy debate abandoned its focus on manufacturing as the main engine of the technological dynamism and the source of the wealth of nations. However recent years have witnessed a renewed interest in manufacturing production. This has led analysts to announce and welcome a worldwide 'manufacturing renaissance' emerging in different contexts with multiple focuses. The thesis provides new analytical and empirical lenses for disentangling the dynamics of manufacturing development. We do this by showing how learning processes are the fundamental category responsible for production capabilities dynamics which in turn trigger structural change.

Essay 1 '**The Manufacturing Renaissance: Transforming Industrial Systems and the Wealth of Nations**' presents a novel synthesis of two strands of economic research, *Structural Economic Dynamics* and the *Economics of Capabilities*. Within this framework we integrate structural change and production capabilities dynamics. The following Essays of this dissertation apply and extend this theoretical synthesis by focusing firstly on learning in production structures and cumulative (non-linear) structural change dynamics (Essays 2 and 3 respectively); secondly, in developing new diagnostics for industrial policies design (Essay 4); finally, in investigating industrial policies for manufacturing development (Essay 5).

Essay 2 '**Structural Learning: Embedding discoveries and the dynamics of production'** extends the current framework by rembedding learning dynamics from which production capabilities are generated in the production structure itself.

Essay 3 '**Manufacturing Agrarian Change. Agricultural production, intermediate institutions and Intersectoral commons: Lessons from Latin America'** than applies the concept of structural learning developed in Essay 2 to the intersectoral interdependencies on the interface of agriculture and manufacturing. Moreover, we show how in the context of Chile and Brazil intersectoral learning from which intersectoral commons derive was facilitated by the development of intermediate institutions.

Essay 4 '**Production Capability Indicators. Mapping countries' structural trajectories and the assessment of industrial skills in LDCs: The case of Tanzania**' addresses the problem of capturing these learning dynamics through production capabilities indicators at the national level. Not only do we propose a new theoretically-sensitive methodology for quantifying learning dynamics but also we apply this to industrial skills assessment in Tanzania.

Finally, Essay 5 '**Industrial Policy for Manufacturing Development. Structural dynamics and institutional changes in a dual economy: A case of dependent industrialisation in the Italian Mezzogiorno**' focuses on the development of industrial policies, the latter understood as mechanisms to trigger learning dynamics at the sectoral and intersectoral level. The Italian 'Mezzogiorno' case is presented to illustrate these dynamics in a context of dependent industrialisation.

Acknowledgments

This dissertation is the result of a research project I conducted as a doctoral candidate at the University of Cambridge and, as a visiting researcher, at the United Nations Industrial Development Organisation (Vienna Headquarters) and at the Vienna Institute for International Economic Studies (wiiw).

In writing the dissertation I owe my biggest debt to my supervisor Ha-Joon Chang. He taught me a fresh perspective on economic problems, cultivating a sound intellectual skepticism for all those theories and empirical studies that overlook historical, political and institutional factors. He was always willing to listen to my ideas and to read my work with openness and intellectual curiosity. Most of all, he transmitted the importance of approaching economic problems with a good dose of pessimism of the intellect and optimism of the will.

Two other people have been extremely important in my intellectual development. Roberto Scazzieri, my mentor and former supervisor at the University of Bologna, has been invaluable in shaping and supporting my intellectual journey over the last ten years. He introduced me to structural economics and theories of production and has always been willing to discuss closely the evolution of my ideas. He read the dissertation and provided enlightening comments and key references. Most of all, he has provided me with much more moral support than I deserve.

Michael Landesmann was my main supervisor during the very prolific visiting research period in Vienna. He taught me to combine intellectual curiosity and analytical rigour as well as the importance of balancing theory with evidence. He read three essays and helped in untangling complex analytical issues. Without his kindness and generous support the visiting research period in Vienna would have not been so productive or pleasant.

I also want to thank Eoin O'Sullivan and Carlos Lopez-Gomez at the Institute for Manufacturing, University of Cambridge. Their generous friendship and willingness to share and discuss ideas have been very important, especially in the last year of my PhD. Manuel Albaladejo, Ludovico Alcorta, Michele Clara and Philipp Neuerburg at UNIDO have also read some of my essays and provided me with insightful comments. Finally, I am grateful for feedback I received at the conferences I attended in Cambridge, Manchester, Bologna, Pisa, Vienna, Jena, Bratislava and Copenhagen. In particular, I want to thank Alberto Quadrio Curzio, Guido Buenstorf, Prue Kerr and Andrew Stirling for their suggestions and enlightening comments to my work.

My friend Hassan Akram has been a long-time intellectual and emotional companion. Without him my PhD would have been a lonely trip. Not only did he help me in refining my work, he also provided superb editorial advice and revisions. Despite the distance, Monica Andreoni and Emilio Corsaro provided me with a lot of love. Finally I wish to thank my parents for having been on my side despite everything. This work is dedicated to them.

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Introduction

A Research Journey in Manufacturing Development

The collection of essays which constitute this PhD dissertation came out of a research journey that started at the University of Cambridge. What originally inspired the work was the desire to rethink the political economy of development from the point of view of production.

Production, its dynamics and structural transformations, was at the very core of the classical political economy and remained the main focus of attention for those economists engaged in designing policies for manufacturing development. This special attention became the hallmark of studies of the specific form of 'manufacturing production' that developed after the first industrial revolution.

The importance of this form comes not simply from its role in the transformation of scarce resources or manufacture of goods for consumption but, more centrally, in its position as the contested domain where social, institutional, economic and technical *transformations* originate. Thus my work originally set out to disentangle the complex system of interdependences linking the social, institutional, economic and technical dimensions. Crucially my analytical efforts were specifically concentrated on understanding what economics was able to reveal about the internal architecture and dynamics of production.

Discovering that, with very few exceptions, economists are unable to understand production *from within* and that manufacturing production remain a black box for most, convinced me of the need to develop new analytical lenses. Most importantly it made me realise the necessity of drawing from other disciplines, in particular operations management and engineering studies.

The final aim of this process was to identify new categories and heuristics capable of assisting in the construction of policies for manufacturing development (i.e. industrial policies). The methodological approach I adopted in opening up the production black box was mainly inspired by the idea that production structures are continuously transformed by 'learning in production'. However, instead of thinking of learning as a behavioural or cognitive process, I reconceptualised the idea of learning as a process in which production structures prepare human minds for intuition, learning and innovation. The possibility of thinking about structures as constraints but also as opportunities through which structural learning trajectories were activated resulted from a comparative historical analysis of technological changes in production.

The application of the newly developed analytical framework to the intersectoral context allowed the research to move across different production units and levels of aggregation as well as to encounter multiple forms of interdependence among production activities. At this point I realised that, in a conventional economic framework, sectoral interdependences are seen as unidirectional, as if linkages unfold just in one direction, (e.g. the structural change from agriculture to manufacturing and services). However, by scrutinising the historical patterns of structural change I realised how sectoral interdependences were much more complex and that, in fact, very often sectors develop in a symbiotic manner.

Starting from this new different perspective I was able to reinvestigate the possibility of manufacturing agrarian change, that is, upgrading agricultural production through an industry-led process of transformation, in the specific context of Chile and Brazil assisted by a number of interviews and detailed analysis of archives and reports. These two case studies and other historical evidence convinced me of the importance of looking at interfaces across sectors (also between manufacturing and services) and at those intermediate institutions where intersectoral commons (e.g. specific bundles of technological capabilities) develop.

One of the fundamental challenges that the empirical analysis posed to me was the problem of measuring endowments of production and technological capabilities and tracking their accumulation (or decumulation). Thus, the third step in my research journey was mainly concentrated on developing production capability diagnostics, in particular tools capable of assessing the existence of skills gaps and mismatches. In the contexts of Chile and Brazil, with a highly skewed distribution of skills and a more balanced distribution of medium skills respectively, I focused on understanding the functioning of intermediate institutions. In contrast my new battery of diagnostics for skills assessment was piloted in the context of Tanzania. Given its lower stage of manufacturing development, the identification of skills gap and mismatches becomes much more important here.

At this point of my research journey, I attempted to apply the new analytics and empirics developed to the specific contexts of manufacturing development, the latter understood both as a specific domain of analysis but also as a space for normative investigation. The current manufacturing renaissance opened a window for reconsidering the debate on the importance of manufacturing in the development process and the possibility of implementing specific industrial policy measures for orienting countries structural trajectories. The structural economic analysis of different manufacturing development countries' trajectories revealed the need to investigate the continuous unfolding of structural tensions, institutional bottlenecks and new forms of dualisms. The Italian Mezzogiorno case was the main 'laboratory' where these analyses were tested and the industrial policies were reconsidered as selective measures aligned over time and aimed at addressing structural tensions, institutional bottlenecks and dualisms.

This collection of essays have shown how rethinking the political economy of development from the point of view of production (specifically manufacturing), expands the space of industrial policies and opens up new scenarios for manufacturing development. However, opening the black box of production has also made me aware of the need for an *engineering economic twist* whereby different production units, capabilities and technologies (in particular enabling infrastructural technologies) are understood in a systemic fashion. In fact, being able to produce something is always the result of a complex interlocked bundle of capabilities embedded in a certain institutional environments. The introduction of this *engineering economic twist* leads a rethinking of industrial policy taxonomies (and, thus, evaluation frameworks) as well as expanding the scope and refining the empirical lenses of foresight exercises.

First Essay

THE MANUFACTURING RENAISSANCE

Transforming Industrial Systems and the Wealth of Nations

Introduction

Over the last three decades, the political economy debate abandoned its focus on manufacturing as the main engine of the technological dynamism and the source of the wealth of nations. However, recent years have witnessed a renewed interest for manufacturing production. This has led analysts to announce and welcome a worldwide 'manufacturing renaissance' emerging in different contexts with multiple focuses, observable in many white papers and scientific research re-examining the importance of manufacturing since 2008. Deindustrialisation, loss of strategic manufacturing industries, increasing trade imbalances, decreasing technological dynamism and industrial competitiveness have been major concerns in advanced economies. Meanwhile in many developing countries governments have begun to question the sustainability of a development model overly focused on natural resource extraction. Other governments, particularly of middle income countries, have been worried about emerging giants capturing global market share to the exclusion of smaller players and dominating the global technological race.

In developed countries, the 'financial freefall' of 2008-2009 further fuelled governments' concern about the overall impact on their economies of an increasingly rapid process of de-industrialisation. Indeed, since the start of the crisis there has been a substantial loss of jobs and redistribution of manufacturing production globally, with overwhelming effects on social welfare. Even middle-income countries in the catch-up phase have witnessed a relative deceleration of their economies as a result of the contraction in global demand. In this conjuncture many governments had to step in to rescue distressed manufacturing firms and to protect national champions, as well as to expand the money supply to counterbalance the credit crunch. The restructuring of the automotive industry and the subsequent efforts by various governments aimed at keeping production at home are striking examples of this renewed scope for public action.

This renewed interest in, and concern for, manufacturing production offers an opportunity for a profound reconsideration of what I call the *pro-service vision*, epitomised by Margaret Thatcher's famous slogan 'we can live on services'. According to this vision, the manufacturing activity is destined to lose relevance as economies develop. Moreover, according to this view for economies that are in the 'catch-up phase' today, industrialisation is not an obligatory step in their development process, since they can follow a service-led process of economic growth instead. It is this pro-service vision that has dominated the political economy debate for almost three decades, pushing out and excluding the proponents of public support for manufacturing development despite its 'symbiotic' relationship with service industries, in particular production related services.

This essay aims to contribute to the renaissance of the pro-manufacturing view in two ways. First of all the essay aims at providing a review of the main turning points in the manufacturing versus services debate and evaluates the analytical and empirical arguments supporting the two opposite visions. By sketching the tensions for the pro-service vision that have arisen because of the current financial crisis and resulting manufacturing loss, a systematisation of old and new rationales supporting a pro-manufacturing vision is presented.

Emphasis is given to the rediscovery of the importance of certain manufacturing industries (such as the machine tools industry) and to those bundles of technological capabilities which take the form of so called industrial commons. The machine tools industry and the industrial commons are at the very core of the manufacturing as the engine of growth, in other words they are for the key factors promoting the circular and cumulative processes of manufacturing self-expansion.

Many of the arguments in support of this 'new vision' may appear as 'old wine in new bottles'. Indeed, pro-manufacturing arguments have been at the centre of the classical work of Alexander Hamilton, Adam Smith, Charles Babbage, Andrew Ure and Karl Marx in the XVIII and XIX centuries. And this interest in the importance of industry just is as much in more recent work such as, *Manufacturing Matters* by Stephen Cohen and John Zysman published in 1987. However, today these traditional rationales have to take into account the new realities and dynamics of manufacturing development. Hence this paper aims to bring the old and the new together in an updated and coherent vision.

The second contribution of the essay is to link this new pro-manufacturing vision to two lines of economic research that provide the fundamental analytical lenses for understanding the dynamics of manufacturing development. The first strand of research, *Structural Economic Dynamics*, focuses on the continuous process of sectoral re-composition of economic systems as well as on the structural interdependencies among its different components at the meso- and macro- levels. It is within this framework that we can best explain the circular and cumulative processes of manufacturing expansion that are triggered by special kind of manufacturing industries such as the machine tools industry. The second strand of economic research we analyse focuses on production and technological capabilities. We examine their dynamics and accumulation (also in the form of industrial commons) as well as their relations with social capabilities at the country level, and consumer capabilities on the demand side. Taken together, these different concepts of capabilities constitute what I call here *the Economics of Capabilities*.

Through a novel synthesis of these two strands which aims to provide the analytical lens for disentangling the dynamics of manufacturing development, we integrate structural change and production capabilities dynamics. We do this by showing how learning processes are the fundamental factor responsible for production capabilities dynamics which in turn trigger structural economic dynamics.

PART I

Man cannot live on services alone:

Towards a new manufacturing vision

1. 'Making' or 'doing': Moving the debate forward

Does the wealth of nations, that is, their socio-economic development and technological power, mainly result from superior capacities in manufacturing (i.e. *making* things) or in *doing* other activities (i.e. providing services)? Furthermore, do different *sectors* and/or *production tasks* performed within each sector contribute to economic growth in specific ways or is the effect identical for all sectors and activities? Finally, to what extent can a sustained process of economic growth rely on the increasing relative expansion of the service sector?

During the second half of the twentieth century, the political economy debate addressing these questions has witnessed two major turning points. Until the late 1970s, the debate was dominated by people working in the classical economics tradition who supported what we call here a *pro-manufacturing vision*. Then, in the subsequent two decades of the twentieth century (1980s – 2000) a *pro-services vision* came to dominate and remained prevalent in the academic and policy debate until the recent financial crisis.

These two opposite visions emerged in (and thus partially reflect) two different phases of the worldwide process of structural change and manufacturing development that started after the World War II. This is why it is necessary to first provide a snapshot of countries' manufacturing development trajectories over the last half of the twentieth century, in order to better understand the context of the industry versus services debate.

1.1 Manufacturing development: Some long-term stylised facts, 1950 - 2005

Eighteenth-century Great Britain was the first country that experienced a process of manufacturing development. Only in the early nineteenth-century (after Great Britain had already demonstrated significant increases in productivity) did European countries such as Belgium, Switzerland and France followed by the United States enter their own different paths of manufacturing development. After this a few other latecomers (most notably Germany, Russia and Japan) joined the group of industrialising nations, while the developing world (both colonies and non-colonies) remained oriented towards primary production (Gerschenkron, 1962; Maddison, 2007).

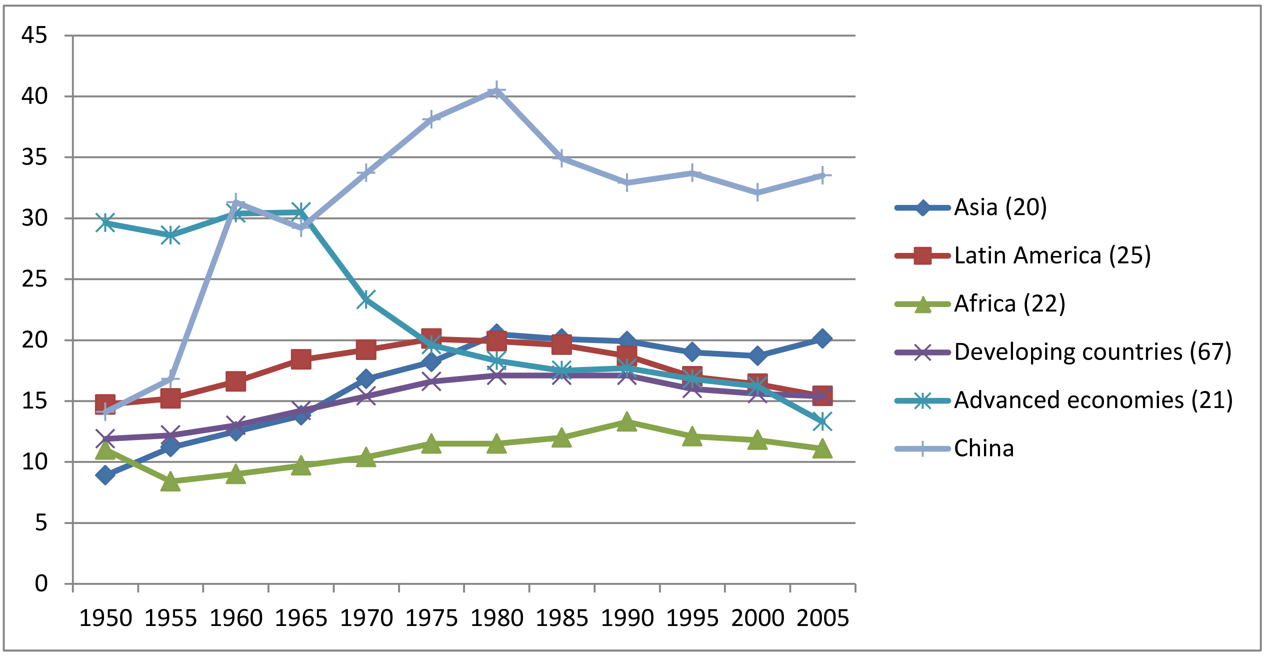
This situation remained basically unchanged until the World War II (with the partial exceptions of Argentina, Brazil and South Africa). This group took the opportunity to start their own manufacturing development process through import substitution because of the contraction of world trade during the Great Depression (1930s).

After World War II more countries began to enter the 'catch-up phase' thanks to the increasing advantages of backwardness, the greater opportunities for technology transfer and the industrial policies implemented by developmental states. This allowed them to enter the worldwide manufacturing development race (Wade, 1990; Chang, 1994 and 2002; Amsden, 2001 and 2007; Reinert, 2007).

At a first glance, three sets of stylised facts emerge as characteristic features of the last half of the twentieth century. Let's start from the most evident stylised fact: a worldwide process of structural change and *quantitative redistribution* of manufacturing across countries. In 1950, when the manufacturing development process became a major worldwide phenomenon, manufacturing constituted around 30% of GDP in advanced economies while in developing countries the figure was around 12 per cent (see Table 1 and Figure 1). Among economies in the 'catch up phase' Latin America remained the most industrialised region until 1975 when the manufacturing sector started contracting to the point that, in 2005, the share of manufacturing in GDP had reverted to 1950s levels. The manufacturing development path followed by countries in Africa was on average almost flat, reaching its peak in 1990 and decreasing again to 11 per cent (again a return to figures seen in 1950).

In contrast manufacturing continued to increase in many Asian economies throughout the last half-century with an impressive acceleration from 1965 to 1980. Finally, in the most advanced economies, the manufacturing share started decreasing in the late 1960s, from 30 per cent to 18 per cent on average in less than a decade (Maddison 2007; Szirmai 2011). During the second half of the last century, few East Asian economies experienced a sustained catching up process responsible for the quantitative redistribution of world manufacturing value added shares and world manufactures trade. At the end of the century in 2010 the three most successful countries in East Asia, namely China, The Republic of Korea and China Taiwan Province taken as a whole accounted for one fifth of world manufacturing value added shares and world manufactures trade.

Figure 1: Worldwide manufacturing development paths (changes in the shares of manufacturing in GDP at current prices per country groups over the period 1950 – 2005)

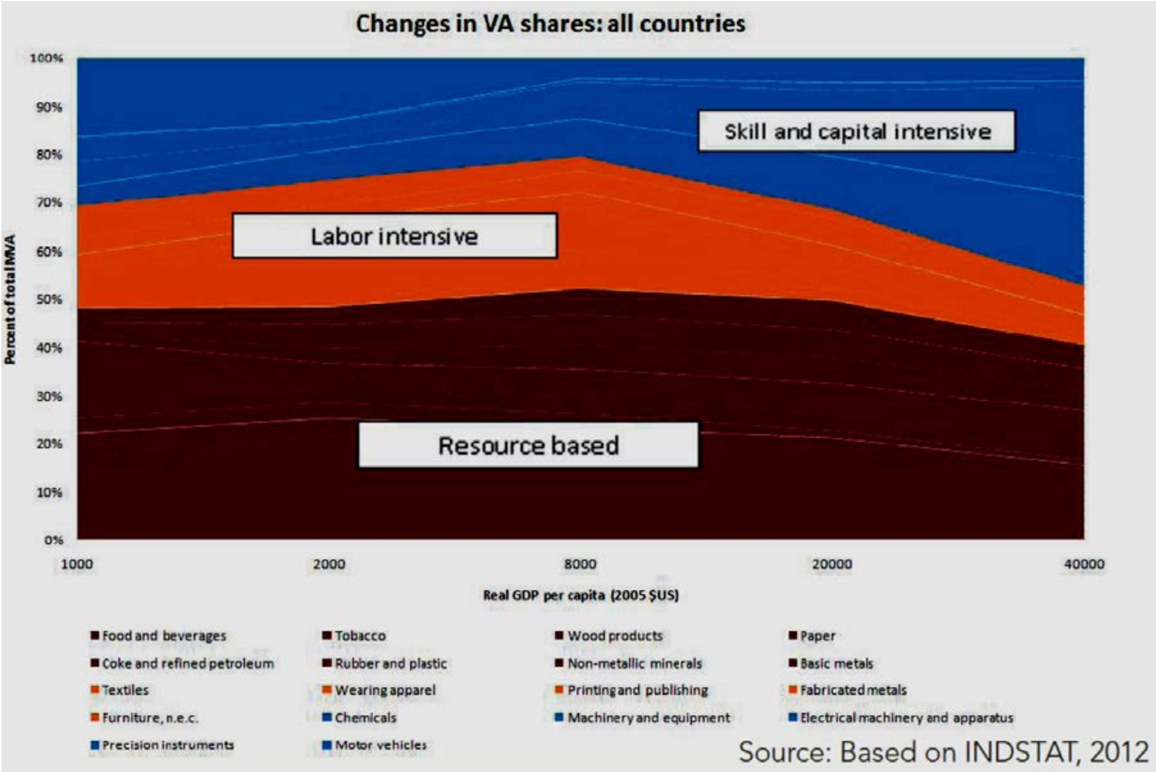


Source: Author (based on Szirmai 2011's database).

The *quantitative redistribution* of manufacturing, from advanced economies to a number of fast growing countries, has also been accompanied by a *qualitative transformation* within countries' manufacturing sectors. At different stages of development (measured in real GDP per capita, US dollars 2005), a country's manufacturing sector is composed of different proportions of resource-based, labour intensive and skill/capital intensive industries. A set of regularities have been observed (see Figure 2):

- Up to US$ 2000 a country's manufacturing sector tends to be composed by almost 50 per cent resource-based industries, 20 per cent labour intensive industries and 30 per cent skill/capital intensive industries;
- Between US$ 2000 and US$ 8000 the ratio of labour intensive and skill/capital intensive industries tends to invert, while resource-based manufacturing industries are unchanged;
- Finally, from US$ 8000 onwards there is a tendency for the resource-based industries to become less prevalent while there is an increase in skill/capital intensive industries (such as machinery production, automotive or chemicals) and a strong reduction in labour intensive industries (such as textiles and apparel).

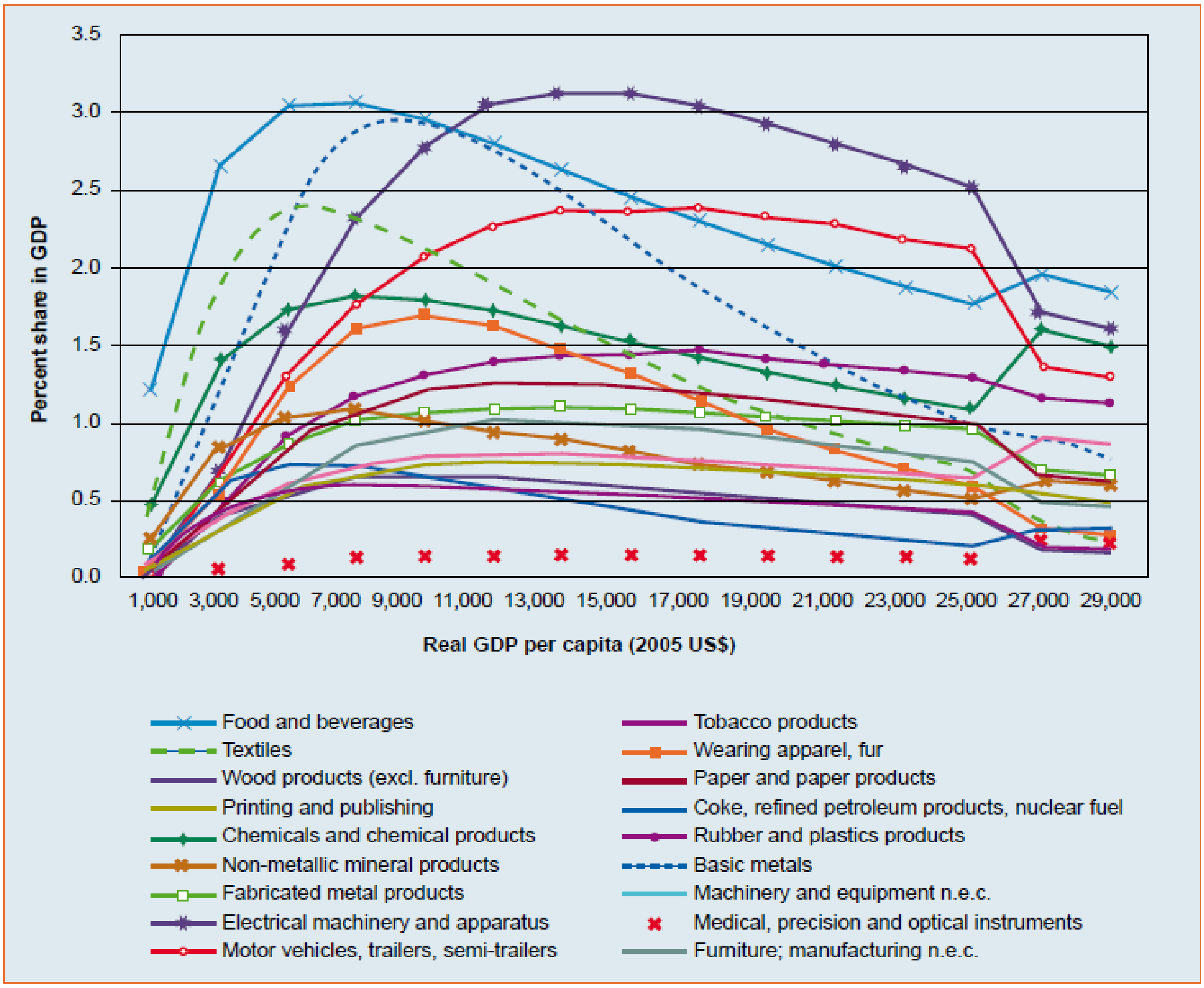
Figure 2: Qualitative transformations in the manufacturing sector (changes in the composition of total MVA for large economies)



Source: UNIDO 2012

An analysis at the sub-sectoral level confirms the existence of qualitative transformations within the manufacturing sector as countries increase their GDP per capita (see Figure 3). Now, as Lall notes, “there are many roads to heaven” (Lall, 2004:7) and the speed at which countries go through qualitative transformations vary over time depending on the pace of their respective technological change. However these analyses (see Figure 3) clearly suggest that while different manufacturing development trajectories are possible, some of them are more likely to occur at certain stages of development than others.

Figure 3: Change in share of manufacturing sub-sectors in GDP at selected per capita income levels for large countries



Source: Haraguchi and Rezonja, 2010; UNIDO 4digit Database.

The third feature of the last half of the twentieth century (as shown in table 1) is that the degree of *variance* among manufacturing development paths is very high even between countries within the same regions or income groups. For example, among the group of today's advanced economies, we observe two different group of countries. On the one hand, there are those such as Germany and Japan who have maintained a strong manufacturing base, and, on the other, there are those such as the US and UK who have increasingly relied on services. And of course the manufacturing development trajectories followed by world giants such as China and India or Brazil are very different (see Table 1)[1].

Table 1: Worldwide Manufacturing Development, 1950 – 2005 (GVA as a % of GDP at current prices, 90 countries)

	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005
Bangladesh[a]	7.2	9.8	5.3	5.4	5.8	7.0	13.8	14.2	13.1	15.3	15.2	16.5
Cambodia			8.5	8.4					8.6	9.1	16.0	17.8
China	14.1	16.8	31.3	29.2	33.7	38.1	40.5	34.9	32.9	33.7	32.1	33.5
Hong Kong. China							22.8	21.3	16.7	7.7	5.4	3.4
India	10.4	12.0	14.1	14.7	14.2	15.8	16.7	16.5	16.7	17.9	15.6	16.0
Indonesia	7.4	9.8	9.2	8.4	10.3	9.8	13.0	16.0	20.7	24.1	27.7	27.7
Iran. Islamic Rep.			9.5	8.7	10.1	7.3	7.8	7.2	11.8	11.9	13.2	11.8
Iraq	6.1	7.0	9.6	8.9							0.9	
Jordan			6.2	11.9	11.3	8.9	12.7	11.5	14.9	15.1	15.7	18.2
Lebanon	6.4			13.3						15.0	13.7	14.1
Malaysia		11.2	8.1	9.5	12.4	17.6	21.6	19.3	24.2	26.4	32.6	29.8
Pakistan[b]	7.2	9.8	12.1	14.5	16.1	16.7	15.9	15.9	17.4	16.3	14.7	18.6
Philippines	8.5	13.1	20.3	19.5	24.9	25.7	25.7	25.2	24.8	23.0	22.2	23.3
Republic of Korea	8.8	11.3	10.4	13.5	17.8	21.6	24.4	27.3	27.3	27.6	29.4	28.4
Sri Lanka	4.2	5.9	15.4	16.8	16.7	20.1	17.7	14.7	14.8	15.7	16.8	14.8
Syrian Arab Republic	7.2	8.3	9.0	8.3						6.4	5.9	8.5
Taiwan	15.0	15.8	19.1	22.6	29.6	31.5	36.2	36.9	32.7	26.5	24.6	22.1
Thailand	12.0	13.8	12.5	14.2	15.9	18.7	21.5	21.9	27.2	29.9	33.6	34.8
Turkey	10.7	12.4	13.2	15.3	15.8	16.3	17.3	18.8	22.7	23.4	20.0	21.8
Vietnam[c]			11.5	20.0				20.5	12.3	15.0	18.6	20.6
Argentina	23.4	30.4	32.2	33.8	31.5	38.2	29.5	29.6	26.8	18.4	17.5	23.2
Barbados		12.7	8.0		7.9	10.3	11.9	10.6	10.1	10.1	6.4	7.1
Belize							23.9	16.7	13.1	10.9	10.9	9.1
Bolivia		13.2	13.4	14.1	14.1	12.9	14.4	17.3	18.5	19.0	15.3	14.0
Brazil	18.7	20.4	29.6	26.2	29.3	30.3	33.5	33.7	26.5	18.6	17.2	18.4
Chile	17.1	19.3	24.9	26.1	25.9	20.4	21.5	16.2	19.6	18.1	19.5	15.7
Colombia	12.9	14.9	16.5	19.7	21.2	23.7	23.9	22.0	20.6	15.9	15.8	16.4
Costa Rica	10.3	11.4	16.2	16.6	18.2	20.4	18.6	25.1	22.6	21.8	25.3	21.8
Dominican Republic	15.9	15.0	17.5	15.6	18.5	20.9	15.3	12.3	18.0	18.2	16.8	15.1
Ecuador	15.7	15.0	15.6	18.5	17.6	16.4	19.5	19.1	19.2	14.0	13.6	8.9
El Salvador			15.6	18.9	20.2	20.0	16.5	17.8	22.1	23.1	24.7	22.9
Guatemala	12.0	12.2	12.8	14.1	15.8	15.1	16.6	15.8	15.1	14.1	13.2	18.7
Guyana	15.2	13.5	10.4	13.1	12.1	14.7	12.1	13.9	10.3	11.4	8.2	7.7
Honduras	8.6	8.7	12.5	12.4	13.8	15.7	15.0	14.5	16.3	17.8	22.7	20.9
Jamaica	11.3	13.4	13.6	15.0					17.2	16.0	13.7	13.6
Mexico	17.2	18.1	15.3	19.5	23.2	22.4	22.3	24.0	20.8	20.8	20.3	17.8
Nicaragua				20.2								
Panama	11.3	9.8	12.8	15.3			11.0	12.3	9.7	9.1	10.1	8.0
Paraguay	19.5	14.6	16.7	15.5	16.7	15.6	16.0	14.2	16.8	15.9	15.5	12.4
Peru	14.5	15.4	20.2	17.1	19.8	20.0	20.0	25.2	17.8	16.8	15.8	16.3
Puerto Rico	16.3	20.7	21.9	23.0	23.6	28.9	36.8	39.0	39.6	41.9	38.3	
Suriname		11.2	12.5	14.9		20.7	18.6	13.2	10.3	13.7	9.0	19.1
Trinidad and Tobago	13.2	12.5	12.5	13.2				8.7	14.0	8.6	7.3	6.5
Uruguay		19.4	21.2	24.4			25.4	29.4	28.0	19.7	16.9	22.5
Venezuela. RB	10.9	11.7	10.7	16.6	16.1	15.7	16.0	18.9	14.9	15.1	19.8	17.9
Botswana				11.6	5.9	7.2	5.1	5.4	5.1	5.5	4.4	3.7
Congo. Dem. Rep.	9.4	6.7		6.3	8.9		15.2	10.5	11.3	7.1	4.8	6.6
Cote d'Ivoire			7.5	9.1	10.3	9.4	12.8	14.6	20.9	15.0	21.7	19.3
Egypt. Arab Rep.	8.3		13.7			17.4	12.2	13.5	17.8	17.4	19.4	17.3
Eritrea									8.2	9.0	11.2	6.8
Ethiopia[d]			6.0	6.7				4.3	4.8	4.8	5.5	4.8
Ghana			5.1	9.8	11.4	13.9	7.8	11.5	9.8	9.3	9.0	8.7
Kenya	10.8	9.6	9.4	11.5	12.0	12.0	12.8	11.7	11.7	9.9	11.6	11.7
Libya			10.7	2.8	2.1	2.3	2.0	4.5	6.5			

[1] See also Andreoni 2013.

Table 1 (continued): Worldwide Manufacturing Development, 1950 – 2005 (GVA as a % of GDP at current prices, 90 countries)

	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005
Malawi		4.8	5.4	6.9	11.3	13.1	13.7	14.5	19.5	15.8	12.9	13.9
Mauritius	23.1	20.1	16.8	15.3		15.6	15.7	20.0	24.7	22.8	23.7	20.2
Morocco	14.7	11.5	13.4	15.7	16.2	17.1	16.9	18.4	19.0	19.0	17.4	17.2
Nigeria	1.8	3.0	3.8	5.4	3.7	5.0	8.4	8.7	5.5	5.4	3.7	4.6
Sierra Leone		0.0	6.0	6.1	6.3	5.5	5.3	5.7	4.6	9.3	3.5	3.7
South Africa	16.4	18.8	20.1	22.9	22.8	22.7	21.6	21.8	23.6	21.2	19.0	18.6
Sudan		4.4	4.7	6.1	7.8	6.9	7.5	8.6	8.8	9.2	8.6	6.8
Tanzania[e]	3.4	2.8	2.9	9.2			12.3		9.3	7.2	7.5	6.8
Togo			7.7	5.9	10.0	7.0	7.8	6.7	9.9	9.9	8.4	10.1
Tunisia		9.9		8.1	8.4	9.1	11.8	15.1	16.9	19.0	18.2	17.4
Uganda		7.9	8.5	8.4	9.2	6.3	4.3	5.8	5.7	6.8	9.8	9.3
Zambia		3.4	4.0	7.9	12.1	17.5	19.2	20.6	26.5	11.7	11.4	11.5
Zimbabwe/South Rhodesia		14.4	16.0	18.7	17.8	19.3	17.7	17.7	21.6	19.6	15.8	13.5
Cyprus	11.7	11.5	12.7	12.0		14.3	17.5	15.6	14.2	12.1		
Malta		8.2	16.1	19.3	21.8	30.5	33.1	29.5	27.0			
Australia	27.1	28.0	28.5	28.4	23.3	22.0	19.0	17.0	14.5	14.6	12.7	11.0
Austria	33.8	33.9	32.1	34.3	28.4	25.0	23.7	22.5	21.4	19.3	20.3	19.4
Belgium	30.1	28.9	29.5	30.7	30.4	24.6	22.6	22.4	21.9	20.2	19.3	17.1
Canada	28.6	27.9	23.3	26.3	25.9	22.2	18.8	17.9	16.9	18.4	19.2	16.5
Denmark	27.7	27.0	29.3	29.3	22.6	19.4	18.9	18.8	17.4	17.1	16.2	14.2
Finland	27.8	26.9	26.8	25.5	25.1	25.8	27.5	24.9	22.6	25.3	26.2	23.1
France	38.3	35.9	36.6	34.8	25.6	25.5	25.5	23.1	22.3	20.1	16.0	13.0
Germany, federal rep.	41.1	40.8	42.2	41.1	35.6	34.6	33.6	32.6	31.7	26.2	0.0	0.0
Germany, United										22.6	22.9	23.2
Ireland	13.5	26.1	28.4	31.5	32.6	30.4	0.0	0.0	0.0	0.0	0.0	0.0
Israel	19.3	22.5	24.0	24.0	23.2	22.0	16.4	20.0	18.5	16.9	17.9	14.5
Italy	31.1	27.1	27.2	27.7	27.6	27.5	28.9	25.2	23.3	22.2	21.0	18.2
Japan	24.8	25.9	32.0	31.1	32.9	27.4	26.6	26.8	25.5	22.5	21.3	21.0
Luxembourg	34.1	42.2	44.8	40.9	0.0	0.0	0.0	0.0	0.0	13.7	11.3	8.3
Netherlands	30.0	30.6	31.6	32.4	25.3	21.6	18.1	17.8	18.6	17.4	15.6	14.0
Norway	0.0	27.3	25.1	26.6	21.0	21.0	15.6	13.5	12.3	13.2	10.6	9.6
Portugal	35.3	26.4	29.9	33.3				19.6	19.4	18.4	17.1	14.7
Spain	21.3	23.4	22.5	25.8							18.6	16.2
Sweden	30.5	32.0	27.1	33.6	28.8	25.4	22.0	22.7	20.3	22.3	22.0	19.7
Switzerland									21.9	21.1	20.2	19.8
United Kingdom	34.6	36.3	36.2	34.5	31.7	28.1	26.5	23.9	23.2	21.7	17.9	13.6
United States	31.3	31.7	28.7	28.8	25.1	23.2	22.8	19.9	19.4	18.9	17.0	14.4
Average 20 Asian countries	8.9	11.2	12.5	13.8	16.8	18.2	20.5	20.1	19.9	19.0	18.7	20.1
Average 25 Latin America countries	14.7	15.2	16.6	18.4	19.2	20.1	19.9	19.6	18.7	17.0	16.4	15.4
Average 22 African countries	11.0	8.4	9.0	9.7	10.4	11.5	11.5	12.0	13.3	12.1	11.8	11.1
Average 67 Developing countries[f]	11.9	12.2	13.0	14.2	15.4	16.6	17.1	17.1	17.1	16.0	15.6	15.4
Average 21 advanced economies	29.6	28.6	30.4	30.5	23.3	19.6	18.3	17.5	17.7	16.8	16.2	13.3

Sources: The primary sources used are: UN, *Yearbook of National Accounts Statistics, 1957, 1962 and 1967*; Groningen Growth and Development Centre, *10 Sector Database*, http://www.ggdc.net/index-dseries.html; World Bank, *WDI Online*, accessed February 2009; World Bank, World Tables, 1980; Advanced economies, 1950, unless otherwise specified from OECD, *National Accounts*, microfiche edition, 1971, Japan 1953 from GGDC ten sector data base. For detailed source notes, see: Szirmai, Industrialisation as an Engine of Growth in Developing Countries, UNU-MERIT, Working Paper Series, 2009–2010, Maastricht, 2009.

[a] Bangladesh. 50–60 shares for Pakistan including Bangladesh.
[b] Pakistan including Bangladesh till 1972.
[c] South Vietnam till 1975. United Vietnam post 1975.
[d] Prior to 1993 including Eritrea.
[e] Till 1963 Tanganyika. excl. Zanzibar.
[f] Average developing countries excluding Malta and Cyprus.

Source: Szirmai, 2011

1.2 The pro-manufacturing vision

For a long time, the term *industrialisation* (i.e raising share of manufacturing in GDP) was synonymous with development, particularly amongst classical development economists such as Roseinstein-Rodan, Hirschman, Prebisch and Kaldor. Participation in the global industrialisation race was regarded as a *sine qua non* for countries that wished to experience accelerated economic growth, increasing labour productivity and socio-economic welfare improvements.

During the 1960s, the historical evidence available pointed to the existence of a solid correlation between manufacturing development and economic growth (see Table 1). Classical development economists provided two sets of explanations for manufacturing being the engine of economic growth. The first one focused on the internal 'special properties' of manufacturing and the second on the way in which these 'special properties' spread to the rest of the economy triggering processes of increasing returns and economic growth[2]. The systematisation of a *pro-manufacturing vision* was mainly due to the seminal work of Nicholas Kaldor and Albert Hirschman (amongst others).

Building on the classical work on increasing returns by Allyn Young (1928) and the empirical regularities pointed out by Kuznets, Chenery and Syrquin, Nicholas Kaldor (1966, 1967 and 1985) developed his three famous *Growth Laws*. These showed the existence of increasing returns within manufacturing and the reasons why manufacturing was the engine of aggregate growth. The first of these laws states that the faster the rate of manufacturing growth, the faster the rate of economic growth of the overall system. The second law (also known as the Verdoorn's law) states that there is a strong positive

[2] The different sources of increasing returns identified in the classical line of Smith, Babbage, Young and Kaldor are discussed in Andreoni and Scazzieri (2013). See Toner (1999) for a review of Kaldor's laws and their contributions to the Cumulative Causation Theory

causal relation between the rate of growth of manufacturing output and the rate of growth of manufacturing productivity[3]. Finally, according to the third law, aggregate productivity growth is positively associated with the growth of employment in manufacturing (and negatively related with the growth of non-manufacturing employment).

The 'special properties' (implicit in the second law) that makes manufacturing more effective in triggering growth of the overall economy than other types of economic activity (through the working of the first and third law) are threefold. Firstly, there is the relatively broader opportunities for capital accumulation and intensification in manufacturing (in comparison to agriculture and services). Secondly, there are greater possibilities of exploiting economies of scale induced by large-scale production and technical indivisibilities, both within and across industries. Finally there are the higher learning opportunities in manufacturing production through which embodied and disembodied technological progress is generated.

Given these special properties, specialisation in manufacturing implies a *double* productivity *gain* (it allows countries to get a 'structural change bonus' and to avoid a 'structural change burden'). The former results from transferring labour from agriculture to manufacturing, the latter relates to the so-called 'Baumol' disease' (an overall slowdown of productivity resulting from an over-dependence on services, especially labour intensive ones such as personal services) (Baumol 1967).

The mechanisms through which manufacturing is able to extend its special properties to the rest of the economy were explicitly formulated by Albert Hirschman (1958). In his 'unbalanced growth

[3] This law is implicit in the idea stated by A.Young (1928) that "the division of labour depends upon the extent of the market, but the extent of the market depends upon the division of labour". This means that "an increase in the market triggers further specialisation which is a process that simultaneously increases the size of the market for specialist skills and activities" (Best 1999:107).

model' each sector is linked with the rest of the economic system by its direct and indirect intermediate purchase of productive inputs and sales of productive outputs – i.e. *backward and forward linkages*. According to its system of linkages, each sector exercises 'push' and 'pull' forces on the rest of the economy. Unlike agriculture, the industrial sector is characterised by both strong backward and forward linkages and thus emerges as the main driver of development[4].

However, sectors are not just linked through the set of physical relations of supply and demand. The embodied and disembodied knowledge generated within the manufacturing sector connects within and across sectors through so-called *spillover effects*. The latter take the form of product and process technologies (hardware) on which software-producing and software-using service sectors are based (see Szirmai, 2011). This is why, according to Hirschman (1981:75), the development process is "essentially the record of how one thing leads to another" through an incremental unfolding of production and technological linkages stemming from manufacturing production.

Economists embracing a pro-manufacturing vision also stressed the importance of manufacturing in relation to other macro-economic issues. Crucially manufactured products have a high income elasticity of demand (as per capita income increases demand decreases for agricultural products and increases for manufacturing products - the so called *Engel law*, 1857). This opens up dynamic opportunities for the development of manufacturing production. Moreover, flourishing production of manufacturing tradeables was considered a fundamental condition for avoiding balance of payments crises. This was particularly the case where countries cannot rely on a high-value primary commodity export sector and the income elasticity of demand for its

[4] The classical debate on agriculture vs manufacturing development is discussed in the Third Essay of this dissertation.

imports is higher than the foreign income elasticity of demand for its exports (Prebisch, 1949; Landesmann 1989).

Although the validity of Kaldor's laws was the object of much debate throughout this period[5], the pro-manufacturing vision remained extremely influential until the mid- 1970s. This was particularly true in developing countries but also in the UK, as evinced by the debate hosted in the *Economic Affairs* (1989)[6]. However the pro-manufacturing vision came under attack during the 1980s and was gradually abandoned in the following decade when the *pro-service vision* became dominant.

1.3 The pro-service vision

The development of the pro-service vision was triggered by the fact that, in both advanced and developing countries, the service sector appeared to be replacing manufacturing as the leader in the process of economic growth. Turning to the figures we can see that since the 1960s the most advanced economies have lost on average almost half of their manufacturing sector as a percentage of GDP as a result of an accelerated process of de-industrialisation, (see Figure 1).

Moreover, in the developing world, a set of phenomena seemed to run contrary to the historical pattern of structural change followed by today's advanced countries (Palma, 2005; Dasgupta and Singh, 2005). Firstly, in several developing economies manufacturing employment (in both relative and absolute terms) started to fall early

[5] Two main debates were hosted in *Economica* (1968) and in the *Economic Journal* (Rowthorn 1975). See Dasgupta and Singh (2005) for a recent empirical test of Kaldor's laws.

[6] During the debate at The House of Lords Select Committee on Overseas Trade in April 1984, one commentator argued "What will the service industries be servicing when there is no hardware, no wealth actually being produced. We will be servicing, presumably, the product of wealth by others… We will supply the Changing of the Guard, we will supply the Beefeaters around the Tower of London, we will become a curiosity. I don't think that is what Britain is about. I think that is rubbish" (Liston, 1989).

by historical standards, suggesting a form of 'premature' de-industrialisation. Secondly, the related phenomenon of 'jobless growth' appeared as even fast-growing economies, such as India, saw employment stagnation. Finally services often grew at a faster long-term rate than manufacturing during the 1990s (once again this was particularly marked in countries like India), which suggested that services can actually substitute for manufacturing as engines of growth.

Theoretical explanations for the rising share of services associated with economic growth mainly concentrate on final expenditure patterns and prices (i.e. *demand side factors*). The basic intuition is that as people increase their income they begin to demand relatively more services. The falling demand for manufacturing goods thus naturally leads (so the argument goes) to the shrinking of the manufacturing sector[7].

Most fundamentally, the idea that productivity increases are limited in service industries came under sustained attack with the flourishing of modern services such as finance, engineering, distribution. The increasing application of information and communication technologies (ICTs) has allowed major productivity improvements in services and the marginal cost of providing services has collapsed, showing the potential for scale effects. Those supporting the pro-services vision thus questioned the notion of 'Baumol's disease'. They also emphasised the possibilities opened up by tradable knowledge-based services such as engineering, consulting and banking

Countries such as Australia, Canada, Luxembourg and the United States (but also mistakenly Switzerland and Singapore) were offered as successful examples of the huge potential contribution that the service sector can have in both employment creation (high-skilled workers in

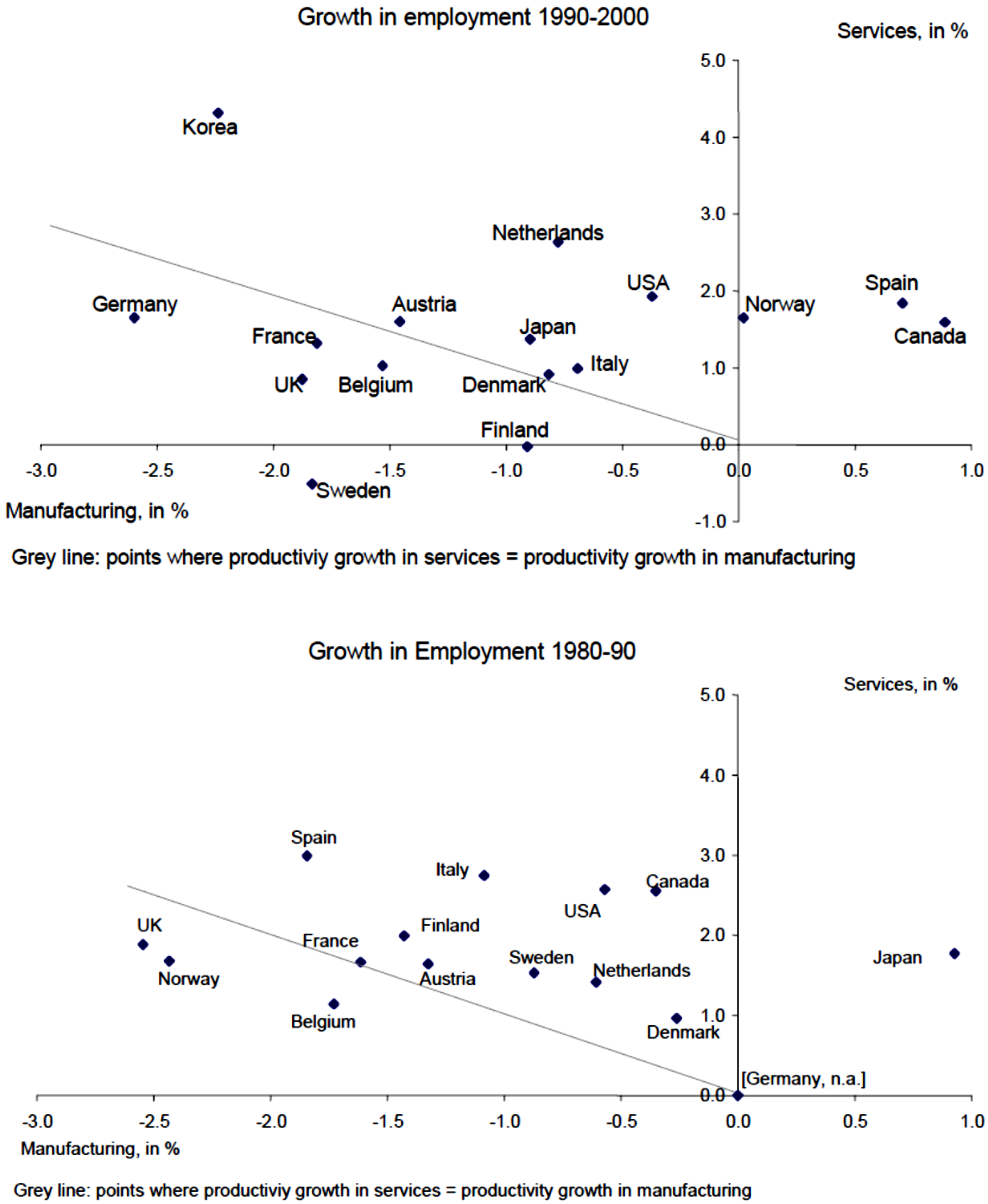
[7] See the seminal work by Fisher (1939) and Clark (1940). Bell (1973) is the classic work on post-industrial society. On income-price linkages see Kravis et. al. (1982), Bhagwati (1984a), Panagariya (1988). And finally on productivity and rising prices in services see Baumol et al. (1985)

finance, business services, education and health in particular) and in productivity growth. The empirical evidence on which the pro-service vision relied is reported for the 1980s and the 1990s (see figures 4 and 5 below).

In terms of developing countries, the idea that industrialisation was no longer synonymous with development also took root and was epitomised by the Indian experience. It was suggested that developing countries now experience a historically novel pattern of structural change that is determined by a new technological paradigm. According to this explanation, services such as ICT, business support and finance are replacing or complementing manufacturing in a pro-growth way. Little emphasis is given to the fact that developing countries run the risk of premature de-industrialisation. There is little concern that this might undermine their capacity to satisfy future changes in consumer demand or to accumulate/build production capacities and institutions. And of course this was precisely what characterised the manufacturing-led pattern of growth (see Cohen and Zysman, 1987; Rowthorn and Coutts, 2004)[8].

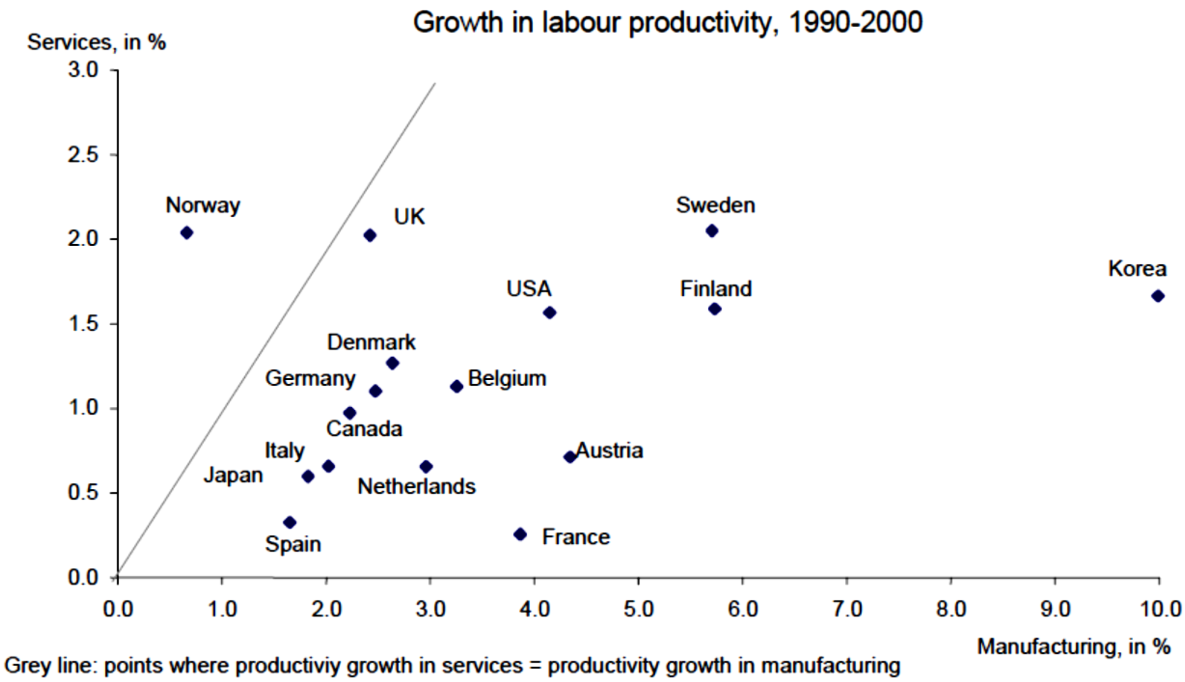
[8] As we will argue, later developed countries may be running the same risk of losing those manufacturing capacities which are vital even for the development of their service sector.

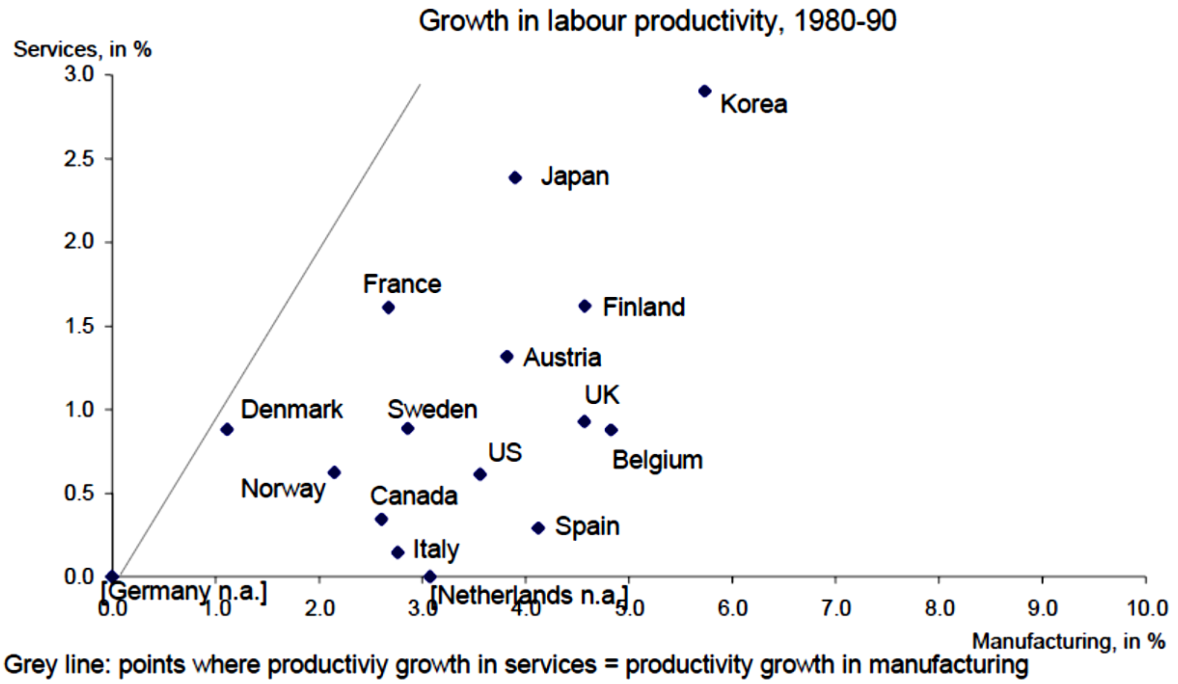
Figure 4: Employment growth in manufacturing & services



Source: Wolfl, 2003:13; based on OECD STAN Database 2002.

Figure 5: Productivity growth in manufacturing & services





Source: Wolfl, 2003:12; based on OECD STAN Database 2002.

The pro-services vision resulted in a new policy package which is well summarised in the OECD *Growth in Services Report* (2005). Here the following set of policies is recommended with the explicit aim of strengthening the potential of services to foster employment, productivity and innovation:

[1] Open domestic services markets to create new job opportunities and foster innovation and productivity.

[2] Take unilateral and multilateral steps to open international markets to trade and investment in services.

[3] Reform labour markets to enable employment creation and adjustment to a growing services economy.

[4] Adapt education and training policies to rapidly changing requirements for new skills.

[5] Adapt innovation policies to the growing importance of services innovation.

[6] Remove impediments that prevent services firms from seizing the benefits of ICT.

[7] Provide a fiscal environment that is conducive to the growth of services.[9]

Although the pro service-vision remained dominant until recently, an increasing number of studies (see next section) have highlighted important fallacies in the pro-service vision and the empirical evidence it offers and argued that the dichotomy between the pro-manufacturing and pro-service visions itself is unhelpful.

[9] It is interesting to note that, in contrast, in the late 1960s, Kaldor as an economic adviser to the British government, proposed a selective employment tax to promote manufacturing in Britain.

1.4 Beyond polarisation: Sources of de-industrialisation, statistical illusions and symbiotic interdependencies

The first issue we must address if we are to move the debate beyond the crude industry versus services dichotomy is that of the sources of deindustrialisation. We must investigate whether de-industrialisation (defined as a decline in the share of manufacturing employment in a given country) is indeed caused by the growing irrelevance of manufacturing as pro-services advocates suggest.

Robert Rowthorn and co-authors (1987; 1999; 2004) have done crucial work on the rapid process of de-industrialisation[10] experienced by most industrialised countries (in particular the EU and UK)[11] and by many medium/high-income developing countries in the 1980s and 1990s. They see this process as the "natural consequence of the industrial dynamism in an already developed economy" while "the pattern of trade specialisation among the advanced economies explains the differences in the structure of employment among them". In other words, the main explanation of deindustrialisation is to be found in the "*systematic tendency of productivity in manufacturing to grow faster than in services*" (Rowthorn and Ramaswamy, 1999: 1-7, italics added). A recent work by Tregenna (2009: 433) confirms this thesis by demonstrating empirically that the decline in manufacturing employment is "associated primarily with falling labour intensity of manufacturing rather than an overall decline in the size or share of the manufacturing sector".

Secondly, just as the sources of deindustrialisation seem to lie more with superior manufacturing productivity rather than strong

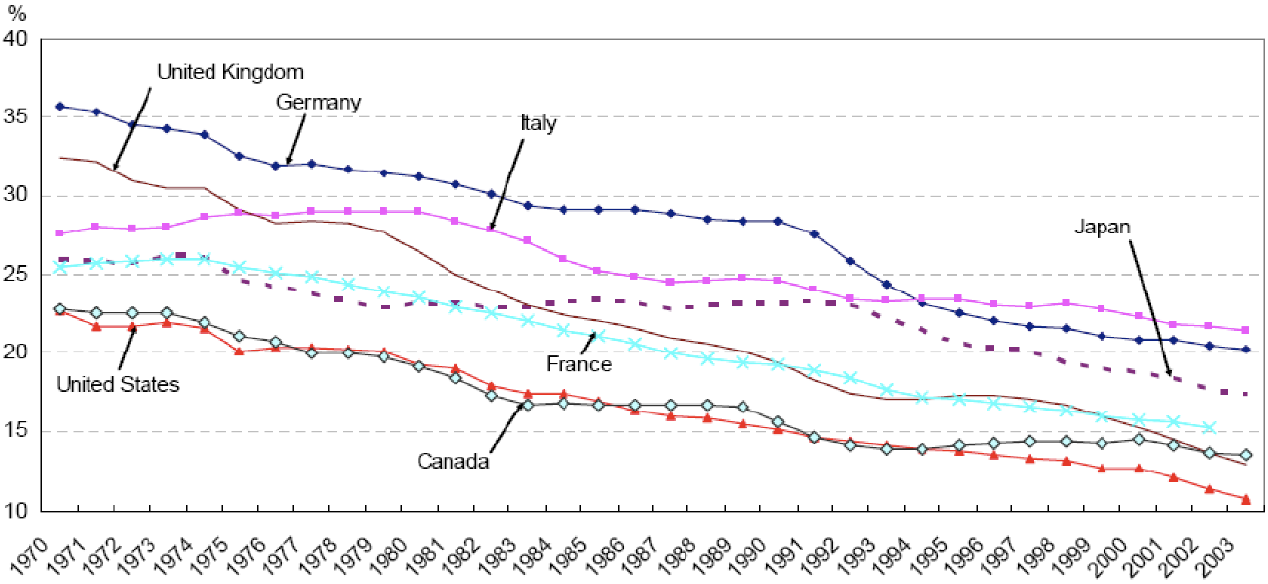
[10] De-industrialisation is registered as a decline in manufacturing employment first in relative terms and then, at least in some countries, also in absolute terms.
[11] Most industrialised countries reached this phase of de-industrialisation around the end of the 1960s and the beginning of the 1970s, while some high-income DCs (such as the rapidly industrialising countries of East Asia) began this phase in the 1980s. The empirical analysis in Palma (2005) confirms the 'inverted- U'-type of trajectory of manufacturing employment with respect to income per capita.

services performance, the statistical illusion issue also undermines the pro-services case. The decreasing relative importance of manufacturing measured as a share of a given country's total employment seems to be partly the result of a 'statistical illusion'. It occurs because a number of activities from design and data processing to transport, cleaning and security have been contracted out by manufacturing firms to specialist service providers.

Even if we ignore the underestimation of manufacturing employment shares resulting from the 'splintering effect' (Bhagwati's 1984b), the reality is that many OECD countries have indeed experienced a *steady* (rather than drastic) decline in the share of manufacturing in total employment (for the period 1970- 2004, see Figure 6). Thus, in contrast with what the pro-services advocates suggested, deindustrialisation has not been a sudden process occurring with declines in manufacturing output, productivity and demand. Rather, employment losses have involved different industries and countries in different ways (with no exception for high tech manufacturing) (Pilat et al 2006). In the very period when deindustrialisation began (1970- 2004), manufacturing production and value added in fact continued to experience strong growth and demand for manufacturing goods was sustained. Most tellingly, productivity growth in manufacturing remained high in many OECD countries while deindustrialisation was occurring and there is evidence that the manufacturing sector continued driving the process of innovation and technological change. Although the growing investment in innovative services and the outsourcing of R&D to specialised labs (counted as 'services') have reduced business investment in manufacturing R&D, the latter sector still accounts for the bulk of spending on technological innovation and development. The recent analysis of the structural evolution of the United States economy provided in Spence and

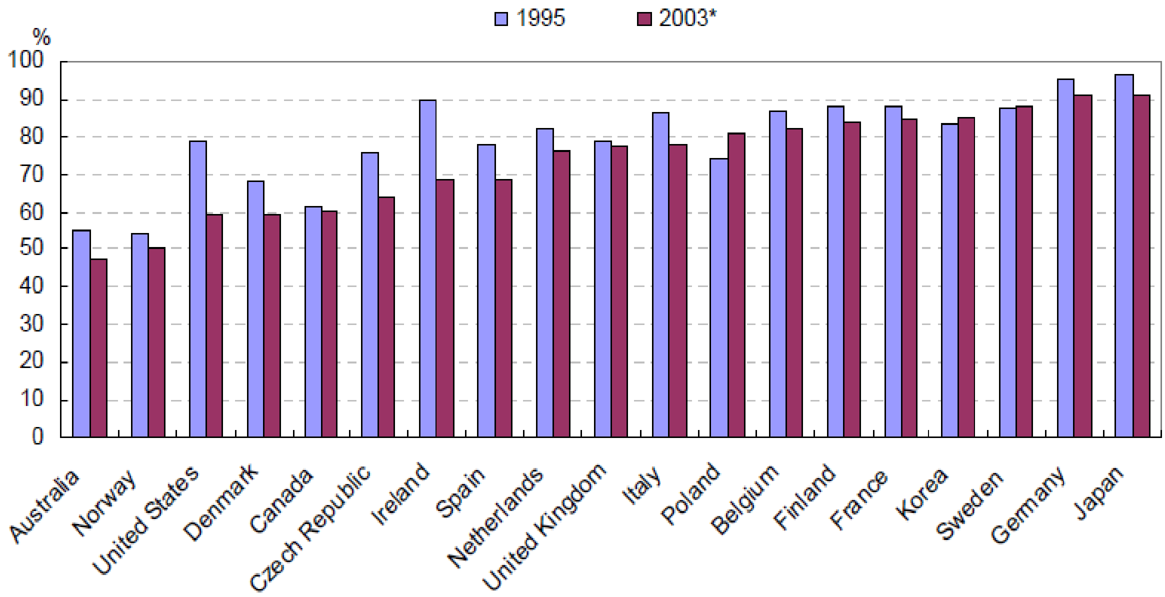
Hlatshwayo (2011) confirms these general trends in mature industrial economies.

Figure 6: Decline in manufacturing employment across developed countries



Source: Pilat et al. 2006:6

Figure 7: Share of manufacturing in total business R&D, 1995 and 2003, in %



Note: * Or latest available year.

Source: Pilat et al. 2006:26

Given the statistical illusions discussed above (the result of a blurring of the traditional distinction between services and manufacturing), measuring intersectoral interactions is extremely complex (Pilat and Wolfl, 2005)[12]. The bundle of interactions that connects manufacturing and services is becoming increasingly dense, given the outsourcing of services activities from manufacturing firms to services providers but also the changing technological linkages between manufacturing and services (in particular production-related services). The existence of strong intersectoral interactions and interdependencies between manufacturing and services is something that was originally revealed by input-output analyses performed by Park (1989), Park and Chan (1989) and Park (1994)[13].

The point which moves the debate ahead, then, focuses our attention on the 'symbiotic' interdependencies between manufacturing and services. This leads to the consideration of a fundamental question which has been very often under-evaluated in the polarised debate between manufacturing and services (between 'making' or 'doing')[14]. Namely, *to what extent and in which direct and indirect ways does manufacturing contribute to the development of services (and vice versa)?*

The influential work by Se-Hark Park and Kenneth Chan addressed this issue by examining separately the linkages existing

[12] Building on the work of Alfred Chandler, the historical analysis developed by Schmenner (2008) has shown how servitisation has antecedents that go back 150 years. At that time the bundling of manufactured goods to downstream services was a business strategy adopted by companies which lacked manufacturing strength in order to establish barriers to entry for potential competitors.

[13] Interestingly Damesick (1986)'s analysis of Britain transformation during the 1970s and early 1980s stressed the idea of a symbiotic relationship between manufacturing and services development (the same intuition has been empirically tested by Park, 1989).

[14] Francois and Reinert note (1996: 2) "While emphasis in the services literature has been placed on final expenditure patterns and prices, some of the most striking aspects of service sector growth relate instead to the relationship of services to the production structure of economies, particularly the relationship of the service sector to manufacturing".

between disaggregated groups of services and various manufacturing industries[15]. Their analysis was based on the classification proposed by Gershuny and Miles (1983) which divides service activities into two major groups: marketed services and non-marketed services, and then break these down into further sub-categories. An important sub-category created by this classification is that of *producer services* which includes specialised technical services which support production processes.

Park and Chan's empirical analysis conducted on 26 countries selected in the UNIDO database confirmed Hirschman's intuition that the manufacturing sector has larger multiplier effects than do services. Specifically, it tends to generate a two to three- fold greater output impact on the economy because of the denser backward and forward linkages formed within and around it[16]. Moreover, their data showed the 'catalytic role' that industry could play in fostering employment opportunities in the services sector (the *indirect employment effect*). This study explicitly stressed that "the evolution of the intersectoral relationship between services and manufacturing in the course of development is symbiotic, in the sense that the growth of the service sector depends not only on that of the manufacturing sector, but also structural change of the former is bound to affect that of the latter" (Park and Chan, 1989: 212).

[15] Empirical studies in regional income and employment multiplier analysis (Stewart and Streeten 1971) had previously shown using input-output techniques that the "the direct employment effect of industrial investment is small relative to its indirect effects resulting from the interindustry purchases of inputs and income induced effects of private consumption". Moreover "as the industrial base broadens and becomes more integrated, both horizontally and vertically, the employment impact of industrial activities should also increase substantially" (Park and Chan, 1989: 201). This scenario is consistent with the 'macro-economic' effects observed by A. A. Young (1928) and later discussed in Kaldor (see above).

[16] The input-output analysis conducted by Pilat and Wolfl 2005 reached the same conclusion stating that "Manufacturing industries interact much more strongly with other industries, both as providers and as users of intermediate inputs. Even though services now contribute as providers of intermediate input to the performance of other industries, their role remains more limited than that of the manufacturing sector".

Precisely these results have been recently confirmed by Guerrieri and Meliciani (2005). Their analysis has shown that a country's capacity to develop its services sector depends on the specific structural/technological composition of its manufacturing sector. This is because different manufacturing industries require different producer services and tend to use them with different degrees of intensity. Their analysis also highlights how the cumulative expansion of services can follow both inter- and intra- sectoral patterns as the same service producers are also intensive users of these producer services.

Now the above mentioned studies certainly debunked some of the misperceptions that lay behind the pro-service vision. They also qualified and refined many of the intuitions supporting the original pro-manufacturing arguments. However, the real turning point in the 'making versus doing' debate was triggered by the massive acceleration in the transformations of the world manufacturing landscape resulting from the financial crisis.

1.5 The Manufacturing Loss[17]

The financial crisis that started in late 2007 in US had a massive impact on world industrial production, both on the total output and on the output distribution between mature industrial economies and developing countries. Focusing on the crisis period 2008-2009, we can estimate the 'manufacturing loss' by comparing three different scenarios (all estimates are given at constant 2000 US$):

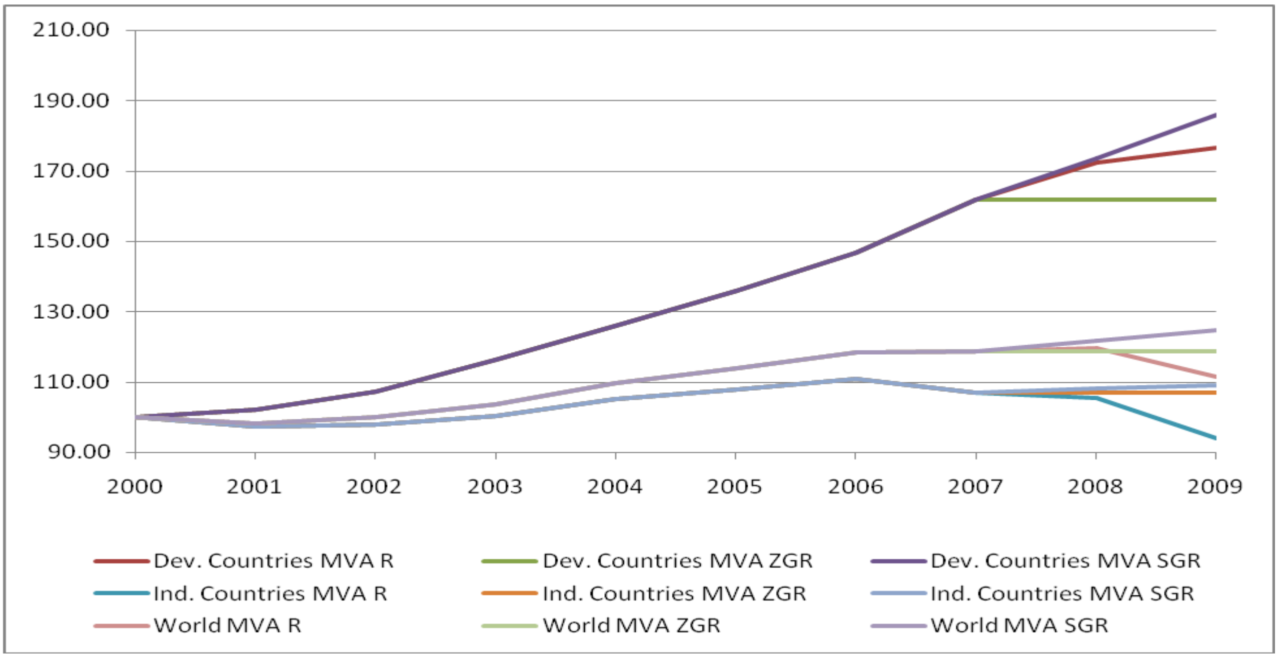
- the first scenario is the *actual* world manufacturing value added (World MVA R) during the crisis period 2008-2009;
- the second one is a *zero growth estimate* of world manufacturing value added (World MVA ZGR) for the crisis period 2008-2009;

[17] This section mainly draws on Andreoni and Uphadaya, 2013 (forthcoming).

- the third one is a *sustained growth estimate* of world manufacturing value added based on the average annual growth rate achieved in the pre-crisis period between 2000 and 2007 (World MVA SGR).

The *manufacturing loss* estimate reveals the collapse of industrial production worldwide with respect to both the zero and the sustained growth rate scenarios (see Figure 8). Specifically world manufacturing loss was US$ 361.32 billion (with respect to the zero growth rate scenario) and US$ 875.72 billion (if we compare it with the sustained growth rate scenario). This later figures comes to more than 1 US$ trillion at current prices.

Figure 8: Real, Zero and Sustained Growth of MVA



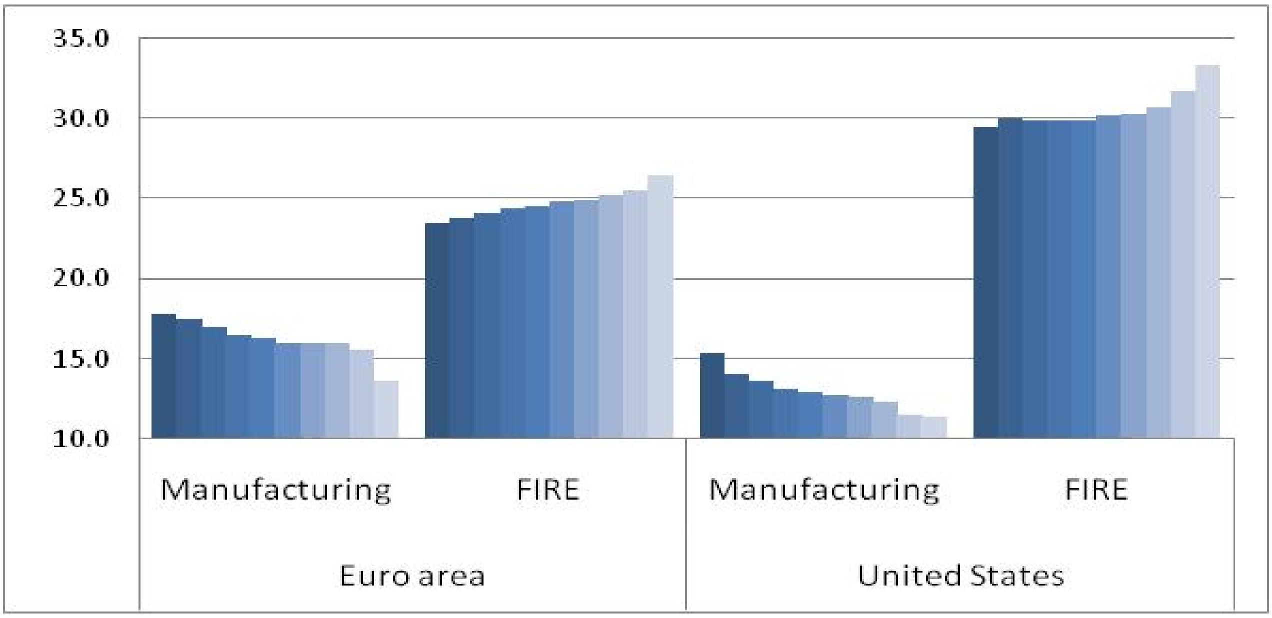
Source: Andreoni and Uphadaya, 2013; UNIDO MVA database 2011.

Now the industrialised countries in North America, Europe and Asia witnessed a severe manufacturing loss calculated to be US$ 671.01 billion (with respect to the zero growth rate scenario) and US$ 814.58 billion (with respect to the sustained growth rate scenario). However, in contrast, the manufacturing value added (MVA) in developing countries continued growing at least with respect to the zero growth rate scenario so there was a total *manufacturing gain* of 309.68 billion US$. In the sustained growth estimate scenario, the manufacturing loss in developing countries was seven times more contained than that of industrialised economies (equal to US$).125.17 billion

These results are not totally surprising if we look at these data in the context of the long term manufacturing trajectories discussed above (see section 2.1). Since 1995 developing countries' contribution to world MVA increased 13 percentage points (going from 20%to 33 %), according to UNIDO statistics. In other words, MVA has multiplied by 2.25 times. Among the developing countries, China and India drove the expansionary process, with the former becoming the world's second largest industrial power and the latter entering the top ten of world manufacturing producers for the first time ever.

In contrast, in the case of the mature industrialised economies, the analysis seems to suggest that the financial crisis introduced a structural break in the data (although it is difficult to isolate the impact of long-term trends from the manufacturing loss experienced in the 2008-2009 period). This means that the process of sectoral re-composition that mature industrialised economies have been experiencing since the 1970s accelerated as a result of the financial crisis. The speed at which mature industrialised economies (in particular US and countries in the Euro area) have been losing manufacturing shares in GDP is remarkable. A good way to visualise this is to look once again at the increasing contraction of manufacturing in favour of service sectors such as finance, real estate and business services. The latter are often abbreviated as FIRE (see Figure 9).

Figure 9: Share of manufacturing and financial and business services in GDP in industrialised countries from 2000-2009, at current US$



Source: Andreoni and Uphadaya, 2013; UNIDO and OECD database.

After the crisis period 2008-2009, countries' performances continued to be extremely differentiated. During the period 2008 – 2011, traditional industrialised countries registered on average a significant shrinking of their manufacturing base (as measured by the fundamental industrial diagnostic, MVA per capita). The Republic of Korea is the only country among the industrialised nations that increased its MVA performance. In contrast, amongst developing countries, China and India witnessed an overall expansion of their manufacturing base. This is shown in Table 3 for a sample of countries including the top twenty performers in terms of share in world manufacturing value added and world manufactured exports in 2010.

It is this dramatic acceleration in the de-industrialisation process experienced in developed countries as a result of the financial crisis that has led to an increasing questioning of the pro-services 'conventional wisdom'[18]. The crisis situation (along with the increasing

[18] For a comparison between the crisis rates and the pre-crisis rate of de-industrialisation see Andreoni 2013.

questioning of pro-services proponents' intellectual assumptions) has led many analysts to ask : 'Has off-shoring gone too far?' and, more importantly, 'Does manufacturing still matters for the wealth of advanced nations?'

Table 2: Winners and losers in a time of global financial crisis, 2008 – 2011

COUNTRY	MVApc AGRate	MXpc AGRate	MHVAsh Change	MVAsh Change	MHXsh Change	MXsh Change	ImWMVA Change	ImWMT Change
Argentina	2,89%	4,20%	0,00	-0,49	7,74	-4,09	0,138	0,084
Belgium	-1,44%	-0,20%	-3,49	-1,07	-1,75	-0,66	-0,029	0,127
Brazil	0,36%	4,88%	0,00	-0,73	-10,80	-2,42	0,085	0,333
Canada	-3,32%	-0,81%	0,00	-1,71	-0,42	-0,20	-0,161	0,072
China	7,01%	6,99%	0,00	0,38	0,82	0,40	4,131	4,362
China, Hong Kong SAR	-6,36%	3,48%	-0,10	-0,49	4,48	-3,94	-0,012	0,654
China, Taiwan Province	2,98%	4,29%	0,00	-0,22	2,62	-0,62	0,244	0,491
France	-2,81%	-1,16%	-2,07	-1,31	0,04	-0,75	-0,258	0,021
Germany	-2,64%	0,47%	-2,33	-2,47	0,99	-1,43	-0,620	0,586
India	6,06%	3,98%	0,00	0,28	0,94	-0,38	0,520	0,331
Indonesia	3,24%	7,16%	-0,60	-0,16	-0,55	-5,00	0,155	0,285
Italy	-4,40%	-1,21%	0,85	-2,27	-0,46	-1,68	-0,434	-0,036
Japan	-4,14%	1,17%	0,00	-3,00	-0,74	-0,74	-2,481	0,511
Malaysia	-0,15%	5,73%	0,00	-1,70	1,17	1,70	0,024	0,422
Mexico	-1,09%	3,19%	0,00	-0,62	0,95	-1,69	-0,016	0,413
Netherlands	-2,11%	-2,29%	0,00	-0,94	1,11	-0,53	-0,062	-0,148
Republic of Korea	2,47%	6,80%	0,00	0,14	-0,81	-0,27	0,332	1,231
Russian Federation	-1,76%	0,99%	-1,41	-1,55	-6,03	4,45	-0,089	0,093
Spain	-5,52%	-3,84%	0,16	-2,28	0,49	-1,27	-0,263	-0,190
Sweden	0,25%	-4,19%	-12,44	-0,43	-0,36	-1,25	0,021	-0,152
Switzerland	-0,54%	2,86%	0,00	-0,75	1,34	-1,25	-0,008	0,269
Thailand	1,76%	5,40%	0,00	0,06	-1,89	-2,87	0,082	0,378
Turkey	1,77%	-4,68%	0,00	0,13	0,28	-1,51	0,116	-0,114
United Kingdom	-3,84%	0,36%	-11,28	-1,41	-0,53	0,16	-0,398	0,202
United States of America	-1,98%	0,52%	0,00	-1,06	-5,76	-2,07	-1,232	0,824

MVApc: manufacturing value added per capita
MXpc: manufacturing export per capita
MHVAsh: share of medium and high tech activities in total manufacturing value added
MVAsh: share of manufacturing value added in GDP
MHXsh: share of medium and high tech products in total manufactured exports
MXsh: share of manufactured exports in total exports
ImWMVA: share in world manufacturing value added
ImWMT: share in world manufactured exports
AGRate: annual growth rate for the period 2008 - 2011
Change: change in share from 2008 to 2011
Countries selection criteria: top 20 performers in WMVA (equal to 85%) and top 20 performers in WMT (equal to 78%) in 2010

Source: Author; UNIDO database

2. *Why* and *how* does Manufacturing still matter: Old rationales, New realities

Since the 2009 crisis there has been a proliferation of policy reports, academic contributions, manufacturing national strategies and white papers in all major industrialised economies, investigating if manufacturing still matters[19]. After having lost 41% of its manufacturing jobs in thirty years, the US is today among the most active players in shaping a *new pro-manufacturing vision*. This is rooted in the following arguments:

(i) Manufacturing is a crucial source of *high quality employment* (in US, during the period 2008-2010, it was estimated that earnings in manufacturing are some 20% higher than earnings in non-manufacturing industries - see Helper at al. 2012).

(ii) Producing tradable manufactured goods is essential to maintain the *trade balance*, given that around two-thirds of world trade is still in manufactured goods (according to UN Comtrade, the figure was 83.4% in 1996, while in 2009 it was 77.4%, of which 38% were medium tech products).

(iii) Manufacturing is the main engine of economic growth, thanks to its *higher productivity* and *scope for innovation.*

Many of the rationales put forward seem like ‘old wine in new bottles’, although they are often supported by new empirical evidence. For example Rodrik (2009) found that, since 1960, developing countries economic growth’ is strongly associated with the development of modern industrial sectors (both manufacturing industries and agribusiness). Another recent empirical analysis confirmed the ‘engine of growth hypothesis’ for a sample of 90 countries (21 advanced

[19] See among the others: Tassey, 2010; Pisano and Shy, 2009 and 2012; Ettlinger and Gordon, 2011; Ezell and Atkinson, 2011; Helper, et al. 2012; Bianchi and Labory 2011.

economies and 69 developing countries) in the period 1950-2005 (Szirmai and Verspagen, 2010). This study found that the share of manufacturing is positively related to economic growth from 1950 to 2005 (in particular for poorer countries), while services have a significant positive effect only until 1990 and with coefficients far lower than those of manufacturing. Interestingly in the period 1990-2005 the coefficient for services becomes insignificant.

Now old rationales and new evidence are not fully satisfactory in addressing the 'why' and 'how' parts of the does manufacturing still matter question. There are two reasons for this insufficiency.

Firstly, without disaggregating the analysis from the country level to the sub-sectors and even production activities/tasks levels, it is difficult to say whether certain manufacturing industries matter more than others (still less why and how).

Secondly, without taking into account the new manufacturing production activities, we are not able to identify the fundamental channels through which certain manufacturing industries perform their 'catalytic role' (the expression is from the input-output analysis of manufacturing-services linkages by Park and Chan, 1989). In this respect, increasing doubt has been cast on the claim that the 'physical' intersectoral linkages are still the main vectors through which manufacturing pulls overall economic development forward. Thus we propose investigating whether today the kind of linkages that make manufacturing central for economic dynamism are in fact 'technological' nature, location-specific and cumulative in the form of 'industrial commons', both at the sectoral and inter-sectoral levels[20].

The following two sections address the reasons why certain manufacturing industries are more important than others and why technological linkages stemming from manufacturing industries are key

[20] These arguments are fully developed below, in the third essay of this dissertation

enablers of a country' systemic capacity to generate technological change. First, we argue that the development of a new pro-manufacturing vision should focus on the crucial role played by certain 'mother industries' (as the machine tool industries are called). In the second section, there should also be a focus on those systemic technological linkages which affect the scope for innovation of the overall economic system. This second issue is going to be addressed by analysing the negative consequences of de-linking manufacturing production from services (off-shoring) which systematically disrupt the bundle of technological linkages constituting the industrial commons.

2.1 The manufacturing engine: 'The production of machines by means of machines'

The machine tools industry is a sub-sector of the mechanical engineering industry. Machine tools are known as 'mother machines' because they enable the production of all other machines and equipment (within the broader mechanical engineering industry), including themselves. There are various reasons why machine tool industries are at the very core of the manufacturing engine (Fransman 1986).

Firstly, machinery producers have a unique capacity of 'self-reproducing themselves' that is, the capacity of manufacturing their own machines (CECIMO, 2011). Secondly, the fact that machine tools critically enable cost reductions, quality improvements and productivity increases, and reduction in set-up and lead production times. Thirdly, machine tools have a wide range of applications in major industries (such as mechanical engineering and construction, computers, automotive and aerospace, wind turbines and satellite and all manufacturing processes including metals).

The relevance of these characteristics was documented by Nathan Rosenberg (1963) in his historical analysis of the machine tools industry. His very comprehensive study began with the emergence of the first specialised producers of machine tools (from 1840 to 1910. By 1910, 82.4% per cent of the world production of machine tools was concentrated in three countries: the US (50%), Germany (20.6%) and the United Kingdom (11.8%)[21]. The historical account provided by Rosenberg provides crucial evidence demonstrating why and how countries' manufacturing development trajectories are driven mainly by their machine tools industry. Among the multiple ways through which machine tool industries introduce and spread technical change, Rosenberg (1963:416) identified three key mechanisms.

Firstly, what he calls the 'external adaptation' principle. According to this principle "all innovations – whether they include the introduction of a new product or provide a cheaper way of producing an existing product – require that the capital goods sector shall in turn produce a new product (capital good) according to certain specification" (1963:416). Indeed, machine tools producers are requested to continuously customise their production and develop innovative solutions for more efficient production systems, often joining their forces with their customers in the consumer goods or other capital goods industries. In doing so, machine tools producers operate as 'innovation bridges'. In other words, they transfer production expertise and transform the way in which goods are produced and services are delivered.

Secondly, the 'internal adaptation' principle, refers to the unique possibility for machinery producers to improve and change the characteristics/specifications/standards of the capital goods they

[21] In 1925 the same three countries still dominated the 84.3% of world machinery production. These data are taken from Dr Karl Lange memorandum presented in May 1927 at the League of Nations International Economic Conference. As stressed in the journal *Mechanical Engineering* (1928:285) Lange's work is "the first analysis of the machinery industry of the world that has been published". After the World War II, the situation remained almost unchanged, although the USSR entered the machine tool industry global race reaching 10% of world production (Rynn, 2010).

produce by improving and changing the machines used for the production of the capital goods themselves. Cost-reduction in the machine tools industry triggers a cumulative process through which investment activities in other industries are boosted, the speed at which technological innovations are installed and spread increases, and the marginal efficiency of capital of other industries rises. Finally, for the economy as whole, cost reductions in the machine tools industry is a form of capital saving.

The third principle is that of 'external economy'. According to Rosenberg, the "high degree of specialisation [in machinery production] is conducive not only to an effective learning process but to an effective *application* of that which is learned. This highly developed facility in the designing and production of specialised machinery is, perhaps, the most important single characteristic of a well-developed capital goods industry and constitutes an external economy of enormous importance to other sectors of the economy" (Rosenberg, 1963:425).

The machine tools industry underwent profound transformations throughout the twentieth century. Initially, the introduction of numerical control (NC) machine tools improved flexibility, allowed automation and reduced costs. Later increasingly refined computerised numerical control (CNC) machines, as well as computer-aided design (CAD) and computer-aided manufacturing (CAM) offered efficiency gains in material consumption, shortened the period between the design and the production process, and allowed the increasing control of complex production systems (Mazzoleni, 1997; Arnold 2001).

Despite these changes, the three mechanisms identified by Rosenberg as making the machine tool industry 'special' still stand and indeed their scope is broadened. The machine tools industry increasingly enables the working of complex production systems in which the traditional manufacturing tasks are intertwined with service activities and new technologies. This has been widely documented in technical reports produced by the European network of machine tools producers[22].

These reports explain how the machine tools "enable to transfer the latest technological developments in information and communication technologies or material sciences into production systems, which allow to increase the efficiency of the production process and to machine new materials which are used later in new fields of application" (CECIMO 2011:12; see also the Thematic Report on *Key Enabling Technologies* produced by the Working Team on Advanced Manufacturing Systems, 2010). The machine tools industry also facilitates the accumulation of engineering expertise that cannot be easily copied/reproduced by competitors. This guarantees a certain competitive advantage to producers in international markets and a 'first mover' advantage in the development of future products and processes.

As a result of these unique characteristics much evidence can be found, throughout the last century, in support of the claim that those countries that saw their machine tools sector go into decline found they had an increasingly reduced capacity to make goods. By the same token these same countries which saw falls in manufacturing output were also those where the remaining manufacturing output became increasingly dependent on the import of 'machines for making goods'.

Among the major industrial economies those countries which underwent a profound process of de-industrialisation in the second half of the last century were also those who lost the higher shares in world machine tool production. The United States went from 26.6 per cent in

[22] CECIMO was founded in 1950 and currently covers almost the entire metalworking machine tool production industry in Europe and a third of worldwide firms. It has as members approximately 1500 companies (over 80% of these are SMEs) with a total number of 150.000 employed people. The turnover in 2011 was approximately 21 billion euros and ¾ of the production was shipped outside CECIMO region (the latter including EU, EFTA and Turkey).

1980 to 11.7 per cent of world machine tool production in 1995 (the United Kingdom lost its major role before the 1980s, and in 1995 accounted for less than 3 per cent of world production). In contrast Japan and Germany followed the opposite trend during the same period, going from 14.3 to 23.5% and from 17.6 to 22.6% respectively (Rynn, 2010).

In 2010 one-third of world machine tool production is concentrated in China and another third in the Euro area (the three major producers are Germany with 43.5%, Italy with 23% and Switzerland with 11%, of total European, CECIMO database). Meanwhile Japan still controls 14%, followed by the Republic of Korea with 7% and Taiwan with 6%. As of 2010 the United States accounts for only 4% of global production.

A full 66% of the machine tools produced in 2010 were consumed in Asia, 21% in Europe and 13% in America. In 2011 China alone accounted for 45% of world machine tool consumption. It was followed by three major net exporters (Japan, Germany and Italy which consumed 9, 8 and 4 percent respectively) and one major importer, the United States, with an 8% share in world machine tool consumption (Oxford Economics, 2012). According to the CECIMO forecast, machine tool consumption will continue shifting to Asia which will reach 70% of world total in 2015, confirming Asia as the major consumer and producer of machine tools.

2.2 Breaking technological linkages: Loosing industrial commons and technological lock-in

After two decades (from the 1980s to the late 1990s)[23] in which the farming out/abroad of in-house operations occurred with almost

[23] According to *The 1999 Outsourcing Trends Report*, the outsourcing of operations and facilities across industries rose by 18 percent only in the period from 1999 to 2000.

religious fervour, more recent attitudes have been cautious and even fearful of their consequences. The dominant view implied that “by shedding assets, companies can be born again as product designers, solutions providers, industry innovators, or supply chain integrators”. They can thus “dump operational headaches and bottlenecks downstream, often capture immediate cost savings, and avoid labour conflicts and management deficiencies” (Doig et al. 2001, p. 24).

However, in many industries such as automotives, electronics and software, it has been observed that companies which outsourcing too much run the risk of ceding and, sometimes, even destroying those capabilities and processes that have constituted their competitive advantages. Moreover, outsourcing companies fail to capture the innovation opportunities that reside in the spaces of interaction and interfaces between manufacturing production and production related services (Quinn and Hilmer, 1995).

In sum, there is considerable evidence that many companies have *overestimated* the advantages of outsourcing and offshoring and *underestimated* problems, such as dealing with inventory, obsolescence, organisational traumas, reaching quality standards and maintaining in- house technological capabilities (Ritter and Sternfels, 2004).

The relocation of manufacturing firms and/or service providers to other countries triggers two simultaneous *transformational processes* which affect outsourcers’ production and technological structures. First, countries relocating the major part of their manufacturing activities tend to experience a process of industrial commons deterioration, increasing relocation of production related services and technological lock-in. Second, in contrast, those countries in which production is relocated experiecne an expansion of the manufacturing sector and an increasing co-location of other manufacturing firms (as well as production related services providers).

The transformation in the US software industry demonstrates this point well. In order to lower software development costs US companies initially started outsourcing mundane code-writing projects to Indian firms[24]. However Indian companies soon developed their technological capabilities in software engineering because of the experience provided by the routine work they had been given. Thus India became increasingly able to attract more complex manufacturing and services activities to India such as developing architectural specifications and writing sophisticated firmware and device drivers (Pisano and Shih, 2009 and 2012).

The opposite trend, namely loss of technological capabilities has been observed in US software companies. Of course a similar process may be triggered by off-shoring services providers as well as manufacturing firms. However, given the multiplier effects which characterise the expansion of the manufacturing base and the fact that certain services (especially production-related services) have to remain near production sites, it seems that off-shoring manufacturing activities is strategically more damaging than losing service-providers.

These cumulative processes of relocation and co-location are responsible for the transformation of the productive and technological structures of countries and for the present and future prospects of innovation and specialisation of private companies. For example, as a result of outsourcing, the U.S. industrial structure is no longer able to manufacture many of the cutting-edge products it invented. As has been widely documented "[a]mong these are such critical components as light-emitting diodes for the next generation of energy-efficient illumination; advanced displays for mobile phones and new consumer

[24] Apple is a well-known exception. Although it has outsourced the manufacture of its notebooks, iPod, and iPhone, Apple has preserved in-house technological capabilities by remaining involved in key phases of the production process. It still plays the major role in the selection of components, industrial design, software development as well as direct interaction with users (i.e. 'learning by using').

electronics products like Amazon's Kindle e-reader". They also include "the batteries that power electric and hybrid cars; flat-panel displays for TVs, computers, and handheld devices; and many of the carbon-fibre components for Boeing's new 787 Dreamliner" (Pisano and Shih, 2009:116).

In contrast there is mounting evidence that countries acquiring manufacturing production and developing production-related services are accumulating technological capabilities and increasingly benefitting from the relocation and co-location of companies at all stages of global value chains. By 2010, Fortune 500 companies have 98 R&D centres in China and 63 in India. Surprisingly, IBM employs more people in the developing world than in America while in 2008, the Chinese telecom giant Huawei applied for more international patents than any other firm in the world (Cataneo et al. 2010). In fact by some estimates as much as 90% of electronics research and development now takes place in Asia (McCormack, 2009).

2.2.1 Loosing Industrial commons[25]

Pisano and Shih (2009) have done important research on the semiconductor, electronics, pharmaceutical and biotech industries. This has has revealed how the production and innovation capacities of a given economic system depend on the presence of multiple resources such as R&D know-how, engineering skills, technological capabilities, and specific manufacturing and prototyping competences. Many of these resources are embedded in a large number of manufacturing and services companies as well as other organisations, typically universities and vocational schools. The co-location of these actors means that the same companies and institutions can have access to their resources. This is the root of the *industrial commons* phenomenon.

[25] The idea of industrial commons is rooted in the classical work on industrial districts (Marshall, 1920) and the work by Michael Best in Greater Boston.

As in almost all high-tech industries, product and process innovations are strongly intertwined. The fact that manufacturing firms can undertake daily interactions with other manufacturers and the providers of production related-services locally constitutes a source of competitive advantage which benefits all actors involved (i.e. *industrial commons*)[26]. It is important to stress that even the development of high-tech cutting-edge products often depend (amongst other factors) on the commons of a mature manufacturing industry.

The deterioration of the industrial commons caused by outsourcing can, in the long-run, affect the ability of a given economic system to introduce new products. This is because the suppliers, skills and services required to set up a new enterprise are no longer available locally. In contrast, countries in which manufacturing and services activities co-locate will experience processes of industrial commons development and benefit from innovation opportunities arising at the manufacturing-services interfaces.

2.2.2 The risk of technological lock-in

The second dynamic related to the de-linking of manufacturing and services in global value chains is that of technological lock-in. This refers to macro-level forces that create systematic barriers to the diffusion and adoption of efficient technologies (Arthur, 1989). One of the major factors associated with technological lock-in is the idea of increasing returns to adoption. Early adoption of a technological solution might give it enough edge to secure its dominance in the market. Even if an improved technology (e.g. more environmentally efficient) is developed, such increasing returns may keep them locked-out of the market (i.e. it doesn't pay off to change production). These

[26] Coffey and Bailly (1991, p.109) emphasise the role of co-location stressing how "it is the cost of maintaining face-to-face contacts between the producer on the one hand, and their inputs and markets, on the other hand, that is potentially the most expensive element of intermediate-demand service production".

technological lock-in dynamics explain the continued dominance of the QWERTY keyboard over the Dvorak Simplified Keyboard (David, 1985), and the VHS video cassette recorder standard over Betamax (Arthur, 1994).

Recent work has shown that manufacturing offshoring can lead to technological lock-in effects. Fuchs and Kirchain (2010) explain that, as production in the optoelectronics industry has been outsourced to East Asia, the manufacture of better-performing designs developed in the US no longer pay off. “Production characteristics are different abroad, and the prevailing design can be more cost-effective in developing country production environments” (Fuchs & Kirchain, 2010). Thus they conclude that offshoring reduces incentives to innovation and can therefore lead to an erosion of technological competitiveness.

The potential consequences of technological lock-in have been increasingly attracting attention among academics and policymakers. Their concern not only focuses on the potential adverse consequences of the loss of production capacity within advanced countries, but also on the potential loss of technology dynamisms and competitiveness in global industrial systems as a whole.

PART II

Manufacturing Causational Chains:
A new theoretical framework for linking structural change and production capabilities dynamics

1. The Dynamics of Manufacturing Development: A synthesis

The development of a new pro-manufacturing vision depends on the possibility of connecting in a systematic way a set of logics operating at different levels. The crucial levels are the *macro* level of national economies, the *meso* level of sectoral and intersectoral dynamics and finally the *micro* level of production capabilities dynamics in an enterprise. Indeed, as we have seen in the previous sections, in order to understand the relevance of certain 'special' manufacturing industries (i.e. the machine tools industry) and technological linkages ('industrial commons'), our analytical lenses have to link the micro, meso and macro levels of analysis.

At the macro/country level, we have seen how manufacturing plays a key role in boosting economic growth, maintaining the trade balance and guaranteeing high-quality employment. At the meso-level (i.e. the level of sectoral composition of the economic system), the catalytic role played by manufacturing industries was explained by referring to the linkages and spillover effects they have on the rest of the production and technological structure. However, in order to fully capture where these linkages and spillovers originate, as well as how they trigger sectoral and intersectoral transformations, it is necessary to scale down the analysis up to the micro level and to focus on production capabilities dynamics and learning in production (see also Essay 2 and 3).

Few contributions have attempted to disentangle the specific causational chains linking micro, meso and macro dynamics. However, if we embrace the idea of development as *"a process that links micro learning dynamics, economy-wide accumulation of technological capabilities and industrial development"* (Cimoli, Dosi and Stiglitz 2009:543), the need for a synthesis becomes inescapable. This definition of development presupposes the existence of a causational chain linking the production capabilities dynamics at the micro and meso levels to the structural change dynamics of the overall economic system (macro level).

The following two sections set the stage for disentangling this causational chain by identifying key analytical points necessary for any coherent account of the nested interaction. The analysis will be based on various often-disconnected research strands. What makes them relevant in the analysis of manufacturing development is the fact that they are rooted in a production paradigm (Pasinetti, 2007). The current debate in development economics is progressively rediscovering production as well as some of the issues that were central for 'classical development economists' like Prebisch, Hirschman, Myrdal and Kaldor as well as 'structuralists' such as Pasinetti, Syrquin, Leontief and Chenery. This focus on production forms the theoretical backdrop for this attempted synthesis of two apparently unconnected strands of economic theory.

Few attempts have been made to combine structuralist theories of economic development with Schumpterian evolutionary microeconomics (Nelson and Winter, 1982) and the capability theory of the firm (Penrose, 1959; Richardson, 1960). The integration and cross-fertilisation among these traditions in economic analysis appears extremely promising given their respective focus on demand-led structural change, supply-side technological efforts as well as institutional persistence and change (e.g. Cimoli and Porcile, 2009; Cimoli, Dosi and Stiglitz, 2009; McMillan and Rodrik, 2011)[27].

It is our conviction that a fruitful dialogue between these multiple lines of investigation will provide the fundamental analytical

[27] It is far beyond the scope of this paper to review and discuss the main potentialities and problems that such an integration would imply from a theoretical and empirical perspective.

basis for investigating manufacturing development its underlying structural change and production capabilities dynamics.

2. Structural Economic Dynamics: A multi-sectoral representation of the economic system

Structural change is best understood as the process sectoral re-composition of an economic system. This means it includes underlying transformation of its productive and technological structures as well as demand composition (Pasinetti, 1981 and 1993; Chenery et al., 1986; Landesmann and Scazzieri, 1990; Andreoni and Scazzieri, 2013). Structural change entails both a process of *inter-sectoral transition* (i.e. moving across sectors, from low to medium and high productivity sectors) and of *intra-sectoral deepening* (i.e. moving within sectors, from low to high value added sub-sectors).

Since Roseintein-Rodan's path breaking research (1934 and 1943), classical development economists have adopted a structuralist approach, that is, they have concentrated on the analysis of long-term structural change and on the identification of those structural bottlenecks impeding industrialisation, in particular manufacturing development. Latin American structuralism, encapsulated in the work of Raul Prebisch (1949) and Celso Furtado (1964), focused on the specific challenges that developing countries face, given the 'centre – periphery' international geography of power. Problems connected to lack of foreign exchange, dualism in international trade, technology transfer were all emphasised.

These lines of research were in dialogue with the work of Albert Hirschman and, later, of two Cambridge economists, Nicholas Kaldor and Joan Robison. However they never managed to achieve a unified analytical framework. Working along Keynesians lines, Robinson found a compromise with the intractability of the long-run by proposing a structural analysis of transforming economic systems in 'historical time'. On the other hand, as we have seen, Kaldor's empirical investigations aimed at identifying those *stylised facts* of manufacturing development through which general principles of structural change were deduced (Kerr and Scazzieri, 2012).

The development of a comprehensive approach for the analysis of structural change dynamics only really took shape with the second generation of post-Keynesian economists, in particular Richard Goodwin and Luigi Pasinetti[28]. At the most fundamental level, a structural economic dynamics approach starts from the recognition that economic growth is a *sector-specific* process (not sector-neutral or activity-neutral as in the more traditional neoclassical model such as Solow's).

Thus at any given point in time, the economic system has to be represented by a multi-sectoral model characterised by a particular *compositional structure*. This structure is inherently subject to change in a '*truly dynamic sense'.* After all, as Luigi Pasinetti (2012: 555-557) pointed out, the structure of the economic system "*evolves* through time, with productivity and demand growing at different rates from sector to sector and independently of one another".

[28] The key differences between the two grand research programmes are summarised in Kerr and Scazzieri (2012) "Common to both is the analytical representation of the economic system in terms of a multi-sectoral model and the interest in the patterns of structural change a multi-sectoral economy undergoes over time. Points of difference are the specific representation of the multi-sectoral economy and the way in which dynamic factors are addressed. In particular, a Goodwin-type economy (in its conclusive and most elaborated formulation) consists of a set of 'dynamically conjoined' sectors such that processes showing similar dynamic characteristics (similar rates of actual or potential growth over time) would be part of the same aggregate sectors. In contrast to Goodwin, Pasinetti adopts a representation of the multisectoral economy whereby productive sectors are identified not by their dynamic features but by their respective final outputs. […] The difference between Goodwin's and Pasinetti's analytical representation of a multi-sectoral production economy are rooted in their respective approach to the study of economic dynamics. For Goodwin the central problem is how to assess the instability of the economic system under the specific institutional set-up of a capitalist economy. Pasinetti's view is different insofar as he is concerned with the identification of permanent and natural features that are in principle independent of specific institutional assumptions".

Moreover, as Pasinetti goes on to observe, “it is within a context of this type that the interaction of the unequal evolution of technology and of the inevitability complex evolution of the *composition* of consumption of goods and services give rise to the *structural* dynamics of quantities, of prices, and of sectoral employment. As a labourer, each single individual contributes to a very specialised part of the division of production tasks in each single sector, but as a consumer, she demands in principle the goods produced by all sectors of the whole economic system. […] Through this channel, owing to the all-embracing effect of the overall demand, the set of all production processes forms a *true* economic system” (Pasinetti 2012: 555-557).

Within the structural dynamics approach, as a result of these compositional changes, the productivity potential of any given economic system will be different and subject to continuous change over time. However, at each given point in time, certain parts of the structure have to remain fixed in order for others to be able to change. In other words structural economic dynamics follow a specific hierarchy of change determined by both the elements of the systems and their interdependences.

In this respect the principle of *relative invariance* postulates that “any given economic system subject to an impulse or force is allowed to change its original state by following an adjustment path that belongs to a limited set of feasible transformations. … The impulse from which the original state of the economy is modified may be purely exogenous but the actual process of transformation can be explained in terms of the dynamic characteristics of the existing structure’ (Landesmann and Scazzieri, 1990:96; see also Andreoni and Scazzieri 2013 on the distinction between feasible and viable structural trajectories).

What occurs when a technological impulse triggers structural change dynamics within and across sectors can be illustrated within a multi-sectoral representation of the economic system where structural dynamics unfold according to a principle of relative invariance (Richard Goodwin 1987 and 1989). As Goodwin stressed, an "important innovation in energy, or transport, or automated control, will gradually lead to alteration of least-cost processes in many other sectors and thus will initiate technological change over a long period. This will persist over time, not only because any such improvement undergoes prolonged small improvements, but also because it usually needs extensive adaptation to a variety of uses" (Goodwin, 1987, p. 147).

The existence of a web of technological interdependencies linking production activities at different levels of aggregation and within different time horizons allows us to open 'the black box of manufacturing development' and create a bridge with the micro-analysis of capabilities dynamics. Production capabilities dynamics, in particular, are the fundamental motor force behind the structural economic dynamics of a multi-sectoral economic system as they operate within a materially constrained framework, whose transformation takes times.

3. The Economics of Capabilities

The history of human societies is replete with extraordinary examples of the increasing capabilities of individuals and collectivities, both as producers of wealth and consumers of resources (Hicks, 1969; Rosenberg, 1976). Through continuous and cumulative innovations, learning and processing of organisational and technological knowledge, human beings have become increasingly capable of mastering their relationship with the physical world.

At the same time, the development of a sophisticated set of institutions, or 'social technologies' such as the market and the firm, has allowed human beings to coordinate their social and economic relationships. It has also permitted them to engage in more complex production activities, both individually and collectively. In particular, the adoption of the Smithian principle of the division of labour in manufacturing production has allowed for shorter idle periods of fund inputs utilisation, greater effectiveness in task execution, and faster learning. Most importantly, it has been a fundamental step in the creation and improvement of specialist competences because ‘knowledge grows by division’ (Loasby, 1999:50).

The concept of capability “floats in the literature like an iceberg in a foggy arctic sea, one iceberg among many, not easily recognized as different from several icebergs nearby” (Dosi et al., 2000: 5-6). Capabilities (generally defined as capacities to act in an intentional way) have been ascribed to very different actors (and their different actions and functions). These run the gamut from individual agents (e.g. entrepreneurs, workers and consumers) to collective entities, organisations and institutions, (e.g. firms or clusters of firms). Taken all together, these concepts are elements of what we have called here the *Economics of Capabilities.*

3.1 Production Capabilities

In the Coasian theory of the firm (Coase, 1937), “production costs determine the technical substitution choices [while] transaction costs determine which stages of the productive process are assigned to the institution of the price system and which to the institution of the firm” (Langlois, 1998: 186). Thus, the firm emerges as a more convenient way of implementing the production process and the lowest cost option for obtaining control over the relevant factors of production.

However, as Edith Penrose (1959) notes, creating a firm may not simply be a way of reducing transaction costs. It may in fact denote the highest value option for the creation and development of capabilities. Penrose’s (1959:149) definition of the firm as “a pool of resources the utilisation of which is organized in an administrative framework" constitutes the original foundation of the capability theory of the firm. In this theory, the firm is a collection of physical and human resources that can be deployed in a variety of ways to provide a variety of productive services. In fact "the services yielded by resources are a function of the way in which they are used – exactly the same resource when used for different purposes or in different ways and in combination with different types or amounts of other resources provides a different service or set of services" (Penrose 1959: 25). In the Penrosian framework the growth process occurs through the firm's recognition and exploitation of productive opportunities, specifically of "all of the productive possibilities that its entrepreneurs see and can take advantage of" (Penrose, 1959:31).

Building on his classic contribution *Information and Investment* (1960), George B. Richardson further developed the Penrosian theory of the firm and was the first to introduce the term capabilities to economics (Richardson 1972; see also Loasby, 1999). Maintaining the analytical distinction between productive resources and productive services, Richardson (1972:888) describes industries and their firms as entities in which a large number of activities are carried out through the adoption of an appropriate cluster of productive capabilities.

"It is convenient to think of industry as carrying out an indefinitely large number of activities, activities related to the discovery and estimation of future wants, to research, development, and design, to the execution and coordination of processes of physical transformation, the marketing of goods, and so on. And we have to recognise that these activities have to be carried out by organisations with appropriate capabilities, or, in other words, with appropriate knowledge, experience, and skills."

Richardson's definition stresses how the concept of capabilities refers to a form of know-how, namely 'appropriate knowledge, experience and skills' that cannot be reduced to know-that. This irreducibility occurs because productive capabilities additionally imply the capacity to apply the know-that needed to obtain a given intended result[29]. This know-how emerges and accumulates through a continuous process of trial and error, interpretations and falsifications. This process functions on the basis of an experimental and pragmatic approach to the solution of technological and organisational problems in production – i.e. learning processes (Arrow, 1962; Rosenberg, 1976, 1982 and 1994; see the second essay of this dissertation). The learning processes through which capabilities develop are cumulative in the sense that "the acquisition of certain kinds of know-how facilitates the acquisition of further knowledge of the same kind, and impedes the acquisition of knowledge of incompatible kinds" (Loasby, 1999:58).

The specific way in which capabilities are built and accumulated has two main implications. First, firms tend to specialise in the execution of a certain set of interrelated production tasks (i.e. similar activities) that only require a limited set of capabilities. Secondly, firms not only need to know how to perform certain production tasks, but also how to get others to perform production tasks for them. Firms can indirectly acquire capabilities through two major means: either by gaining control of the capabilities of others (e.g. through the institution of the firm itself or through inter-firm cooperation) or by obtaining access to them (e.g. through the institution of the market)[30]. Thus, as Richardson (1972) shows, capabilities dynamics are at work at the very basis of *The Organisation of Industry* (the latter being the title of Richardson's 1972 paper).

Within industries the execution of different technological and organisational *functions* and productive *activities* by a given firm

[29] The need to identify the set of feasible operations in production processes given a set of existing 'work capacities' or capabilities has also been stressed in Scazzieri (1993) and Landesmann and Scazzieri (1996).
[30] As Marshall (1920) noted, evolution through the division of labour tends to favour both greater specialisation (increasing capabilities) and closer integration (an increasing number of institutional devices to coordinate capabilities and activities).

requires a set of relevant capabilities. Specifically, each function entails the execution of a certain number of production activities (and *tasks* as their components). These functions and activities are, of course, industry-specific as well as process and product-specific. The reason why a multitude of concepts of capabilities has been proposed is that each theoretical and empirical contribution has formulated a new set of concepts according to (i) the specific functions or activities focused on; or (ii) the static versus dynamic role played by the capabilities under consideration.

A good example of a capabilities taxonomy whose peculiarities depend on the first problematic (the specific activities focused on) is the technological capability matrix proposed by Sanjaya Lall (1992:167). This systematises firm-level capabilities according to different functional areas (e.g. process and product engineering) and the degree of complexity of different activities (from simple routines to innovative activities)[31]. Based on his matrix, Lall identified three main sets of capabilities:

(1) *Investment capabilities*: those capabilities needed to identify, prepare and obtain technology
for the expansion or commission, design, construction, equipping and staffing of a new facility;

(2) *Productive capabilities*: the skills involved in both process and product engineering as well as the monitoring and control functions included under industrial engineering;

(3) *Linkage capabilities*: the skills needed to transmit information, skills and technology to component or raw material suppliers and

[31] The work by Dosi, Nelson and Winter (2000) focuses on the non-reducible and collective nature of some of these productive capabilities. Thus, they highlight the fact that productive capabilities are owned more by organizations than by their individual members. The concept of organizational capabilities they propose seeks to capture the different dynamics responsible for: firstly, the spontaneous emergence of routines vis à vis the intentional development of organizational capabilities; and secondly, the process through which a certain productive capability becomes routinized and, vice versa, a routine emerges as a distinctive organizational capability.

subcontractors, consultants, service firms and technology institutions. Also included are the converse skills to receive information from said groups.

A good example of a capabilities taxonomy whose peculiarities depend on the second problematic (the static versus dynamic issue) is the work of Bell and Pavitt (1993). They distinguish capabilities used to produce industrial goods at a given level of efficiency and given input combinations (the static perspective) from those needed to discover, absorb, adapt and change productive and organisational techniques (the dynamic perspective)[32].

Building on a critical analysis of the main theoretical and empirical contributions in the capabilities field[33], we propose here the following operational definition of *production capabilities* (see also Essay 2 and 4):

Capabilities are personal and collective skills, productive knowledge and experience that are embedded in physical agents and organisations. Production capabilities are specifically those needed for firms to perform different production tasks as well as to adapt and undertake in-house improvements across different technological and organisational functions.

From the 'static efficiency' point of view, production capabilities are skills, experiences and productive knowledge that agents require in

[32] The same focus on a specific subset of productive capabilities, namely those required to manage technological change, can be found in the operation management and business studies literature. The concept of capabilities used there is that of dynamic capabilities. These are the "firm's ability to integrate, build and reconfigure internal and external competencies to address rapidly changing environments" (Teece et al., 1997: 516). This set of capabilities is crucial in explaining differences in firms' competitive advantages as it refers to the specific capacity of the firm to balance continuity (i.e. execution of invariant processes) with change (i.e. transformation of capabilities) given a certain exogenous shock.

[33] This proposed definition of productive capabilities is based on a literature whose roots can be found in the empirical research conducted in Latin America in the 1970s (the so called 'Katz Programme') and in the research work of Sanjaya Lall in India. See also Stewart and James (1982); Katz (1987); Dahlman et al. (1987); Lall, (1987 and 1992); Bell and Pavitt (1993); See also Romijn (1999) for a review.

order to choose, install and maintain capital goods and perform technical and organizational functions. In fact performing production tasks requires both capable agents, (i.e. agents endowed with productive knowledge and relevant skills) and the establishment of a certain *production capacity* (scale-appropriate assortment of equipment, machinery and other capital goods). The consideration of production capabilities independently of a firm's production capacity is impossible, since particular combinations of 'production capabilities-functions/activities/tasks' that can be realised are partly determined by the production capacity installed. Moreover, the expansion of the production capacity of a given firm results from strategic investment in capital goods such as machines, equipment, hardware and software.

From the 'dynamic efficiency' perspective, the absorption, adaptation and improvement of given production techniques, as well as innovations across different organisational and technological functions, mainly depends on the availability of a specific subset of production capabilities called *technological capabilities*. Capabilities needed to generate, absorb and manage technological and organisational change may differ substantially from those needed to maintain existing production systems. Although this distinction may be useful as a focusing device, it tends to underestimate the fact that technical change (especially in the form of small improvements) takes place throughout the entire production process and in all functional areas. This means that in reality change requires the activation of all kinds of production capabilities and not just narrowly defined technological capabilities.

Although some production capabilities (i.e. technological capabilities in a narrow sense) represent the main drivers in the process of technological and organisational change, they are not the only set of capabilities these processes require. In other words, it would be misleading to believe that 'labs' and 'R&D departments' where technological capabilities are presumably concentrated are the unique *loci* of technological and organisational change. In fact, as economic historians (Schumpeter, 1934; Rosenberg, 1976, 1982 and 1994; Kline and Rosenberg, 1986) have shown, the accumulation of production capabilities (and, in particular, of technological capabilities) results from deliberate in-house efforts. Specifically it requires the cumulative processes of *learning by doing*, *by using* and *by interacting*. This involves and includes the initial investment process, the product design phase and goes all the way up to the organisational and production phases.

We now develop a detailed taxonomy to identify the different classes of production capabilities that allow firms to operate across different functional areas and to perform production and technical change activities (see Table 5). The taxonomy is structured on two main axes. The vertical axis identifies different *functional areas*, while the horizontal axis distinguishes between a list of *productive activities* (static perspective) and a list of specific *technical change activities* (dynamic perspective) for each functional area.

As discussed previously, technical change activities require a specific subset of production capabilities, namely those technological capabilities that are necessary (albeit not sufficient) to change the way in which production activities are performed in each functional area. The proposed taxonomy also demonstrates that, while few production capabilities are function-specific and activity-specific, performing even the simplest production activities very often requires the activation and matching of interdependent clusters of production capabilities. In other words, taxonomies should not fix specific sets of productive capabilities in one exclusive functional area.

Table 3: A taxonomy of production capabilities

	Functional areas				
	1.Investment	**2.Product design**	**3.Process organization**	**4.Production process**	**5.Linkage and cooperation**
Productive Activities:	Feasibility studies	Replication of fixed specifications and designs	Production planning and control	Work flow scheduling and monitoring	Exchange with Suppliers
	Negotiations and bargaining suitable terms	Standard design for manufacturing	International certification (ISO 9000)	Manufacture of components	Horizontal cooperation across firms
	Equipment and machinery procurement	Development of prototypes	Automation of processes	Sub-assembly and assembly of components and final goods	Distribution and Marketing
	Recruitment of skilled personnel		Adoption modern organizational techniques (e.g. just in time and total quality control)	Stretching, control and maintenance of machinery and equipment	After sale services
			Flexible and multi-skilled production	Inventory control	
			Architectural services	Productivity and quality control	
Technical change activities:	Search for technology sources	Adaptations to product technology driven by market needs and request	Selection of technology and organizational formats	Efficiency improvement in tasks execution	Technological transfer and S&T linkages development
	Equipment design and adaptation	Improvements of product standards and quality	Minor changes to process technology to adapt it to the local conditions	Improvement and cost savings in machinery and equipment	Coordinated R&D and joint ventures
	Engineering training	Development of complementary products (e.g. embedded software) or components	Improvement and development of new organizational techniques	Inverse engineering and development of machinery	Licensing own technologies to others
	Joint ventures	R&D into new product generation	Improvement to layout		
		R&D (basic) into new materials and new specifications	Process oriented R&D (basic) for radical innovation		

Source: Author

3.2 Consumer capabilities

As we have seen, the concept of production capabilities has been widely adopted for representing production dynamics in a manner that goes beyond the 'black box' production functions representation. Crucially this concept is inherently intertwined with the idea of learning in production, the fundamental process through which production capabilities develop and transform over time and firms discover new productive opportunities(see also Essay 2). However as Michael Best (1999:108) pointed out, "productive opportunities link the firm to the customer in an interactive relationship in which new product concepts are developed".

This suggests two important points. Firstly that the development of products and the development of consumers' needs are interdependent and. Secondly, that just as producers learn in production and in the continuous interaction with consumers of final and intermediate commodities, consumers also learn, that is, change/adapt/refine their consumption behaviours.

The process of change of consumption patterns and the consequent change in the consumption structure have no place in traditional neoclassical consumer theory which rests on a static allocation model. Few attempts have been made to disentangle the complexity of consumer dynamics or consumer learning (Gualerzi, 2001 and 2012; Walsh, 2003)[34]. Pasinetti's (1981) explanation of consumer learning is based on a generalisation of *Engel's Law* according to which consumption expenditure does not expand proportionally but instead is endogenously determined by income growth and within a certain needs-hierarchy. In parallel to the development of these theories Amartya Sen (1977 and 1985) removes the 'continuity of preferences' assumption from consumer theory in his 'rational fools' article, focusing instead on consumers' needs (instead of preferences). By doing so, Sen shows how different goods and consumption forms may allow different types of needs-satisfaction. In this framework, the idea of *subjective capability* captures a specific consumer's needs-satisfaction resulting from a certain good (Walsh, 2003).

The concept of *consumer capabilities* defines the specific consumer needs in a given socio-historical context based on a certain needs hierarchy (determined by income growth) and the specific capabilities that different products allow consumers to exercise. Indeed the development of needs, their hierarchy and the ways in which

[34] For example Lancaster's characteristic model (1966) focuses on product differentiation and innovation and it shows how the domain of consumers' choice is continuously reshaped by the availability of new products.

consumers satisfy them (consumer practices) are fundamentally learning processes realised in the social space. Most crucially, they occur in a continuous interplay with learning process within firms where commodities are produced. As Gualerzi notes (2012:380), "need development depends on the development of commodities, which, together with social practices and consumer learning, define the forms of consumption". Our study of the process of development of new commodities within firms (and, thus, the development of capabilities necessary for producing them) must be complemented by an analysis of the evolving structure of demand, its quality and composition.

3.3 Social Capabilities

Neither production nor consumption occur in a vacuum. And more importantly neither do the underlying learning dynamics driving their transformation. Crucially, firms are collective entities operating within a given historical and institutional context that affects both production capabilities and consumer capabilities dynamics. Moses Abramovitz (1986) developed the concept of social capability at the country level to capture those '*tenacious societal characteristics'* that influence the responses of given societies to economic opportunities[35]. Interestingly Abramovitz includes in social capabilities not just managerial competencies (especially in the organisation and management of large-scale enterprises) and technical competences but more crucially the set of political, commercial, industrial and financial institutions with which a country is endowed[36].

[35] This concept was originally used by Ohkawa and Rosovsky (1973, especially Chapter 9) in their historical account of the Japanese postwar industrialisation experience.

[36] In order to analyse the relationship between social capabilities and economic development recent contributions have undertaken econometric analysis and attempted to quantify social capabilities (Temple and Johnson 1998; Fageberg and Srholec, 2008). This systemic concept of capabilities has also been re-proposed in various contributions to regional/national technological capabilities or innovation systems literature (Lall, 1992), as well as in recent work on business environment and industrial commons (Pisano and Shih, 2009).

The concept of social capability was introduced with the specific aim of factoring in a series of elements that remained outside mainstream explanations of development and traditional growth models. Abramovitz's most complete systematisation of the concept was presented in 1991[37]. His analysis starts from an historical account of different countries' catch-up experiences and technology convergence trajectories (the latter measured in terms of productivity gap reductions). Looking at a large number of countries, the historical evidence reported by Abramovitz (see Kutznets 1966; Cornwall, 1977; Maddison, 1989) suggested certain general tendencies. Specifically he argues that "in the post World War II years, from 1950 to 1980, it is only among the small set of highly industrialised countries that there is clear tendency for levels of productivity to converge. There was no such clear tendency among the group of partially industrialised, middle-income countries. And among the poorest countries, there was even a suggestion of divergent experience" (Abramovitz, 1991:8).

The historical and comparative national record clearly contradicts the convergence/catch-up hypothesis. In order to better capture the realities of international differences in economic growth paths and manufacturing development trajectories, Abramovitz focuses on four factors/constraints:

1. natural resource scarcity
2. technology congruence
3. factors supporting the rate of realisation potential,
4. social capability

The relevance of the first factor is considered "hard to appraise a priori" but increasingly "of much diminished importance". Abramovitz also stress that "apparent scarcity may itself be a result of failure to develop

[37] In the social capability literature this contribution remained almost unnoticed. However, the paper 'The Elements of Social Capability' (given at the Korea Institute in 1991) is Abramovitz first systematic attempt to clarify the analytics behind the concept of social capability.

the resources available but badly exploited" (Abramovitz, 1991:14-15). The second factor, corresponds to what Kuznets (1968) called 'relevant technology'. If we remove the mainstream economic assumption that "technology that represents best practice in the productivity leaders [countries] can [always] be efficiently exploited by the backward economies" we can explain why economies may fail to catch up and converge in productivity levels (Abramovitz, 1991:14-15).

Technological incongruity or irrelevance may result from disparate factors proportions (typically when technologies are capital intensive and, thus, difficult to apply in a capital scarce/labour abundant context) or from scale problems, both with respect to market size and institutional factors. The third factor is defined by both internal and international policies affecting trade, capital flows, currency exchange rates and employment.

Fourth and finally, the *social capability* factor is best understood as sub-divided into two classes of elements: 'people's basic social attitudes and political institutions' and collective 'ability to exploit modern technology'. The former encapsulates the so-called Kuznets triad (secularism, egalitarianism and nationalism), while the latter comprises the capacity of collectivities to deal with the "three technological feature of modern production: scale and specialisation, capital-intensity, and expanded auxiliary activity" (Abramovitz, 1991:31).

Although these features might be changed over time the concept of social capability encapsulate a powerful idea. This is the view that manufacturing development is not simply a firm-level or state endeavour, but rather is made possible by the convergence of efforts of different actors and institutions operating within the polity. Finally, as the production and consumer capabilities dynamics interact in a cumulative causational process, social capabilities also develop in historical time ('normally, but not always' becoming stronger as development proceeds).

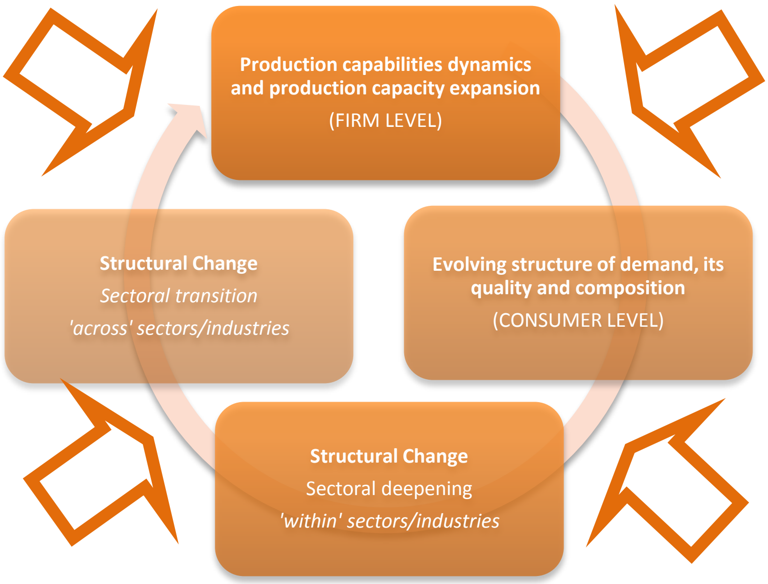
4. Causational chain: A synthesis

The analysis developed in the previous sections starts from the recognition that there is a specific *causal structure* linking capabilities dynamics and structural change dynamics. Clearly, production and consumption capabilities dynamics are important in sectoral transition (from agriculture to manufacturing and services). Additionally they are also responsible for sectoral deepening (for the technological upgrading and the consequent increase of productivity within each sector or subsector of particular manufacturing industries). In this dual process, the presence of certain social capabilities play a key role in determining the potential and speed of catching up and manufacturing development.

The difficulties of identifying the broader causal structure, as well as of disentangling the complex causational chains linking micro, meso and macro level processes, arise from two main problems.

Firstly, causational chains are not linear. At the micro (firm) and meso (sector and sub-sectors) levels, production capabilities interact in a circular and cumulative process of mutual reinforcement. Thus the introduction of new production techniques leads to new production activities and opportunities of consumption (consumer learning) that, in turn, spur on new technological innovations and eventually trigger processes of sectoral deepening and sectoral transition (see Figure 10).

Figure 10: Causational chains



Source: Author

Secondly, the process of 'production capabilities building and accumulation' has to be complemented by a congruent expansion of the production capacity. These processes unfold in historical time. For example, if one firm in a given economic system experiences a process of production capabilities building and accumulation, this can only be fully realised if the firm also undertakes strategic investments for the expansion of its production capacity.

If production capacity is not adjusted to meet the increasing level of production capabilities then the firm will be constrained in fostering continued capabilities building. Key constraints include the existing material structures of production that constrain the full realisation of new capabilities (a given assortment of machines, equipment, hardware and software), the emergence of organisational and technological bottlenecks and the changing inter-firm vertical and horizontal relationships.

Clearly, the lack of coordination among different but interdependent investments in production capacity expansion and production capabilities building may prevent processes of sectoral deepening and/or sectoral transition, especially in the context of catch-up economies. An explanation of manufacturing development trajectories, and the sectoral recomposition of the economic system favouring manufacturing, requires understanding the complex bundle of circular and cumulative causations linking production capabilities and consumer capabilities dynamics.

Finally, without factoring in the set of elements comprised by the concept of social capability we would be unable to explain the different speeds and intensities of various industrialisation experiences. Nor would we be able to account for the degree of resilience of mature economic systems thanks to their high social capabilities accumulated in institutions, organisations and policies.

Concluding remarks

This essay reviews the current debate on manufacturing development looking specifically at the role of manufacturing in economic development, and the theoretical lenses through which the different positions may be disentangled and tested empirically. By setting the scene of manufacturing development, the paper also aimed at reviewing the broad theoretical, empirical and policy realms within which the five essays in manufacturing development will be developed.

In the first part of this essay we reviewed the pro-manufacturing versus pro-service debate. We showed how, over the last part of the XX century, the extreme polarisation of said debate has increasingly led to a dismissal of the role of manufacturing development. As a result of the financial crisis and the massive manufacturing loss experienced by developed economies many have started to question “Why and how does manufacturing still matters?”. This essay has discussed how the development of a new-pro manufacturing vision must reconsider the old rationales in favour of industrialisation and focus on the importance of specific special industries and technological linkages in the current world manufacturing landscape. The investigation of the strategic role that machine tools play in the manufacturing system has led us to identify the unique properties of this industry. Moreover, the reasons why off-shoring abroad might break the manufacturing engine and destroy the industrial commons on which modern manufacturing systems rely have been illustrated.

The second part of the essay provides an analytical synthesis of a selected number of theoretical contributions that investigate, from different angles, the fundamental dynamics of manufacturing development. In particular, the essay takes stock of a set fundamental analytical points raised within the structural economic dynamics approach and what we have called here the economics of capabilities.

Not only does the essay distil the main insights for understanding the complex dynamics of manufacturing development, it also tries to show the existence of a interdependent causational chains linking structural change and production capabilities dynamics. The evolving structure of demand as well as the impact that different institutional settings have on the dynamics of manufacturing development are considered and the essay factors in the concepts of consumer capabilities and social capabilities.

Second Essay

STRUCTURAL LEARNING:

Embedding discoveries and the dynamics of production

Introduction

Production and learning of productive knowledge are profoundly intertwined processes as the activation of either process triggers the other, very often implying interdependent transformations. Production theory has conventionally explained production processes as relationships between combinations of productive factors – i.e. input quantities – and certain quantities of outputs. By assuming that producers 'know how' certain inputs may be combined and transformed to obtain certain outputs, production functions do not make any explicit reference to the capabilities needed to perform real production processes. Thus, in standard production theory, there is no production process strictly speaking (Loasby, 1999). Not only is the production process treated as a black box, also the learning dynamics occurring in given production structures are fundamentally ignored. Indeed, economists often treat learning as a costless and automatic process functionally dependent on cumulative output, time, or investment, whose main effect is to reduce average production costs.

A very influential attempt to cope with the fundamental limitations of more conventional production models can be found in the *capability theory of the firm*, an approach that emerged at the intersection of various research fields, specifically organisational studies (March and Simon, [1958] 1993; Penrose 1959; Richardson 1960 and 1972; Teece, 1980; Langlois, 1992), and institutional and evolutionary economics (Nelson and Winter, 1982; Cohen and Levinthal, 1990; Lundvall, 1992; Dosi et al. 2000), and empirical work in development economics (Bell 1982; Lall 1992). With a particular focus on the transformation of cognitive contents and evolving capabilities, these contributions have shown how the knowledge of productive possibilities – i.e. input combinations – has to be complemented by the availability of relevant capabilities for productive tasks being performed. Most notably *evolutionary economics* has highlighted the complex cognitive dynamics underlying learning processes. It has drawn attention to the multifaceted nature of knowledge, its tacit components as well as the complexities connected to its creation, diffusion, adaptation, adoption and accumulation in organisational 'routines'.

By integrating the above mentioned research streams with *structural theories* dealing with the complex 'architecture of production', this essay analyses production structures in transformation, examining the embedded opportunities and constraints which are responsible for learning dynamics. From this perspective, learning is understood as a dynamic process triggered and constrained by existing production structures. This means that production structures set the stage for learning dynamics, that is, they are the 'structured horizon' which prepares human minds for the intuitive discovery of new productive possibilities. The essay also recognises that structures of cognition and structures of production are linked by a bundle of bidirectional transformative relationships.

The goal of the present essay is two-fold. Firstly, the paper embeds different forms of learning such as 'learning by doing' and 'learning by using' in production structures. The essay therefore proposes an 'analytical map of production' as a stylised representation of the system of interrelated tasks through which transformations of materials are performed according to different patterns of capacities/capabilities coordination, subject to certain scale and time constraints (section 2).

Within this new analytical framework, the second contribution of the paper is to introduce the concept of 'structural learning'. In conventional approaches learning is simply described as a cognitive/behavioural dynamic involving production agents. In contrast, in our analytical framework, learning is understood as a process through which 'structural constraints' in production such as bottlenecks, incompatibilities and technical imbalances are transformed into 'learning opportunities'. In this context, static and dynamic complementarities, as well as similarities and indivisibilities, are essential focusing devices for activating compulsive sequences of technological change which permit the discovery of new 'worlds of production' (section 3).

Productive possibilities have to be 'seen', that is discovered and 'actualised' by productive organisations, for structural learning to be feasible. The concept of structural learning highlights a fundamental analytical tension between structure and agency or, more specifically, between productive structures and productive agents (the latter including both individuals and collectivities). Given the same productive structures, structural learning may follow different patterns according to different *forms of productive organisation* (section 4).

1. Embedding Learning in Production Dynamics

1.1 Learning in production: a taxonomy

In their critical review of learning curve studies[1], Adler and Clark (1991: 270) proposed a fundamental distinction between first-order and second-order learning. *First-order learning* refers to those 'learning by doing' processes directly experienced by workers via repetition of productive tasks and the resulting incremental development of

[1] The long tradition in learning curve studies is usually associated with the empirical analysis of 'learning by doing' effects on productivity and was initiated by Wright (1936) and his work in the aircraft industry.

expertise. The concept of 'learning by doing' expressed in Kenneth Arrow's seminal contribution (1962) captures the Smithian intuition that the accumulation of production experience increases workers' productivity. In particular Smith mentions three 'different circumstances' responsible for this increase in labour productivity: 'the increase of dexterity in every particular workman', 'the saving of the time which is commonly lost in passing from one species of work to another', and 'the invention of a great number of machines which facilitate and abridge labour' (Smith 1976 [1776]: 17).

Conventional learning models based on 'learning by doing' and learning curves have been mainly used for explaining productivity growth at the sectoral and macro level (Malerba, 1992:846). In these models, production is treated as a *timeless black box* and heroic assumptions are made concerning producers' knowledge of the entire spectrum of production possibilities as well as the availability of appropriate productive capabilities[2]. On the contrary, as the literature on localised technical change (Atkinson and Stiglitz 1969) has shown, given the local and cumulative character of knowledge, producers are only aware of a limited number of factors composition laws – i.e. proximate production possibilities. Moreover, as shown in the capability literature, production "has to be undertaken by human organisations embodying specifically appropriate experience and skills" (Richardson, 1972:888)[3].

Second-order learning refers to those managerial or engineering actions purposefully aimed at changing the internal structure of production by introducing new technologies, new equipments or investing in workers training. Learning dynamics of this second kind are

[2] The stochastic model by Jovanovic and Nyarko (1995) is an exception in providing a microfoundation of Arrow's 'learning by doing'.
[3] The analytical and technical limitations of the production function models are discussed in Georgescu-Roegen, 1970; Scazzieri, 1993.

triggered by a series of factors which are both internal and external to the firm (Malerba, 1992). In terms of the former, not only may the firm specifically invest in search activities and production/technology research aimed at expanding its knowledge base (Nelson and Winter, 1982) but it may also attempt to increase its learning and absorptive capacities themselves (Stiglitz 1988; Cohen and Levinthal 1990). As for the latter, in some cases, triggers of learning dynamics are external to the firm and may involve users of final goods (Rosenberg 1982; Rhee et al. 1984), other producers of intermediate or final goods in the same or in different industries (Lundvall 1992) or possibly other actors, typically those involved in scientific and technological research (Kline and Rosenberg 1986). Figure 1 provides a taxonomy of these different forms of learning.

Figure 1: Learning dynamics: a taxonomy

Triggers / ***Learning dynamic***	***Internal to the firm***	***External to the firm***
First-order learning		
Producer – production	Learning by doing (Arrow, 1962)	
Second-order learning		
Producer – research	Learning by searching (Nelson and Winter, 1982) Learning to learn (Stiglitz, 1988)	
Producers – users *Producers – producers*		Learning by using (Rosenberg, 1982) - Learning by exporting (Rhee et al. 1984) - Learning by interacting (Lundvall, 1992)
Producers – science		Learning from science (Kline and Rosenberg,1986)

Source: Author

Rosenberg's 'learning by using' (1982:122) arises from the recognition that "in an economy with complex new technologies, there are essential aspects of learning that are a function not of the experience involved in producing the product but of its utilization by final users…the performance characteristics of a durable capital good often cannot be understood until after prolonged experience with it"[4]. The related concepts of 'learning by exporting' and 'learning by interacting' with upstream and downstream producers develop Rosenberg's fundamental intuition and, thus, may be considered as sub-categories of 'learning by using'. Lundvall (1992) introduced the concept of *learning by interacting* as a critical feature of societies. Capabilities are collectively developed through social interactions mainly by observing and imitating others' actions as well as by mirroring their attitudes. This is why the organisational design of production processes as well as firms' underlying relational structures can affect people's disposition towards mutual learning and knowledge discovery. Historically, learning by interacting is realised in various ways from more co-operative to more competitive forms such as copying, foreign skilled workers' recruitment, technician exchange, pooling of technology, organisation of expos (industrial exhibitions) and industrial espionage (Chang 2002; Poni 2009).

In all these cases, learning dynamics are initially triggered by factors external or internal to the firm that eventually result in the reconfiguration of the firm's internal production structure. Of course this reconfiguration may or may not happen depending on how the firm in question reacts to the internal or external stimuli. All of the above suggests that in order to analyse these compulsive sequences of transformation it is necessary to embed learning dynamics in

[4] Mukoyama (2006) develops a stochastic model of learning based on this idea.

production structures and to understand in which ways these dynamics are constrained, but also triggered, by existing production structures.

1.2 The analytical map of production

In mainstream economics, *production functions* represent complete sets of feasible input combinations for a given output; in an isomorphic way, utility functions establish a relationship between combinations of consumption goods and the satisfaction that they provide – i.e. utility. Both production and utility functions are designed to show in the universe of rational choice and equilibrium allocations how the combinations chosen (respectively of inputs and consumption goods) reflect relative prices. Given that conventional production theory does not provide any analytical representation of the internal structure of production processes, qualitative transformations generated by innovations and changes in the technology and structures of production remain completely unexplored. In other words, conventional economics adopts an 'outside the production machine perspective' and, as a result, production and, thus, learning dynamics remain black boxes.

In contrast, the analysis of the internal structure of production combined with a strong emphasis on the representation of the complex system of interrelated production processes in different sectors was at the centre of the *classical theories of production*. Classical economists focused on the limited availability of non-producible goods, the utilisation problem and the various constraints determined by the production scale and its time structure (Landesmann, 1988). There are four main components of the Classical theoretical framework. Francois Quesnay's early formulation of the concept of *productive interdependencies* called attention to the 'circular flow' of wealth production and reproduction (see also Leontief, 1928). Adam Smith's analysis of the internal structure of the pin factory revealed the microeconomic advantages of *the division of labour* and the macroeconomic conditions on which it is based – i.e. stock of circulating capital flows. Charles Babbage's focus 'on the causes and consequences of large factories' led to the formulation of the *law of multiples* and, thus, to the discovery of different patterns of proportional utilisation and maintenance of indivisible inputs. Finally, Karl Marx's analysis of different *arrangements of production processes* highlighted the main features of the modern factory system and thus the working of the so called 'collective machine' (Landesmann, 1986; Scazzieri, 1993).

In this line, more recently, Wassily Leontief's (1947) *input-output analysis* and Nicholas Georgescu-Roegen's *fund-flow model* (1970; 1971 1990) developed the building blocks for a series of structural approaches to production (Landesmann 1986; Scazzieri, 1981 and 1993; Bianchi 1984; Morroni, 1992; Landesmann and Scazzieri 1996; Buenstorf, 2004 and 2007). These contributions view a given production process P_r ($r = 1,\dots, k$) as a particular system of interrelated tasks through which a sequence of transformations of materials are performed according to different combinations of flow inputs (such as productive agents and mechanical artefacts) and fund inputs (such as fuel, chemical catalysts and electricity), subject to certain scale and time constraints.

Approaching production from the point of view of structural economics implies an analytical focus on the following set of both quantitative and qualitative coordination problems: (i) how to synchronise and arrange the system of interrelated *tasks* in time; (ii) how to arrange the production process given the specific properties of *materials* in transformation; (iii) how to organise and activate the production process by combining different fund input*s* each of them endowed with certain capabilities or capacities*.* Interdependencies among these coordination problems are pervasive in the sense that for example tasks arrangement depend on both the properties of materials in transformation and firm's availability of capabilities/capacities[5].

Tasks refer to those production operations that are purposefully performed in a given production process. Each task T_j (*j = 1, 2,…, J*) can be decomposed into elementary operations or clustered in groups of tasks. They can be arranged simultaneously or sequentially in various *stages of fabrication* j (*j = 1, 2, …, J*), sometimes in a discrete way but sometimes in a continuous way, that is, with or without interruptions[6]. This last distinction proves to be very relevant as soon as we consider how different forms of production organisation have historically developed different techniques for inventory and storage capacities management (Rosenberg 1994; Landesmann and Scazzieri 1996: chapter 8).

Materials refer to what is transformed in the fabrication stages of a production process[7]. The relationship between materials and stages of fabrication can be represented by a descriptive matrix M = $[m_{ij}]$ in which any element refers to the material *i* that has been transformed in the fabrication stage *j*. At each fabrication stage, given a certain stock of materials available to the productive organisation, only some materials will be utilised and thus transformed. This implies that for each production process we will observe a certain 'realised' matrix

[5] Richardson (1972:885) stresses how "the habit of working with models which assume a fixed list of goods may have the unfortunate result of causing us to think of coordination merely in terms of the balancing of quantities of inputs and outputs and thus leave the need for qualitative coordination out of account".
[6] As for the time structure, the material transformation processes can be visualized as a system of pipelines (Landesmann, 1986; see also Morroni 1992).
[7] In the case of 'immaterial production' – e.g. service activities – 'materials in process cannot be identified, at least in the usual sense, and the production process generally takes the form of a close interaction among fund agents, in the course of which some of the characteristics of such agents (and sometimes their capabilities as well) may get transformed (Landesmann and Scazzieri, 1996:252-3).

$M^* = [m_{ij}]$, whose internal structure represents all the *materials in use* in the stages of that production process.

In order to perform a certain system of interrelated tasks through which materials are transformed into final commodities, the production process has to be 'activated' by a *series of inputs* such as fuel, chemical catalysts, but also machines and productive agents, that is, workers. *Flow inputs* such as fuel, chemical catalysts, electricity and fertilisers are utilised in certain stages of material transformation but they do not materially constitute the final output of the process as the materials in use do. Flow inputs used in a certain production process can be described through a descriptive matrix $F = [f_{ij}]$ in which any element refers to the flow input *i* that has been consumed in the fabrication stage *j*. For each production process we will observe a certain realized matrix $F^* = [f_{ij}]$.

$$\mathbf{M} = \begin{bmatrix} \mathbf{m_{11}} & \cdots & & \mathbf{m_{1J}} \\ & & \mathbf{m_{ij}} & \\ & & \cdots & \\ \mathbf{m_{q1}} & & & \mathbf{m_{nJ}} \end{bmatrix} \qquad \mathbf{F} = \begin{bmatrix} \mathbf{f_{11}} & \cdots & & \mathbf{f_{1J}} \\ & & \mathbf{f_{ij}} & \\ & & \cdots & \\ \mathbf{f_{q1}} & & & \mathbf{f_{mJ}} \end{bmatrix}$$

In contrast, *fund inputs* are both mechanical artefacts such as machines, tools and equipment and productive agents (i.e. workers, supervisors, engineers and managers). Fund inputs maintain their characteristics substantially unaltered during the production process, provided that certain tolerance thresholds are not violated (Landesmann, 1986). Mechanical artefacts present a certain *production capacity*, while each productive agent is characterized by a set of *complementary productive capabilities*. By activating some of these capabilities, each productive agent is able to perform a single task or a set of *similar tasks* (i.e. those tasks which require the utilisation of the same set of complementary capabilities). Although productive agents may learn to perform different tasks, their capabilities are limited so they cannot switch between all productive tasks, especially when complex products are considered.

Just as we did with materials and flow inputs, we can distinguish between the bundle of capacities/capabilities embodied in a certain set of fund inputs (i.e. *potential capacities/capabilities*) and the capacities/capabilities actually utilised by the productive organisation in performing a certain set of tasks (i.e. *capacities/capabilities in use*)[8]. The former is described by the matrix C = [c_{ij}] while the latter by the matrix C* = [c_{ij}], where c_{ij} denotes the relationship between the capacity/capability *i* and the task T_j performed at the stage of fabrication *j*. The distinction between the matrix C = [c_{ij}] and C* = [c_{ij}] illustrates how the same production process P_r (*r = 1,…,k*) can be performed by using different bundles of mechanical artefacts and productive agents, that is, different combinations of production capacity and productive capabilities. However, even when two different productive organizations perform the same process P_r by combining the same bundle of productive capacities/capabilities, the latter can be employed in different proportions. For example, two firms Firm $_1$ and Firm $_2$ can perform the same production process by using the same two fund agents – i.e. workers *w* and machines *m* – but in different combinations – for example, one fund-input combination may be more labour intensive than the other.

[8] As has been stressed, this distinction leads us to interpret the emergence of new productive structures within the space of virtual practices as "the outcome of a clustering process that brings about a rearrangement of the primitive elements of productive activity; [thus] structural change may be considered as a case of variation within a spectrum of virtual possibilities" (Scazzieri 1999:230)

$$C^{1*} = \begin{bmatrix} 5w & 7w \\ 1m & 1m \end{bmatrix} \qquad C^{2*} = \begin{bmatrix} 1w & 2w \\ 3m & 3m \end{bmatrix}$$

Thus, by comparing the two matrices C^{1*} and C^{2*} we can discover specific features of the production process P_r performed by Firm $_1$ and Firm $_{2.}$ In particular, the two matrices express different relationships of *complementarity* among the two fund inputs considered (machines and workers respectively). In our case, the first stage T_1 of the production process P_r can be performed either by combining one machine with five workers or three machines and one worker (see above). Given these relationships of complementarity between fund inputs and also the fact that machines tend to be tasks-specific and only partially flexible, the kind of combinations of fund inputs that firms can select from the space $C = [c_{ij}]$ for performing P_r are limited. Moreover, scaling up the production process not only requires the consideration of these relationships of complementarity but also that a law of proportionality among all the structural components of the process is satisfied (see below).

Based on Cartwright (1989), it has been noted how very often the capabilities (and capacities) of fund inputs can be expressed in a quantitative form, so that we can assume they are comparable in cardinal space (Landesmann and Scazzieri 1996:197). One possible quantitative specification of the matrix $C = [c_{ij}]$ relies on the consideration of the time structure of the production process in relation to the capacity/capabilities in use. The matrix $C^* = [c_{ij}]$ can be transformed into a matrix of *capacities/capabilities use – times* $\Omega^* = [\Omega_{ij}]$ where the generic Ω_{ij} represents the use-time of the capacity/capability c_{ij} in the production process P_r.

$$\mathbf{C} = \begin{pmatrix} c_{11} & & & c_{1J} \\ & \cdots & & \\ & & c_{ij} & \\ & & \cdots & \\ c_{q1} & & & c_{qJ} \end{pmatrix} \qquad \mathbf{\Omega^*} = \begin{pmatrix} \Omega_{11} & & & \Omega_{1J} \\ & \cdots & & \\ & & \Omega_{ij} & \\ & & \cdots & \\ \Omega_{q1} & & & \Omega_{qJ} \end{pmatrix}$$

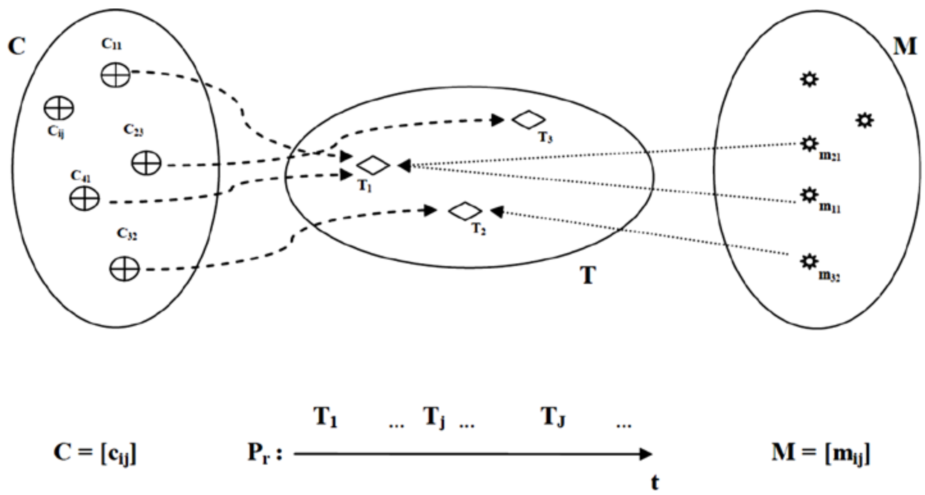
Taking the case in which two different productive organisations perform the same process P_r with the same combination of fund inputs described by $C^* = [c_{ij}]$, we can compare the matrices Ω^* to discover if one time arrangement of P_r is more time wasting than another. For example, the reconfiguration of the time structure of P_r from one *in line* to one *in parallel* can reduce the amount of idle time of fund inputs across fabrication stages (see below). Given appropriate transformations such as the one proposed above, as soon as the productive capabilities and capacities become comparable in cardinal space, the capacity-capability ratios can be calculated for each productive task (or groups of tasks) and organized in a matrix. This will elucidate the interdependencies between different kinds of fund inputs. However, the set of interdependencies characterising each production process does not simply involve one subset of its structural components (here, fund inputs). Instead, each production process requires the coordination of all its structural components (namely tasks, materials and flow inputs as well as fund inputs).

Interdependencies among structural components can be visualised by mapping the relationships between capacity/capabilities, tasks and materials[9]. The *entire spectrum* of possible combinatorics is

[9] For clarity the flow agents are taken out of the picture. The decision to privilege the other three dimensions matrices C, T and M is due to the fact that commonly there are higher degrees of freedom in their combinatorics and the use of flow agents is strictly dependent on the utilisation of fund agents.

represented through the *analytical map of production relationships* (see figure 2)[10]. The mapping from the capacity/capability space C to the task space T (i.e. *job specification programme*) can be determined following different criteria (Landesmann and Scazzieri, 1996). For example different combinations of fund inputs may be relatively more or less adequate for the execution of one task (or cluster of tasks) than another. Also, a reconfiguration of the job specification programme (i.e. different mapping from the space C to the space T) may allow the activation of previously unused fund inputs or the achievement of higher efficiency in the utilisation of the capacity/capabilities in use.

Figure 2: The analytical map of production relationships



The network of relationships and interdependencies among the spaces C, T, M has to be synchronised *over time* and according to specific *scale requirements* determined by the existence of process indivisibilities as well as indivisible fund inputs[11]. As for the time structure, synchronisation has to be pursued at three different levels

[10] The concept of 'analytical map of the true [interpersonal] relations' is proposed in Georgescu-Roegen (1976:205) as one possible realisation of the 'entire spectrum of peasant institutions'.
[11] For a comprehensive discussion of time and scale as structural dimensions of production see Landesmann, 1986; Bianchi 1984; Morroni 1992; Scazzieri 1993; Landesmann and Scazzieri 1996.

(coordination in the utilisation of fund inputs, arrangement of interdependent tasks over time, and transformation of materials over time). The difficulty of matching the 'time sequencing requirements' of these three dimensions makes perfect synchronisation across the three above mentioned levels impossible and explains the co-existence of patterns of simultaneity or sequentiality. Time gaps and idle time in production processes are thus largely structurally determined and, within the given structure, only partially reducible through various forms of learning (Landesmann and Scazzieri, 1996).

Moving on to indivisibilities, processes are indivisible when they are not 'indifferent to size'. As in the biological world, all individual production processes "follow exactly the same pattern: beyond a certain scale some collapse, others explode, or melt, or freeze. In a word, they cease to work at all. Below another scale, they do not even exist" (Georgescu Roegen, 1976:288). The fact that processes are 'scale-specific' (in other words that they are characterised by upper and lower bounds) implies that conducting a process on a smaller or a larger scale can only be done if a law of proportionality among the structural components of the process is satisfied. This idea was originally formulated by Charles Babbage's law of multiple. In Babbage's view: '[w]hen the number of processes into which it is most advantageous to divide [the production process], and the number of individuals to be employed in it, are ascertained, then all factories which do not employ a direct multiple of this latter number, will produce the article at a greater cost' (Babbage 1835: 211).

At the level of the structural components, limitations in the bundling and unbundling of fund inputs are extremely stringent, while flow inputs as well as materials in transformation are more often divisible. As far as fund inputs are concerned, the existence of *indivisible funds of capacities* (i.e. machines, equipments, tools) as well as *indivisible funds of capabilities* (i.e. workers, engineers, managers) mean that, for a fund input to be fully utilised, a specific scale of production has to be achieved. For small scales of production, fund inputs would inevitably be underutilised. However, if fund inputs are not too specialised in the execution of some productive tasks, productive organisations can overcome scale constraints by utilising the same indivisible fund inputs for the production of other commodities. Nevertheless these new commodities generally possess a certain degree of similarity as fund inputs are endowed with only a limited set of complementary capacities or capabilities.

1.3 Embedding learning dynamics

The structural representation of production provided above now allows us to see some of the many limitations arising from the understanding of learning dynamics as a disembedded process, as is the case with today's mainstream economics. To give one example, Arrow's concept of 'learning by doing' refers to a process involving one subset of the space C (i.e. capabilities of fund inputs such as workers, engineers and managers). In this case, 'learning by doing' is nothing more than an increase in productive capabilities, which generally result in a reduction of capabilities use-times. In other words the execution of the same productive task will require less time due to accumulated experience and as a result the overall productivity of the productive organisation will be increased. However, as we shall see below, our analytical map of production shows how 'learning by doing' does not always imply such productivity increases and it might even lead to the emergence of bottlenecks and imbalances[12].

[12] In fact in his seminal work on 'learning by doing', Kenneth Arrow recognizes how "learning associated with repetition of essentially the same problem is subject to sharply decreasing returns" and, thus, that learning mainly consists of finding new

The reason for this becomes clear as soon as we visualise interdependencies among structural components, i.e. tasks, materials, flow inputs and fund inputs (and their capacity/capability). The development of increasing capabilities in the execution of a certain set of productive tasks generally implies that certain stages of fabrication will require less time, while other stages remain invariant as a result of constraining factors such as fixed times for material transformation (e.g. time needed for fermentation of certain chemical reactions) or the scale of other existing fund inputs, in particular machines and equipment. These latter stages of fabrication, given their invariant structural properties, will appear as bottlenecks in the production process and may end up affecting the entire job specification programme, potentially even neutralising or counteracting the productivity increases of 'learning by doing'.

To give a second example of the importance of understanding learning as embedded we can look at Rosenberg's concept of 'learning by using'. This concept was developed with reference to 'products involving complex interdependent components or materials'. As a result of the particular industry he focused on, that is, aircraft[13], Rosenberg underlined the fact that 'learning by using' implies a "feedback loop in the development stage which, in turn, increases efficiency and/or requires changes in productive techniques" (1982:123)[14]. Rosenberg distinguishes between two kinds of useful knowledge arising from 'learning by using' in both products and

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solutions to emerging 'stimulus situations' (1962:155). However, the effects of 'evolving stimuli' in the transformation of productive structures are not analysed given the lack of an analytical map of production.

[13] Even today aircraft are among the most complex products, composed of almost 6 million parts (by way of comparison a car is typically composed of just 6 thousands parts).

[14] In this respect, see also von Hippel (1988) whose contribution links the learning by using dynamics to product diversification patterns. Also, Kline and Rosenberg (1986) presents a 'chain-linked model' where feedback loops in the innovation process are recognized as key factors.

processes. Embodied knowledge is that which requires 'appropriate design modifications', while disembodied knowledge "leads to certain alterations in use that require no (or only trivial) modifications in hardware design", although even the latter still "leads to new practices that increase the productivity of the hardware" – for example modification in maintenance practices in the aerospace industry (Roseberg, 1982:124).

Of course, these two forms of 'learning by using' are intertwined. By generating new embodied knowledge, 'learning by using' in fact facilitates the discovery of new forms of disembodied knowledge and even makes them necessary. What is implicitly suggested here is that 'learning by using' may trigger the rearrangement of the job specification programme. This occurs because of the new productive tasks and fund inputs required to cope with design modifications (*embodied knowledge*), or as a result of alterations in productive practices whose performances depend on the rearrangement of fund inputs available (*disembodied knowledge*).

The first case is more clearly detectable as it requires definite design modifications (i.e. technological improvements) while the second set of transformations tend to be under-estimated as they do not call for the introduction of any new fund inputs. The analytical map of production allows us to understand how a production process may be qualitatively transformed even without equipping the productive organisation with new fund inputs or without transforming the existing ones. Instead, the production process may be transformed just by re-arranging fund inputs among the system of tasks which have to be performed or by synchronising tasks in a different way over time. In fact there are various ways of combining elementary operations into new tasks or clustering existing tasks in new ways. Once again the extent to which this can be done depends on the capacities/capabilities embedded in funds inputs and their degree of utilisation, as well as on the properties of the materials in transformation and on time arrangements.

Learning processes are intrinsically heterogeneous and occur through time at several nested levels of production, the latter being structurally determined by productive interdependencies[15]. As soon as we attempt a restructuring of 'learning by doing' or 'learning by using', it becomes obvious that the majority of existing studies focus their attention on what triggers the learning process or what its output is. The process *per se* not discussed. In other words, the conventional analysis of learning ends exactly where the learning process starts. Even when there is a more detailed investigation of learning dynamics in production, as in the work of economic historians (Rosenberg, 1969, 1976, 1979, 1982; Noble, 1986; Piore and Sabel, 1984; Mowery and Rosenberg, 1998; Mokyr, 2002; Landes, 2000; Poni, 2009), production structures are generally seen only as constraints that productive agents overcome through problem-solving activities and changes in productive techniques. For example, Mokyr (1990:9 italics added) argues that '[t]echnological change involves an attack by an individual on a *constraint* that everyone else has taken as given'.

However, as we shall see below, an analytical account of a number of historical cases allows us to understand how existing and evolving production structures are not just constraints. Instead, existing production structures orientate productive agents towards

[15] Another aspect that conventional approaches tend to forget is that 'learning in time' can proceed at different speeds according to the time required for reconfiguring the production structure or according to the time knowledge requires to flow (i.e. be disseminated and absorbed) throughout the production organisation or at the inter-firm level. In other words the problem is not only 'what to learn' or 'how to learn to learn' but also 'how to learn faster'. As shown by Dodgson (1991), the differential ability in learning quickly about technological opportunities is a crucial determinant especially in those sectors (e.g. biotechnology) characterised by an uncertain and generally rapid process of transformation.

certain learning trajectories and allow them to discover structurally embedded opportunities. As shown by Hicks (1969), the adoption of an analytical approach to economic history can be a vehicle for developing a 'quasi-theory', that is to say a stylised representation of economic facts through which theories can be developed.

2 Structural Learning: an analytical framework

2.1 Learning in a structured space: an analytical account of historical cases

The analytical map of production relationship elucidates firstly the 'architecture of complexity' in production (Simon, 1962; Buenstorf, 2005) and secondly, the fact that learning dynamics are realised in a 'structured space' over time. This means that learning in production is not simply a process occurring as a result of cognitive dynamics; rather it is also a process triggered and orientated by structural dynamics. The latter open up the possibility of transforming 'structural constraints' such as indivisibilities, bottlenecks, incompatibilities and technical imbalances into 'structural opportunities'. As highlighted in structural analyses of production (see above), coordination problems in the space of capacity/capabilities, materials and tasks may be solved in multiple (albeit interdependent) ways. In other words, there are '*worlds of production'*, that is, a variety of production arrangements ('world of possibilities') that are feasible even under same sets of contextual conditions (Salais and Storper, 1997).

'*Worlds of possibilities'* permit the transformation of production processes and their outcomes – i.e. process and product innovations (Sabel and Zeitlin, 1997). Of course saying that there are multiple possibilities should not blind us to the fact that indivisibilities, bottlenecks, materials properties, technical imbalances and interdependencies are all pervasive constraints. In fact discovering these possibilities, given certain structural constraints, is the very essence of what I call the structural process of learning. The concept of *structural learning* is introduced here to identify the continuous process of structural adjustment and transformation of production 'triggered' and 'orientated by' existing and evolving production structures. Static and dynamic complementarities, as well as similarities and indivisibilities, are essentially focusing devices for activating compulsive sequences of technological change and *discovering new production possibilities* at the firm and inter-firm level.

We will now move to an analytical account of historical cases in which "[c]omplex technologies create internal compulsions and pressures which, in turn, initiate exploratory activity in particular directions" (Rosenberg, 1969:4). This historical analysis is the first step towards disentangling those structural dynamics that prepare the setting for learning and those specific factors triggering learning processes in production. The second step is to identify the '*laws of motion'* of structural learning dynamics and illustrate them with an analytical map of production relationships. The third step will be to re-link dynamics occurring at the level of production structures with those occurring at the level of the structures of cognition in productive organisations. As we shall see, this third step will allow us to show the analytical tension between structure and agency in learning dynamics and also elaborate how structure and agency are linked by a bundle of bidirectional transformative relationships (Bourdieu, 1972)[16].

Rosenberg (1969) identifies three main 'inducement mechanisms' of learning, namely technical imbalances or bottlenecks,

[16] At the centre of Bourdieu's analysis there is a dialectic between 'externalising the internal' and 'internalising the external' which attempts to go beyond precisely the same tension.

labour-saving/uncertainty-reducing machines and substitutes or alternative sources of supply of fund and flow inputs or materials. A number of historical examples will help to illustrate this point. In 1900 the machine tool industry was revolutionised by the introduction of high-speed steel which allowed an increase in the hardness of cutting tools. However "it was impossible to take advantage of higher cutting speeds with machine tools designed for the older carbon steel cutting tools because they could not withstand the stresses and strains or provide sufficiently high speeds in the other components of the machine tool" (Rosenberg, 1969:7). As a consequence, structural transmissions, control elements and other machine tool components had to be redesigned and this change "in turn, enlarged considerably the scope of their practical operations and facilitated their introduction into new uses" (Rosenberg, 1969:8).

This is a typical example of a technical imbalance leading to changes in complementary processes as well as structural components, that is, tasks, materials and capabilities/capacities. It highlights how a technical constraint can actually activate a process of exploration and searching in which "the size of the discovery need bear no systematic relationship to the size of the initial stimulus" (Rosenberg, 1969:9). Indeed, the initial technical imbalance in a certain industry may trigger structural learning processes in other industries and sectors. The experience of the John Deere company who revolutionised agricultural production by introducing the steel plough in the early nineteenth century is a case in point and will be developed in the Third Essay, with specific reference to the way in which manufacturing development contributes to agrarian change. In sum, technical complementarities among fund inputs or the application of an innovation (e.g. a new material with certain properties) in the execution of a broad set of similar productive tasks are the fundamental dynamics underlying the learning processes as conceived by Rosenberg.

It is not just constrained posed by existing technical processes that can work as triggers for structural learning dynamics: social process can function in this way as well. In the *Poverty of Philosophy* Karl Marx observed how “after each new strike of any importance there appeared a new machine” (n.d.:134; first source Rosenberg, 1969). The threat of strikes introduces a critical element of uncertainty to the supply of labour and strongly affects the delicate time structure of a production process, thereby promptly the invention of new labour-saving machines . Social changes induce the invention or discovery of new machines and this in turn sets off a further train of changes.

Robert’s self-acting mule, the Jacquard punching machine and the introduction by the British Government of the ‘American System of Manufacturing’ in the gun making industry in 1854, are all cases in which the invention or acquisition of a new more powerful machine is just the first step in a subsequent process of structural learning (Rosenberg, 1969; see also Chang, 2002). All these cases highlight how when a new machine becomes available production that was technically feasible but not economically convenient becomes possible. This possibility depends on increasing the scale of complementary machines or in the re-arrangement of workers in the production unit, provided that they can perform a certain set of similar productive tasks.

Together with the above mentioned inducement mechanisms identified by Rosenberg, the need/opportunity of increasing the scale of production is another factor triggering processes of structural learning. For example complementary innovations such as refrigerators, railways and steamships affected the reduction of transportation costs, increased the degree of regional specialisation and opened the opportunity to benefit from scale technology expansions and from specialisation in a limited set of productive tasks performed at high productivity standards. Indeed, as soon as the scale of production increases ‘a shifting succession of bottlenecks’ will emerge. Focusing on them, engineers will start exploring new possible structural configurations of the production process, which may lead to serendipitously discovering ‘singleton techniques’ (Mokyr, 2002). Problems related to scale constraints, which arise both from indivisible fund inputs and indivisible processes, may trigger the discovery of innovative (structural as well as organisational) configurations of production processes. A good example of this is the typical problems faced by small farmers and small firms when trying to gain access to indivisible fund inputs such as machines and other equipment. Historically fund inputs indivisibilities as well as scale invariant processes have triggered institutional innovations such as ‘renting/sharing’ solutions implemented by producer cooperatives (Lissoni, 2005) as well as forcing productive agents to rearrange job specification programmes.

2.2 Structural Learning’s Laws of Motion

The historical cases document how inducement mechanisms of learning dynamics, and the resulting ‘compulsive sequences’ of transformations, are embedded in and triggered by existing production structures at each point in time. Specifically complementarities and similarities among tasks or materials, as well as fund inputs indivisibilities, have been crucial focusing devices in structural learning dynamics. The analytical account of these historical cases leads to the identification of three fundamental laws of motion of structural learning. The first two of these principles are based on the existence of similarities and of complementarity among materials, tasks and fund inputs. The third principle is due to the issue of indivisibility and scale constraints.

The fundamental intuition behind the first two laws of motion may be found in G. Richardson's (1960, 1972 and 2003) observation that different forms of inter-firm cooperation we see arise from different patterns of similarity and complementarity among productive activities. Richardson breaks down the production of each final commodity into various stages or activities, each of them executable by different types of firms. "Activities which require the same capability for their undertaking" are called *similar activities* (Richardson 1972:888). On the other hand, activities are *complementary* "when they represent different phases of a process of production and require in some way or another to be coordinated [...] both quantitatively and qualitatively" (idem: 889-890).

Building on this dichotomy, Richardson explains how the complex and interlocking clusters, groups and alliances of firms we observe are in reality different responses to the same problem: the need to coordinate "closely complementary but dissimilar activities"[17]. As firms cannot accumulate all the capabilities required for performing a broad set of dissimilar activities, they will specialise in a few activities and cooperate with those firms specialised in closely complementary activities. Principles of similarity and complementarity also operate at the firm level and are responsible for distinct structural learning trajectories.

[17] This analytical point is developed in section 4 with respect to the different forms of production organisation.

2.2.1 The First Law of Motion: learning trajectory triggered by similarities

Overcoming a productive constraint by introducing a new set of tasks, capabilities or materials may induce the same or other firms to adopt the same set of tasks, capabilities or materials for overcoming a similar constraint, in the same or other kind of productive processes. As documented by Rosenberg (1963:422-3, italics added) "industrialisation was characterised by the introduction of a relatively small number of broadly *similar* productive processes to a large number of industries. This follows from the familiar fact that industrialisation in the nineteenth century involved the growing adoption of a metal-using technology employing decentralised sources of power". Furthermore, discovering a *new way* of performing a certain task affects all those productive processes in which similar tasks are performed. This explains why "many of the benefits of increased productivity flowing from an innovation are captured in industries other than the one in which the innovation was made" (Rosenberg, 1979:41; see also Usher 1954)[18].

Many examples might be provided which highlight the existence of technological linkages among apparently uncorrelated products such as guns, sewing machines, bicycles, motorcycles, and automobiles. Among the many historical examples 'the development of the universal milling machine by Brown and Sharpe is, perhaps, the most outstanding example of a machine which was initially developed as a solution to a narrow and specific range of problems and which eventually had enormous unintended ramifications as the technique was applied to *similar* productive processes over a wide range of metal-using industries' (Rosenberg 1963: 432, italics added).

[18] This analytical point will form the basis of our discussion in the Third Essay of the concept of intersectoral learning.

In the specific case of firms whose production process consists of a system of similar tasks, the discovery of a new way of performing a certain task or the introduction of a new material implies a complete reconfiguration of the entire process. However, as in this specific case productive agents would already be endowed with similar kinds and amounts of capabilities, they will be substitutable and can be arranged in many different ways across time.

The production process of more complex products (or components) tends to assume the form of a system of dissimilar tasks. Indeed, complex products are defined as those "composed of many subsystems that interact in complex ways" (Rosenberg, 1982:136). In the case of complex products requiring the performance of closely interdependent dissimilar tasks, intra and inter-firm complementarities will be pervasive.

2.2.2 The Second Law of Motion: learning trajectory triggered by complementarities

"[I]nnovations hardly ever function in isolation" (Rosenberg, 1979:26). The theoretical framework we have constructed allows us to analytically specify and explain this intuitive insight of Rosenberg's. Innovation occurs in this bunched fashion because of the utilisation and the productivity of fund inputs (i.e. machines with certain capacities or productive agents with certain capabilities) both critically depend on the simultaneous availability of complementary fund inputs.

Complementarities among fund inputs may trigger direct learning dynamics, or learning dynamics over time. *Direct learning dynamics* occur when one fund input makes the functioning of another fund input possible or more efficient. *Learning dynamics over time* occur when one fund input makes the functioning or introduction of other fund inputs possible over time. In the specific case of a production process constituted by a *system of dissimilar tasks*, fund inputs performing a specific task in one stage of fabrication are combined with others performing other tasks in other stages of fabrication in a relationship of complementarity rather than of substitutability.

Now if tasks are very dissimilar and complex, productive agents (or even entire productive organizations) have to specialise in the execution of only one task, or even in performing elementary operations of more complex tasks. In this case, a number of processes of the same type can be organized *in series* (also called *in sequence*) so that specialised productive agents (or organizations) can perform the task in which they are specialised without long periods of inactivity. Discovering this possibility and applying it to the production process allows firms to reduce time wastage as productive agents will shift over time from one process to another.

Additionally, according to the degree of decomposability of a given production process, firms may decide to adopt a modularisation strategy (Langlois, 2002; Buenstorf, 2005). Interestingly, in the case of productive processes composed of closely complementary but dissimilar tasks, modularisation may guarantee static efficiency at the cost of dynamic efficiency. This problem occurs because modularisation tends to reduce the number of learning trajectories triggered by complementarities. This point will be developed in the last section when the concept of structural compatibility will be discussed in relation to producers networks. This specific form of production organisation developed as a specific response to the need of coordinating closely complementary but dissimilar production activities.

2.2.3 The Third Law of Motion: learning trajectory triggered by indivisibilities

Indivisible fund inputs and materials as well as scale-invariant tasks (or processes) impose a proportionality path on all transformations of the internal structure of production (see above the reference to Babbage's law of multiples). This means, for example, that if a certain indivisible fund input (e.g. a new machine) is adopted, then, the firm has to reconfigure the job specification programme in such a way that scale economies generated by the use of the new machine are exploited and potential bottlenecks and time or material wastes are avoided.

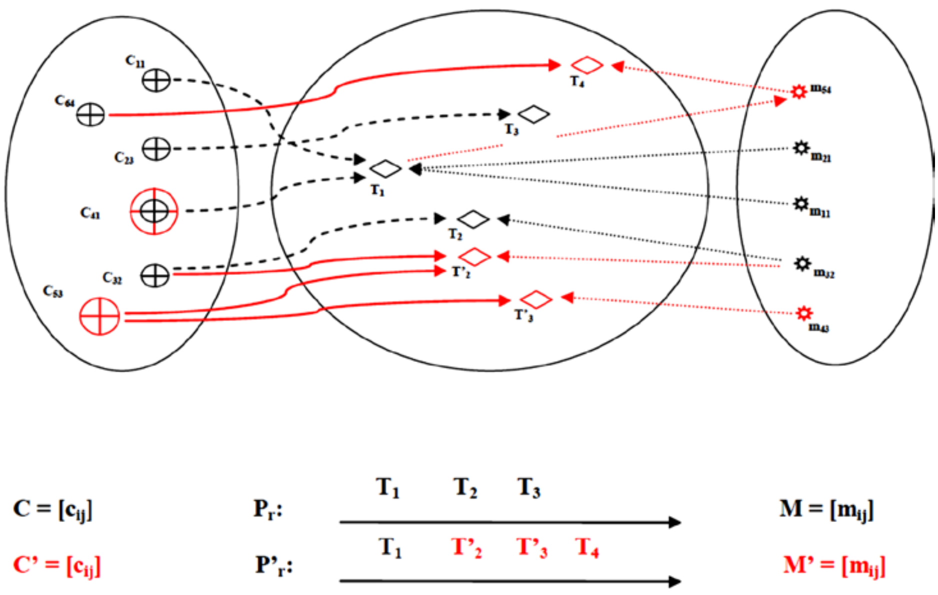
The existence of an indivisibility might also trigger incremental innovations both at the technological and organisational levels. For example adopters of the new indivisible input (or scale-invariant task) "could invent *around* the new machine and remove those technological constraints that limit their *ex ante* or *ex post* size. [...] Alternatively they could attack it directly by finding the way to split the different functions that the original innovation performs jointly, thus decomposing the latter into a few (possibly compatible) modules, each of them being cheaper than the original item" (Lissoni 2005:364, italics added). Indivisibility-led innovations may also affect the way in which indivisible fund inputs are acquired and adopted and, thus, production is organised. As documented in Paul David's (1966) analysis of smaller firms and their ways to deal with indivisibilities, another form of innovation triggered by indivisibilities is the creation of producers' consortia and cooperatives or pro-renting innovations.

Structural learning trajectories triggered by indivisibilities also interact with those triggered by similarities and complementarities (see above). Specifically, indivisibilities 'shape the form' of those learning trajectories triggered by similarities and complementarities. This means that the application of new indivisible fund inputs and materials to similar production activities (in the same or different sectors) will introduce in the new production context in which they have been applied a new indivisibility. The latter will reshape the overall job specification programme and the scale of the production process (when its introduction is not too costly). As for the case of complementarities, at the firm level they mainly arise in three ways: (i) among indivisible fund inputs or materials, (ii) as a result of scale-invariant processes, and finally, (iii) among different production processes when the combined execution of scale-invariant tasks reduced the costs of each production process (i.e. *economies of scope*, Morroni, 1992).

2.2.4 Analytical map of structural learning trajectories: An illustration

One of the possible ways to visualise how these three laws of motion interact is to make use of the *analytical map of production relationships* we developed earlier. Different examples can be inserted into the analytical map of production relationships (see figure 3). Let us consider the following illustrative case. The acquisition of a new fund input c_{53} (e.g. a new machine introduced through technology transfers or a traditional machine transformed by small improvements) can trigger a cascade process of production reconfiguration. The task T_2 has to be decomposed into two tasks (T'_2 and T'_3) while the obsolete fund input c_{23} can be dismissed. The discovery of a new material m_{54} requires the execution of a new task T_4 to be transformed. the scale of fund input c_{41} has to be changed, given the introduction of a new indivisible fund input c_{53}. A previously unutilised capabilities fund c_{64} is activated so a new complementarity with the new material m_{54} has been discovered.

Figure 3: Structural learning trajectories



These dynamics may be also analysed by adopting the virtual matrix C = [c_{ij}] and C* = [c_{ij}] (see above). Here, through the process of structural learning, some relationships of complementarity among funds inputs will end, others will change (although maintaining the same proportions) while others still will be completely transformed. A similar idea is presented by Simon (1962:475) when he suggests that, given a hierarchical system of interdependencies, the architecture of complexity may be disentangled by adopting what he calls a *nearly decomposable matrix.*

2.3 Structures of production and structures of cognition

The cascade process of reconfiguration triggered by structural learning dynamics cannot be thought of as an automatic one. In order to react to *structural stimuli* and *feedback loops,* they have to be 'seen' (that is, discovered) by productive agents and 'used' by productive organizations for reconfiguring their internal processes[19]. Poni's comparative study of the silk industry in Lyon and Bologna clearly illustrates this point when he highlights how feedback must "end in the hands of the right persons [as feedback management] require capabilities and knowledge of techniques which are not necessarily available in the right moment, in the right sector, in the right hands" (Poni, 2009:297; my translation).

The likelihood that opportunities embedded in productive structures are seen by productive agents and used by productive organisations depends on three set of issues:

(i) the individual and collective cognitive dynamics through which opportunities are discovered;

(ii) the collective capabilities of productive organisations to transform production structures (provided that certain new opportunities have been discovered);

(iii) the specific form assumed by the productive organisation. We will discuss the first issue in the present section and then the last two conditions in the following section.

To return to the issue of individual and collective cognition dynamics, psychologists (e.g. Kellogg, 1995) and experts in behavioural and organizational studies (March and Simon, 1993), have done a great deal of research on the mechanisms responsible for agents' memorisation. Most interestingly they have looked at agents' embodiment of perceived stimuli and past experiences such as various forms of 'analogical thinking'. Moreover the same studies have elucidated how the positions held in certain structures affect agents' understanding and representation of stimuli and experiences (for a review see

[19] The mapping of the reconfiguration problem, as done in figure 3, is an heuristic for tracking complex evolving interdependencies.

Buenstorf, 2004)[20]. This set of results have been synthesised by March and Simon (1993:335 italics added) when they stress how "[p]roblems in learning from experience stem partly from inadequacies of human cognition *habits*, partly from features of *organisation*, partly from characteristics of the *structure* of experience". In this passage there is a clear emphasis on the collective and structural dimensions of cognition and learning.

The collective character of learning was originally highlighted by Herbert Simon (1957) in his analysis of the bounded rationality problem. Simon introduced the idea that individuals' learning is socially constructed, in other words, that '[w]hat an individual learns in an organisation is very much dependent on what is already known to (or believe by) other members of the organization and what kinds of information are present in the organizational environment' (Simon, 1991:125).

However, as the collective and thus organisational dimension affect human cognition habits, also the structure of experience does. Now a fundamental analytic tension arises here. Structures of production and structures of cognition are linked by a bundle of bidirectional transformative relationships. On the one hand, agent's cognitive structures are continuously shaped by evolving productive structures (given that the former are embedded in the latter). On the other hand, productive agents may take different decisions and reshape productive structures in a unpredictable way (based of course on certain stimuli coming from productive structures).

It will now become possible to see how the three laws of motion discussed above provide agents with focusing devices to decompose the complex architecture of production and select from amongst the

[20] Buenstorf (2007) is one of the few contributions addressing these analytical conjunctures by posing the building blocks of an evolutionary theory of production.

set of possible learning trajectories the one they want to follow. In order to explain this process we make use of the work of Herbert Simon (1962:468) and conceptualise the production process as a complex system "composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem".

When faced with the 'architecture of complexity', Simon (1962:472-3) suggests that "[P]roblem solving requires *selective* trial and error" and adds that "[t]he selectivity derives from various rules of thumb, or heuristics, that suggest which paths should be tried first and which leads are promising". Thus seen, the complementarities, similarities and indivisibilities embedded in production structures can be seen to trigger and orientate cognitive dynamics in Simon's sense, giving rise to what we have called here structural learning dynamics.

Now from a methodological standpoint, in order to decompose the complex architecture of production and investigate further these structural learning dynamics, the paper has maintained a separation between two fundamental levels of analysis. As suggested by Luigi Pasinetti's separation theorem (2007:255) "it is possible to disengage those investigations that concern the foundational bases of economic relations – to be detected at a strictly essential level of basic economic analysis – from those investigations that must be carried out at the level of the actual economic institutions, which at any time any economic system is landed with, or has chosen to adopt, or is trying to achieve"[21]. The next section investigates structural learning dynamics from the level of the actual production organisations[22]

[21] See also Herbert Simon (1962) on techniques for decomposing the architecture of complexity and Scazzieri (1993:11-13) on the distinction between social and technical division of labour.
[22] Of course this essay recognises "the importance of the immaterial side of production, that is, of the complex network of cognitive rules and practices, customs and social norms from which production is made possible| (Landesmann and

3. The organisation of production and structural learning

As we have already discussed, opportunities embedded in the productive structure not only have to be 'seen' by productive agents but also have to be captured and actualised by production organisations. The latter may take various *forms* in different historical contexts and are endowed with different *organisational capabilities* to operate as collective entities.

As stressed by Luigi Pasinetti (2007:271) "[The production paradigm cannot] abstract, as the models of exchange usually do, from historical specificities, since the kind of institutions that shape an industrial society, besides being far more complex, are inherently subject to changes induced by the evolving historical events, much more extensively than those that shaped the era of trade". In this respect, the notion of *forms of production organisation* captures the different ways in which "coordination problems have been resolved in particular circumstances, taking into account the state of technological knowledge, the evolution of patterns of demand, natural resources and environmental constraints, etc." (Landesmann and Scazzieri, 1996:218). The emergence and disappearance of different forms of production organization testify that the coordination of tasks, productive agents and materials in transformation can follow different patterns according to specific objectives and constraints (see above). Thus, the 'virtual coordination patterns' actualise as 'real responses' to specific historical and contextual circumstances.

Scazzieri, 1996:4). However here we have focused our attention on the often-overlooked role that production structures play in triggering and orientating learning dynamics of the cognitive kind. In the concluding section the paper addresses the issue of how structural learning trajectories, given the same set of structural stimuli, may be framed in different ways by different organisations according to their collective capabilities and the specific organisational form assumed.

In evolutionary economics the collective capabilities of production organisations have been referred to as 'organisational capabilities' (Dosi et al. 2000). *Organisational capabilities* are a particular form of know-how which enable organisations to perform their "basic characteristic output actions – particularly, the creation of a tangible product or the provision of a service, and the development of new products and services" (Dosi et al. 2000:1). In this context, for an organisation 'to be capable of something [it has] to have a generally reliable capacity to bring that thing about as a result of intended action' (Dosi et al., 2000:2). To the opposite of organizational routines, which are characterized by a high degree of tacitness, automaticity and repetitiveness, capabilities are developed and deployed by organizations as a result of intentional and conscious decisions. However, as routines constitute one of the building blocks of organizational capabilities as well as individual skills contribute to the emergence of organizational routines, these two functional features of organizations – i.e organizational capabilities and routines – remain strongly intertwined. Here, the central point is to understand contextually to what extent a capability became routinized and or a routine emerge as a distinct capability[23].

By definition structural learning is not an individual process, since productive agents (and/or productive units understood as organised sets of production agents) are intrinsically interdependent. In other words, to different degrees, structural learning involves a number of interdependent tasks, as well as fund inputs and materials in transformation. Thus structural learning is a systemic process, which means that firms have to be endowed with organisational capabilities to manage all the transformations entailed by structural learning

[23] In this respect organisational routines that are characterised by a high degree of tacitness, automaticity and repetitiveness are problematic since structural learning dynamics will tend to destroy old routines and introduce new ones.

trajectories. To the extent that learning trajectories are variously triggered by similarities, complementarities and indivisibilities, firms will require increasing amounts of organisational capabilities in order to reconfigure the analytical map of production relationships. However, the organisational capabilities required will be different according to the specific organisational form adopted by the firm and this will affect possibility of following certain structural learning trajectories.

3.1 The *job-shop*, the *putting-out system* and the *traditional factory model*

Not all forms of production organisation – such as the *job-shop*, the *putting-out* system or the traditional *factory model* – are suitable for transforming certain structural 'constraints' into structural 'opportunities' along certain structural learning trajectories. Thus it may happen that certain organisational forms have to be abandoned for new ones. Otherwise we can face situations in which structural learning trajectories that are feasible will never been realised in historical time.

For example, the *job-shop* model, adopted in the craft system, is a form of production organisation characterised by (i) multi-task productive agents performing similar tasks and (ii) a 'stop and go' process of material transformations. These two features provide the craft system with high flexibility and adaptability in solving unexpected problems, although low capacity in satisfying increasing levels of demand. With the exception of a few productive agents who coordinate the entire production process, in the job-shop model productive agents tend to be highly substitutable and each of them is only capable of performing the same limited set of tasks. Given this organisational form, structural learning dynamics will tend to follow patterns of diversification in similar activities. These do not require any investment in the acquisition of new fund inputs endowed with different capacities/capabilities.

Clearly, this organisational form is limited by a number of quantitative (e.g. scale) and qualitative (e.g. specialisation) constraints. Thus in the case of increasingly complex products whose production requires the performance of dissimilar but closely complementary activities, firms using the job-shop model may have to change their organisational forms because non- specialised multi-tasks agents cannot make such products. The same problem may arise when firms attempting to satisfy increasing levels of demand have to introduce specialised fund inputs in order to scale up processes (according to specific laws of proportionality). Production processes operating at different scales may then require different organisational forms.

The *putting-out* and the traditional *factory* model are responses to some of the above-mentioned structural constraints faced by the job shop model (Landesmann and Scazzieri, 1996). The putting-out model (also known as *Verlagssystem*) is structured as a network of separate 'specialised workshops', each of them performing a limited number of tasks related to a specific stage of fabrication. Very often the workshop (or the merchant) executing the final stage of production is responsible for the coordination of the different production processes performed in the different workshops**.** Sometimes they are also involved in previous stages of fabrication, for example by assuring the provision of raw materials (Hicks, 1969). Here, given the high degree of interdependence among productive tasks performed by each member of the network as well as the fact that each workshop is highly specialised, we observe *overlapping* structural learning trajectories triggered by indivisibilities and new complementarities.

In contrast, the traditional *factory* model was developed as a concentrated form of production in which complex productive tasks were subdivided in an increasing number of elementary operations performed by highly specialised productive agents inside the same production organisation. Historically the traditional factory model was adopted in the automotive industry at the time in which Ford and General Motors were dominating the global car production. Here, both workers and machines and, thus, their capabilities and capacities, are coordinated in a way that guarantee their full and continuous utilization in executing networks of dissimilar tasks (Landesmann, 1986:294). By increasing the scale of production, in the factory context indivisible funds can be more efficiently utilized and, thus, both economies of scale and scope achieved. In the traditional factory context, structural learning dynamics triggered by indivisibilities tend to be pervasive. This last point was outlined in the 'Maxcy-Silberston curve' in the specific context of Western vehicle manufacturers.

3.2 Structural learning and the modern forms of production organisation

Just as the factory model developed as a response to a series of structural constraints characterising previous forms of production organisation (see above), the 'flexible manufacturing system' as well as the 'network form of production organisation' were introduced as a response to structural limitations of the traditional factory model. Firstly, the traditional factory model is too rigid for responding to firms' increasing need to accommodate consumer preferences for product diversity and, as a result, to produce large varieties in small volumes. Secondly, given the scale and organisation in time of production stages, the traditional factory model is handicapped by large inventories and a relatively high number of defects. Thirdly, diversification in closely complementary but dissimilar activities, such as producing "a particular car with a particular brake and a particular brake lining" in the same factory (Richardson, 1972:891-892), requires increasing investment for building (or acquiring) new bundles of very specialised and diversified capabilities and, very often, a complete reconfiguration of the job specification programme.

3.2.1 The flexible manufacturing system

The *flexible manufacturing system* or, as it is sometimes called, *lean production technique* was pioneered by Toyota and resulted from the visionary ideas of its mechanical engineer Taiichi Ohno (Cusumano 1985; Ohno, 1988; Fujimoto 1999). The Toyota Production System invented by Ohno was based on two fundamental pillars: 'autonomation' and 'just in time' (JIT). The former, the introduction of 'autonomous machines' in production, opened up the possibility of reducing costs by eliminating waste of materials and machines' idle times. The JIT developed the idea according to which "in a comprehensive industry such as automobile manufacturing, the best way to work would be to have all the parts of the assembly at the side of the line just in time for their user" (Ohno 1988:75).

The application of these two principles resulted in the 'small-lot' production technique, i.e. a combination of the flexibility and high quality standards of craft production with the low cost of mass production techniques (Womack et al. 1990). This form of production organisation is characterised by higher levels of flexibility for two reasons: (i) the costs of switching from one product line to another are minimised and (ii) multi-task workers organised in teams are equipped with less highly specialised machines and tools than those used in the mass production factory model. The high quality standards of production are also made possible by the fact that every worker is allowed to stop production every time a fault is discovered (instead of assigning this decision to the senior line manager) and by the fact that product's components are supplied to the work station just in time (instead of keeping large stocks of each component beside the work station).

Although this organisational arrangement implies that initially stoppages in the production line are frequent, in the medium run workers are increasingly able to discover the sources of problems (and their interdependencies) in the space of capabilities, 'materials in use' and 'task execution'. These discoveries trigger a sequence of structural learning dynamics according to which solutions to a certain production problem or bottleneck are applied to similar problems. Additionally solutions to a particular production problem or bottleneck make the solution of complementary problems necessary. As the complementary production problems are identified and solved the number of stoppages diminishes to the point that they become much less frequent than in the typical mass production assembly line.

In the flexible manufacturing system structural learning trajectories are also triggered by the fact that design teams work closely with production engineers and producers of product components. As a result the specification of product design proceeds hand in hand with the design, calibration and adaptation of tools and equipment that are used in production. In this way not only does the overall production system achieve high quality standards, but also in the product's design process a stream of diversified products rapidly develop. Thus the overall production system experiences reductions in the unit costs of production. The successful application in the Japanese car industry of this form of production organisation was at the centre of the International Motor Vehicle Program started in 1979 whose results were collected five years later in the MIT book *The Future of Automobile* (1984)[24].

As is amply documented in Fujimoto's (1999) review of the evolution of the Toyota Production System and its transformation into the flexible manufacturing system, these new forms of production organisation allowed firms to enter structural learning trajectories which were unfeasible within the traditional factory model. Indeed their discovery was the result of a structural learning dynamic in itself which involved precisely what we have called here *intersectoral learning*. In the words of Fujimoto (1999:50 italics added) 'Toyota's production organisation [. . .] adopted various elements of the Ford system selectively and in unbundled forms, and hybridised them with their ingenious system and original ideas. It also learnt from experiences with *other industries*'. In particular, as reported in Cusumano (1985), Taiichi Ohno declared that "the automotive loom was a text book in front of [his] eyes". The application of the same solutions to similar production problems arising in different sectors was at the very root of the Toyota Production System and its evolution in flexible manufacturing system or lean production technique. Throughout the 1990s lean production techniques were increasingly applied from the automotive to other industries such as aerospace, producing highly-complex products (Roos 2003).

3.2.2 The network form of production organisation

The *network form of production organisation* developed as a way of coordinating closely complementary but dissimilar activities[25]. In this context coordination "cannot be left entirely to direction within firms because the activities are dissimilar, and cannot be left to market forces

[24] Among others see Bianchi's contribution on 'Flexible Manufacturing and Product Differentiation in the automobile industry'.
[25] See Powell (1990) for a classical analysis of network forms of organization.

in that it requires […] the matching, both qualitative and quantitative, of individual enterprise plans" (Richardson, 1972:891-892). Thus the network is composed by independent and highly specialised production organisations, each of them working together in a coordinated way to carry out a set of closely complementary but dissimilar activities. This point was originally stated by Alfred Marshall (1920) when he suggested that every firm builds up an *external organisation* as a means not only of developing a special market and establishing preferential relationships with customers, but also for acquiring the kind of knowledge that cannot be attained by anonymous contracting[26].

Networks of producers at the regional and global level overlap and interact in a *multilayered network structure*. For example, complex and interlocking clusters such as the industrial district in Emilia Romagna or the Baden-Wurttemberg region (Piore and Sabel, 1984; Lorenzoni and Ornati, 1988; Best 1990; Pyke and Sengenberger, 1992: Quadrio Curzio and Fortis, 2002; Becattini, 2004; Poni 2009) are regional cases of network forms of production organisation. At the global level, the creation of international networks of producers characterised by a certain degree of stability is another example of close cooperation in a network form among increasingly specialised organizations (Shi and Gregory 1998; Srai and Gregory 2008). From a historical perspective, these international networks appear far from new if we think of the classic organizational form adopted in the traditional textile industry (the Smithian 'putting-out system' led by merchants who controlled the 'circulating capital' network; see above). However, more recently, both regional and global networks are

[26] The creation of these continuing relationships is based not only on the establishment of forms of cooperation between different firms, as well as among customers and firms, but also on the same competitive dynamics that are achieved through market transactions. Richardson (1972:896) explains this point eloquently observing: "firms form partners for the dance but, when the music stops, they can change them. In these circumstances competition is still at work even if it has changed its mode of operation".

increasingly showing complex patterns of systemic integration. This means that production is performed within multilayered manufacturing systems "where the relationships are many-to-many rather than one-to-the-next" (Dyker and von Tunzelman, 2002:2; see also Srai and Gregory 2008; Tassey 2010). From a value chain perspective this point stresses the fact that, at each link of the chain, a bundle of factor inputs (embodying varying degrees of added value) provided by multiple organisations enter into the production process.

In the network form of production, the transfer and pooling of technology, drawings, tools, personnel are among the main triggers of structural learning dynamics and, thus, the most strategic dimensions of connection within the network[27]. However transfers of complementary production knowledge and capabilities within the network of producers is not sufficient. In fact the effective functioning of network forms of production organisation is very much determined by the degree of *structural compatibility* between two (or more) different production organisations embedded in a network.

Now, in order to be 'structurally compatible' two or more firms have to be able to integrate their production processes in all the relevant dimensions identified in the analytical map of production (not only capabilities but also tasks and materials). If they are not able to do so firms' opportunities of structural learning driven by complementarities, similarities or indivisibilities within a production network are drastically reduced. For example, given the space of capabilities:

$$\mathbf{C^1 = [c_{ij}]} \text{ and } \mathbf{C^2 = [c_{ij}]}$$

[27] See Shi and Gregory (2005); Lomi and Pattison (2006)

of two different production organisations $\mathbf{f^1}$ and $\mathbf{f^2}$, their structural compatibility $\mathbf{\Phi}$ is a function of the number of feasible connections among the fund agents' capabilities respectively owned by $\mathbf{f^1}$ and $\mathbf{f^2}$. The mapping between $\mathbf{f^1}$ and $\mathbf{f^2}$ can be extended to consider the other relevant dimensions of materials in transformation and production tasks. By recurring to adjacency matrices, we can analytically develop a *matrix of proximity* $\mathbf{\Phi}$. Here, each element indicates (according to a binary codification) if capabilities, materials or production tasks of one firm are compatible with those of the others.

For example, it will show if the machine owned by $\mathbf{f^2}$ achieves the standards of precision or scale which are necessary to complement the production of the machines owned by $\mathbf{f^1}$. Below a certain level of structural compatibility $\mathbf{\Phi < \underline{\Phi}}$, it is very unlikely that the two firms will adopt a network form of production organisation or that they will be able to experience structural learning dynamics.

An example would help clarify things here. Let us consider a high-tech manufacturing firm $\mathbf{f^1}$ interested in outsourcing the production of a set of components of the capital good A to another manufacturing firm $\mathbf{f^2}$. To be sold in international markets the capital good A has to satisfy certain properties and quality tests. In order to achieve these output standards, $\mathbf{f^1}$ has to be sure that the capabilities, tasks and materials adopted are compatible with those in use in the firm $\mathbf{f^2}$. For example, as stressed above, $\mathbf{f^1}$ has to be sure that machines, workers etc. used by $\mathbf{f^2}$ are able to perform the production of certain components according to specific production standards. When this condition is not satisfied, the production of complex goods might be delayed or might not achieve certain quality standards. This is exactly what happened in the case of the Boeing 787 Dreamliner whose production relies on a network form of production organisation involving 287 different companies specialised in single components of the aircraft (Tassey 2010).

Thus, especially in the case of complex products such as aircraft, outsourcing is not a problem of cost reduction but mainly one of *structural compatibility* of closely complementary but dissimilar production activities. This is also why firms adopting the network form of production have to invest in the transfer of tools, machines, mutual personnel training, drawings exchange, effective knowledge transfer etc. At the end, all these strategies are meant to connect (and make compatible) different productive organisations and to make possible the discovery and exploitation of complementarities among them.

To recap, the historical analysis of different forms of production organisation allows us to identify two main stylised facts that are of immediate relevance to the study of structural learning trajectories. First of all, forms of production organisation structurally persist over time and, very often, old ones compete with new ones for considerable periods (Landesmann, 1988:173; Rosenberg, 1976). This occurs because transition is costly and requires the reconfiguration of production processes along different structural learning trajectories. Moreover, as each form of production organisation is a response to specific socio-technical circumstances, old ones can reappear. Examples are today's re-emergence of 'modern craftsmen' adopting the job-shop form of production organisation[28] as well as the increasing pervasiveness of global production networks, a model which share many features with the putting-out system developed in early modern Europe (Dyker and von Tunzelman, 2002).

Secondly, production can be organised by adopting various coordination devices, namely (i) by market transactions; (ii) by directing

[28] See also Andreoni and Pelligra (2009) for an analysis of various forms of relational credit adopted for financing modern micro and small medium enterprises.

and controlling production activities within a single organisation; or (iii) by collaborative arrangements (Richardson, 1960; 1972; 2003). The resulting organisational forms will affect the possibility of firms following certain structural learning trajectories instead of others. Specifically, the classification of production activities along the dimensions of similarity and complementary proposed by Richardson and discussed above, contributes to an explanation of (i) patterns of diversification within a single organisation triggered by *discovering similarities*, (iii) patterns of specialisation within a single organisation triggered by *exploiting indivisibilities*, and (ii) patterns of specialisation in interlocking networks of production organisations triggered by the *discovery of new complementarities* among structurally compatible firms.

In all the above-mentioned cases, even if certain structural stimuli and feedback loops were to make certain structural learning trajectories feasible, only firms adopting a certain organisational form will be capable to follow these trajectories. Specific organisational features of production organisation may enable (or block) the three fundamentally alternative routes described above (structural learning trajectories triggered by discovering similarities, those triggered by discovering new complementarities and, finally, those triggered by overcoming indivisibilities).

Concluding remarks

Learning dynamics are the main transformative forces of economic systems. Economists have always been interested in this fundamental reality. Some recent studies (e.g. Hidalgo and Hausmann, 2009) have attempted to link micro-learning dynamics and macro-transformative effects by tracking countries' specialisation/diversification patterns driven by similarities in the 'product space' (a network-type representation of the international market architecture). However, these studies do not disentangle the different forms of learning realised at the firm level (as we have done in this paper) and thus are not able to explain how learning dynamics trigger structural change and economic growth of economic systems at different stages of development (as we are now in a position to do).

As learning processes are embedded in productive structures, any attempt to understand how economic systems change over time through learning dynamics cannot avoid looking at the reality of production processes. In this respect, the contribution of this paper is twofold. Firstly, building on structural theories dealing with the complex architecture of production, the paper has proposed a new heuristic for analysing interdependencies among structural components of production processes. The 'analytical map of production relationships' provides a stylised representation of the system of interrelated tasks through which transformations of materials are performed according to different patterns of capacities/capabilities coordination, subject to certain scale and time constraints. On this basis the two main forms of learning ('learning by doing' and 'learning by using') have been re-formulated in a way that sees them as being affected by and affecting the production structure.

Learning in production takes many forms and is realised at several interconnected (nested) levels, the pattern of nesting being structurally determined. Thus the concept of *structural learning* has been introduced to identify the continuous process of structural adjustment triggered and orientated by existing and evolving productive structures. The paper identifies three laws of motion driving different structural learning trajectories. Static and dynamic complementarities, similarities and indivisibilities are essential triggers for activating compulsive sequences of technological change as well as for *discovering new productive possibilities* at the firm and inter-firm level.

These structural learning dynamics have to be 'seen' by productive agents and 'used' by productive organisations. At this point, we have identifies a fundamental tension underlying structural learning dynamics. Namely, the fact that structures of production and structures of cognition are linked by a bundle of bidirectional transformative relationships. This tension is partially solved by the adoption of different forms of productive organisations, whose specific features may enable (or block) a number of structural learning trajectories.

From a methodological standpoint, in order to decompose the 'architecture of complexity' in production as well as investigate structural learning dynamics, the essay has maintained a 'separation' between two fundamental levels of analysis (Simon, 1962; Rosenberg, 1963; Pasinetti, 2007). As Rosenberg (1963:440) notes "an analytical explanation of many of the technological changes in the manufacturing sector of the economy may be fruitfully approached at the purely technological level. This is not to deny, of course, that the ultimate incentives are economic in nature; rather, the point is that complex technologies create internal compulsions and pressures which, in turn, initiate exploratory activity in particular directions".

At one level, the analysis focused on those dynamics inherent in productive structures independently of specific organisational/institutional configurations. At a deeper level, the analysis considered how, given certain possibilities and 'laws of motion' embedded in productive structures, different organisations may follow different learning trajectories. The analytical account of specific historical cases has been adopted as the main heuristic for disentangling structural learning dynamics. At this point in the analysis the historical emergence and reappearance of different forms of productive organisation have been stressed.

Looking at the production process and its transformations from a structural perspective has allowed us to re-link production and learning dynamics. This goal has profound implications for policy design. Structural learning trajectories (and their laws of motion) are transformative processes operating *within* the black box of production and, as such tend to remain 'invisible' to policymakers. The 'political economy of structural learning' suggests a number of unconventional policy options, such as the possibility of policy intervention in sectors that are similar or complementary to those that were initially taken as the object of policy intervention.

In this respect Silver (1984) argued that "in developing countries, or in developed economies when innovation renders the market's existing capabilities obsolete, a firm may have to integrate into many dissimilar activities in order to generate all the complementary activities it needs" (Langlois, 1992:108).

In economies in their catch-up phase, where constraints in production structures appear pervasive, the structural learning perspective also suggests possible strategies for overcoming indivisibilities or scale-invariant process constraints. Finally it points to the possibility of discovering unexploited opportunities embedded in existing productive structures at the sectoral and intersectoral levels, following patterns of diversification in similar activities, and building/exploiting technological linkages with those dissimilar activities towards the selective creation of new productive opportunities. The final aim of these structural learning policies is to facilitate the discovery of new ‘worlds of possibilities’ and, thus, the emergence of ‘new ‘worlds of production’.

Third Essay

MANUFACTURING AGRARIAN CHANGE

Agricultural production, intermediate institutions and intersectoral commons: Lessons from Latin America.

Introduction

The structural relationship between agriculture and industry in the process of economic development is at the very root of development studies. Unfortunately throughout the last century the debate has been dominated by the 'industry first' *versus* 'agriculture first' debate, although some classical development economists like Arthur Lewis were aware of the strong interdependencies between industrialisation and agricultural improvements. The 'industrialisers' maintained that the ultimate road to modernisation and independence for less developed countries (LDCs) was one of structural change triggered by manufacturing development. Thus, agriculture was asked to contribute to industrialisation in multiple ways: by transferring agricultural surplus to industry, by supplying cheap food and labour, and finally by supporting internal demand for domestically manufactured products. In contrast, the 'agrarianists' supported the comparative advantage argument according to which LDCs should specialise in exporting agricultural and primary commodities[1].

With few exceptions, industrialisers and agrarianists frame the relationship between agriculture and industry as *unidirectional* (i.e. going from agriculture to industry) instead of truly *intersectoral*. Thus they ignore circular and cumulative interdependences (i.e. causation going from agriculture to industry but also from industry to agriculture, Myrdal, 1958; Kaldor, 1966). In the few cases where intersectoral interdependencies are addressed, scholars have focused their attention on backward and forward linkages as broadly defined macro-intersectoral relations. Admittedly these contributions recognise how increases in agricultural productivity result from

[1] In spite of some minor updates the recently influential *World Development Report 2008* has restated the World Bank's 'agrarianist' perspective rooted in the neoclassical view of development.

adopting/adapting/applying various kinds of technological innovations developed both within the agricultural sector and in the manufacturing sector. However they leave largely unexamined the specific way in which these technological innovations transform in-farm agricultural production. Most crucially there is no attempt to understand the relevant dimensions involved in processes of agrarian change by analysing the full set of learning dynamics. These occur at both the farm level and at the intersectoral level (the latter referring specifically to learning dynamics located at the interface between agriculture and manufacturing). These remain neglected by the literature.

The aim of this essay is to investigate how industrial development (particularly manufacturing) contributes to agrarian change. To address this issue we analyse the technical bases, relevant dimensions and structural specificities (i.e. time and scale constraints) of agricultural production. Technical change in agriculture involves improvements in both organic transformation processes (i.e. *biological production* and *reproduction*) and in the mechanical functions necessary to obtain certain output (i.e. *agricultural work*). This essay shows how 'in-farm technological capability building', 'intersectoral learning' and 'technology transfer' are all necessary for successful technical change. Specifically they are required if farms are to acquire and adapt bio-chemical innovations (e.g. new seeds, fertilisers or pesticides) and mechanical technologies (e.g. agro-processing machines, tractors or water pumps)[2].

To the extent that a country experiences a sustained process of industrialisation, the development of agricultural technologies becomes more complex and science-based. It thus moves gradually away from

[2] The analysis of agrarian technical change triggered by 'in-farm learning', 'intersectoral learning' and 'technology transfer', is developed by integrating peasant studies with evolutionary and structural approaches to economic development. This integration seems to be particularly promising as it clarifies the central role of agricultural-manufacturing synergies in economic development and moves away from a linear and unidirectional understanding of structural change dynamics.

the farm to the firm, so to speak. Although on-farm testing, adaptation and evaluation of new technologies are still needed, agricultural machinery and fertilisers (especially those adopted by large scale farms) are very often manufactured by the machine tools and chemical industries. Thus agrarian change becomes increasingly less dependent on a country's geographical position, climate or natural endowments and increasingly more determined by its manufacturing development, agricultural policies, and the implantation of intermediate institutions, that is, institutions bridging and transferring knowledge across different sectors and, thus, facilitating various forms of intersectoral learning.

Agricultural development requires lumpy investments that have typical features of public goods, thus tend to bring about network infrastructures and interdependencies. For this reason the paper focuses on those agrarian public policies which allow the emergence of *intersectoral commons,* such as the creation of intermediate institutions and the provision of technical support through 'itinerant instructors' and 'extension services'. The concept of *intersectoral commons* refers specifically to that specific bundle of technological capabilities that are concentrated in certain areas of strong intersectoral interdependence as a result of intersectoral learning.

Building on the analysis of agriculture-manufacture interdependences and learning dynamics in agricultural production as well as on our discussion of intersectoral commons, the second part of the paper looks at the agricultural policies adopted by certain successful LDCs like Chile and Brazil. It identifies those institutional innovations and policy measures they have adopted to trigger and reinforce the process of transformation and productivity-improvement in the agricultural sector. Two in-depth case studies of intermediate institutions are presented: Fundación Chile, and Embrapa in Brazil.

PART I

Manufacturing Agrarian Change: A theoretical framework for the analysis of intersectoral learning and intermediate institutions

1. Agrarianist versus industrialisers: moving the debate forward.

It is widely acknowledged that the development of a socio-economic system occurs via a process of structural change. In other words it advances via a process of change of the sectoral composition of the economic system and underlying transformation of its productive structures and demand composition (Deane and Cole, 1969; Kuznets, 1973; Pasinetti, 1981; Baranzini and Scazzieri, 1990; Scazzieri, 2009). Increasing consumer, technological and social capabilities are the ultimate drivers of this process of development and, thus, of *sectoral transition* (Myrdal, 1958; Stewart, 1981; Abramovitz, 1989 and 1991; Lall, 1992). At both the intra- and inter- sectoral level, consumers' capabilities and producers' capabilities interact with each other in a circular and cumulative process of mutual reinforcement. This means the introduction of new technologies leads to new productive activities and opportunities for consumption that, in turn, spurs on new technological innovations[3].

The very circular and cumulative nature of these causational dynamics led Nicholas Kaldor (1960-1979) to analyse the role played by effective demand (in particular the quality and the composition of internal and external demand) in activating structural change dynamics. He argued that changing demand played a crucial role in changing sectoral proportions, increasing returns in certain industries and external economies. Gunnar Myrdal (1958) focused on the role played by 'non economic factors', namely institutional, cultural and ideological elements, which lead a country towards a virtuous or vicious circle of cumulative development or underdevelopment. At the core of Myrdal's theory, is the suggestion that different endowments of what Abramovitz (1989 and 1991) defined as 'social capabilities' can strongly

[3] Scazzieri (2009) provides an analysis of the 'structural dynamics tradition' starting from the early discussion of the relationship between technical progress and Engel's law, and of the structural interdependence between growth, resource utilisation and capital accumulation.

affect the speed, depth and sustainability of a process of structural change. Consequently it can also strongly affect sectoral transition[4].

Now, as we have discussed, sectoral transition constitutes the structural basis of the development process. It is thus unsurprising that the last century of development studies debate has centred on the transition from an agriculture-based economy to an industrialised one (i.e. industrialisation). For the same reasons the most recent developments in this debate have focused on the process of change from an industrialised economy to a service-based one – i.e. servitization[5].

As we have seen this debate has been dominated by two main contending visions: those of the 'industrialisers' and the 'agrarianists' (Bernstein and Byres, 2001; Kay, 2009). Their visions with respect to the role of agriculture in the process of economic development, as well as the timing and models of industrialisation, were influenced by the previous 'Soviet Industrialization debate'. In order to understand the theoretical differences between today's industrialisers and the agrarianists we will now briefly review of the contrasting positions emerged in the Soviet Union, during the 1920s (Saith, 1985; Bernstein, 2009). This should help us better understand the theoretical frameworks constructed by their sucessors .

On the one side Nikolai Bukharin envisioned a process of industrialisation triggered by the peasants' increased capacity to provide marketable surplus and to purchase industrial commodities. On the other Evgeney Preobrazhensky argued for a forced 'primitive socialist accumulation' which would have accelerated and increased the net transfer of resources from agriculture to industry (Mahalanobis,

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[4] The integration of structural economics with capabilities approaches is attempted in the First Essay. See also Von Tunzelmann and Wang (2007) and Von Tunzelmann (2009). For a review of the main currents in cumulative causation theory see Toner (1999).

[5] In 1940s the emergence of a service economy and post-industrial society was predicted by Clark (1940) and Fisher (1939) and formalised in the Clark-Fisher hypothesis.

1985; Chakravarty, 1987)[6]. The latter vision proposed a twofold strategy. Firstly Preobrazhensky's followers advocated the adoption of a collectivised form of agricultural production for exploiting economies of scale and, thus, increasing agricultural output. Secondly they argued for the manipulation of the terms of trade in favour of industry in order to extract maximum surplus from agriculture. However, given the unexpected fall of agricultural output, the net agricultural transfer mainly derived from squeezing the agricultural sector and from lowering living standards of rural workers and also those of the urban workers who were often paid below subsistence wage.

Despite this, during the first twenty years after the WWII, classical development economists produced a large number of different arguments supporting the so called *'industry first'* argument (cfr. Toner, 1999; Kay 2009). The transfer of a large agricultural surplus was recognised as a necessary precursor for structural change. Thus the agricultural sector was mainly treated as instrumental to industrialisation. On the supply side agriculture was asked to support industrial development by transferring raw materials, food, capital and foreign exchange (arising from surplus in agricultural production) and finally surplus labour (Johnston and Mellor, 1961). At the same time, despite the contradiction, agriculture was expected to provide an effective internal demand for manufacturing goods[7].

The prolific work of the classical development economists produced two key theoretical innovations in this period. One of these

[6] The debate around economic planning in the Indian experience and the specific contribution and policy recommendations of Ragnar Nurske are discussed in Kattel et al. (2009). See also Scazzieri (2009) on the links between Indian and Italian economists on the importance of historical conditions in determining both the pace of structural change and the character of structural breaks in a developing economy.

[7] Ishikawa (1967) was among the first to challenge the theory according to which the early phases of industrialisation must be financed by a net outflow of resources from agriculture. In his study of intersectoral flows in Meiji Japan, he attacks the conventional historical reading, pointing to the existence of other resource channels for industrial development such as government expenditure, farm debts, inflows of salaries and income from subsidiary occupations.

was Mandelbaum's pioneering idea (1945)[8] of transferring surplus labour from less to more productive sectors was formally developed in the celebrated 'dual economy model' by Arthur Lewis (1954). According to this model, given unlimited supply of labour in the 'traditional' sector, the increasing employment of labour at subsistence wages in the technologically superior sector triggers 'modern' sector capital accumulation and economic growth[9].

A further fundamental theoretical contribution came from the 'un-balanced development model'. By embracing an intersectoral perspective, Albert Hirschman (1958) provided a strong rationale for industrial development. In his model each sector is linked with the rest of the economic system by its direct and indirect intermediate purchase of productive inputs and sales of productive outputs (i.e. backward and forward linkages). Each sector exercises push and pull forces on the rest of the economy according to its system of linkages,. Unlike agriculture, the industrial sector is characterised by both strong backward and forward linkages and thus emerges as the main driver of development. Given these theoretical pillars, industrialisers mainly focused on the relationship going 'from agriculture to industry', that is to say the ways in which it was possible to extract surplus from agriculture to push industrial development.

Around the mid 1960s, after two decades of import-substituting-industrialization (ISI), the agricultural sector in many countries started showing signs of deterioration. Most problematically production began to decrease and, as a result, critiques of the industrialisers' position

[8] Kurt Mandelbaum changed is surname to Martin. The author mentioned in the next section, Martin (1982) is actually Kurt Mandelbaum. His pioneering contributions are discussed in Fitzgerald (2002).

[9] As Kay notes (2009:106), the Lewis model "left open the possibility of a modern sector within agriculture and a traditional sector within the urban sector". It also stressed how "industrialisation is dependent upon agricultural improvements" (Lewis 1958: 433). However influential contributions such as Ranis and Fei (1964) do make the simple identification of the traditional sector with agriculture and the modern one with industry.

arose[10]. Both neoclassical agrarianists such as Schultz (1964) and neopopulist agrarianists such as Lipton (1968; 1977) and other followers of Chayanov (1966; 1925 orig.) found fertile ground for their 'agriculture first' argument[11]. The Neoclassical Agrarianists' essential point was that, as poverty has a rural face, development policies should prioritise this sector as the basis for development. Grounding their vision on the neoclassical theory of comparative advantage, they recommended that LDCs should specialise in exporting primary commodities and raw materials and import the manufactured goods they needed from industrialised economies.

The strong contraposition, both theoretical and ideological, which has characterised the industrialisers versus agrarianists debate has obscured what, in a recent contribution, Kay (2009) describes as the 'synergy perspective' This is a perspective focused on the complex and dynamic synergic relationships linking the development of the agricultural and industrial sectors. In order to make the above debate more productive, it seems sensible to pay more attention to these intersectoral relationships. This will allow us to see beyond the

[10] Throughout the 1970s, the industrialisers' perspective was reinvigorated by innovative contributions which addressed the demand side linkages between agriculture and industry (Kaldor, 1975; Mellor, 1976). The Kaldorian model, in particular, was lately extended by Bhaduri's contribution (2003), in which both the role of effective demand and terms of trade between agriculture and industry are reconsidered.

[11] As Kay (2009:109) clarifies, the main difference between the two groups is that "neopopulists believe that small-scale peasant households farming is superior to large scale commercial farming (the inverse relationship), neoliberals allow for the possibility of economies of scale and efficient large scale farming. (…) Neopopulist are in favour of state support for smallholders while neoclassicals and neoliberals prefer a minimal state". The Neopopulist vision, encapsulated by the work of Michael Lipton, is more concerned with problems of poverty-alleviation than development per se while it was the Neoclassical Agrarianists who put forward the unidirectional vision of structural change patterns of development. The influential 'urban bias thesis' proposed by Lipton (1968:141) stated that "farm policy is made by the towns, and to some extent for the towns". By controlling public development policies and government expenditures the urban class is able to squeeze the rural poor and to maintain terms of trade against agriculture (in favour of industry), at least according to Lipton. The artificial condition built by the urban bias was criticised as both inefficient in allocative terms and inequitable.

unidirectional vision of structural change in favour of one in which development is understood as a circular and cumulative process.

2. The matrix of intersectoral interdependences

Despite the dominance of the two opposing positions reviewed above, scholars have increasingly come to recognise the risks connected with a unidirectional understanding of the relationship between agriculture and industry (Kuznets 1964 and 1968; Johnston and Kilby, 1975; Martin, 1982; Hwa, 1989; Kay, 2009). New studies have focused on the consideration of sustainability, which is linked with the ways in which surplus is (i) generated in the agricultural sector, (ii) transferred to the industrial sector and (iii) used for fostering manufacturing production and technological innovation. The sustainability of all three of these processes explain how much and for how long the agricultural sector is able to nurture industrialisation without any significant change of the production techniques adopted in agriculture.

As Arthur Lewis (1958:433) notes, "it is not profitable to produce a growing volume of manufactures unless agricultural production is growing simultaneously. This is also why industrial and agrarian revolutions always go together, and why economies in which agriculture is stagnant do not show industrial development". This sustainability problem (i.e. guaranteeing a sustained level of agricultural output) is especially critical in the early phases of development when manufacturing growth is still strongly dependent on the agricultural sector for surplus labour, savings, and inputs for industrial processing and demand for manufactured goods. At more advanced stages of industrialisation, the manufacturing sector tends to 'self-reproduce' while the intersectoral transfer of resources from agriculture to other sectors tends to be balanced and, finally, eventually reversed.

Writing on this same sustainability problem, Kuznets (1964; 1968) observed how a self-sustained process of structural change requires technological advancement and thus increasing productivity in agriculture *as well as* in industry. In his view the shifting of the productive structure towards manufacturing and the redistribution of employment from agriculture to industry are consequences rather than causes of industrialisation occurring because of technological change in the industrialising economy (Vogel, 1994). This vision illustrates how increasing productivity in the agricultural sector arises from 'manufacturing agrarian change', that is through the adoption/adaptation/application to the agricultural sector of those technological innovations which were developed intra or intersectorally[12].

For this reason, consideration of how much and how long agriculture can support industrialisation, has to be complemented with consideration of how much and in which ways industrialisation can 'technologically push' agrarian change. This observation directs our attention to the identification of a *technological interdependence* existing between agriculture and manufacturing, a relationship that can also be extended to services. This technological interdependence refers to the transformative power that an increasing technologically advanced manufacturing sector can have with respect to the agrarian sector (and other sectors).

The existence of a technological relationship going 'from industry to agriculture' was stressed by Kurt Martin (1982:7) who argued that "resource outflows from agriculture [and] rising agricultural productivity … can go together, provided that the productivity gains in agriculture do not themselves necessitate large-scale capital investment *within* agriculture". He added that "quite often they do not require

[12] Interestingly the importance of technological advances in agriculture was also stressed by Kalecki (1976) who dedicated much attention to the existence of bottlenecks in the agricultural sector.

that'[13]. As documented in Mellor (1973:2) in a detailed comparison of Taiwan's and India's development patterns, the specific condition described by Martin occurs precisely "when technological change in agriculture sharply increases returns to investment in agriculture and consequently sharply reduces the capital-output ratios"[14].

According to Martin (1982), the allocation of part of investable funds (coming in part from agricultural surplus) for the establishment of agro-industries in rural areas can stimulate agricultural progress in two main ways. Firstly, it allows a Lewis-type process of intersectoral transfer of labour without urban migration. Secondly, it permits the creation of industries whose production process is strongly interconnected with the agricultural one through strong backward and forward linkages (Martin, 1982). These linkages going 'from industry to agriculture' as well as 'from agriculture to industry' express what Hwa (1989:107) defined as "the relationship of interdependence and complementarity between agriculture and industry".

Technological interdependencies between agriculture and industry are structurally embedded in a bundle of intersectoral interdependencies characterised by multidirectional, circular and cumulative dynamics. A useful way to visualise these interdependencies (including the technological ones) is to think of a *matrix of intersectoral interdepencies*, that is a matrix defined by both supply side and demand side linkages among different sectors[15]. Inside the matrix industries

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[13] As Martin himself explains (1982:11) this condition is satisfied "when the capital to output ratio in agriculture is less than one … What is relatively costly is the provision of rural infrastructure, i.e. rural electricity, transportation, marketing facilities, etc., but these are non-agricultural activities and investments, which serve agriculture from outside it: they bring 'external economies' to the farmers (as well as to non-farmers in rural areas)".

[14] Mellor (1973) identifies other three factors which, together with changes in the capital-output ratios, control the magnitude and direction of resource flows in the matrix of interdependences: the rates of return on capital; the savings rates and the demand from agricultural outputs. Of course, other social and institutional factors strongly affect these economic relationships.

[15] Different methodologies that aim to shed light on the matrix of intersectoral interdependencies have been developed over the years. These include Leontief's

within the manufacturing sector are characterised by a comparatively higher density of inter-industry and inter-sectoral forward and backward linkages, albeit to different degrees, (Hirschman, 1958).

Now these intersectoral linkages are destined to change and "vary according to the particular phase of the development process and as structural conditions and international circumstances change" (Kay, 2009:116). For example it has been observed how, with the increase of productivity in agriculture, backward linkages between agriculture and services have been expanding in magnitude and quality. Good examples include post-harvest facilities such as transport, communication, information services for production control in agriculture, marketing services, etc. (FAO UNIDO and IFAD 2009).

Despite these sectoral specificities which change in historical time, all sectoral activities persistently affect the rest of the economy through both direct and indirect linkages which accumulate in successive rounds of intersectoral expansion of the productive matrix. This is the reason why, for example, Park and Chan (1989:211) argue that 'the evolution of the intersectoral relationship between services and manufacturing in the course of development is symbiotic, in the sense that (…) structural change of the former is bound to affect that of the latter'.

The existence of a 'symbiotic' evolution of intersectoral relationships between agriculture and manufacturing has found empirical support in various studies. Interestingly, in the context of Malaysia, it has been shown how an expansion of manufacturing output associated with a contraction of agricultural output in the short run, is also correlated with a process of agricultural expansion over the long run (Gemmell, et al. 2000). Furthermore, the experience of highly

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production matrix for input-output analysis, through to the social accounting matrix (SAM) as well as various econometric models like the computable general equilibrium model (CGE).

industrialised countries such as Japan and U.S. (in which a comparatively higher multiplier effect for the agricultural sector is registered) demonstrates how agro-based industries can effectively emerge from the increasing exploitation of intersectoral synergies and complementarities (Park and Chan, 1989 and Park 1989). In sum, these studies confirm the idea that structural change does not simply imply a process of *sectoral transition* but also one of *sectoral deepening* (i.e. a technological transformation of production processes performed in each sector).

Among the bundle of intersectoral relationships, those linkages through which innovative technologies are developed, transferred, adjusted and adopted across sectors take centre stage. This is because these interdependencies (which are technological in nature) are the main drivers of the processes of qualitative transformation and quantitative expansion of the productive structure of a country. Through processes of transformation and expansion of the productive structure, an economic system may experience increasing returns, occurring at both at the intra- and inter- sectoral level (Young, 1928).

As stressed in Scazzieri (2010: 38), increasing returns "presuppose an underlying process of scale-technology expansion, which is subject to specific complementarities and constraints". These complementarities and constraints arise from interdependences both at the intrasectoral and intersectoral level. If increasing returns are associated with Babbage's law of multiples and Schneider's law of full capacity utilisation at the intrasectoral level then *increasing returns at the intersectoral level* may be realised when certain *thresholds* of technological interdependence among sectors are satisfied. As discussed in section 4 a process of intersectoral learning underlies this process of increasing returns at the intersectoral level.

Intersectoral learning has been defined as a dynamic process of interlocking and mutually reinforcing technological developments which link the innovative patterns of two or more sectors in a relationship of complementarity. Understanding technological expansion at the intersectoral level as well as how an economy may experience increasing returns at the intersectoral level requires overcoming black box views of production and studying intersectoral learning with more care. In fact improving or inventing new technologies and discovering complementarities with new or existing technologies are all learning processes that result in the qualitative transformation of production processes. This is the reason why, as Nicholas Georgescu Roegen suggested (1969), it is necessary to shed light on these specific features of production processes in different sectors, manufacturing and agriculture.

Few contributions in the economic literature, have systematically attempted to look 'under the surface' of agricultural production[16]. An attempt in this direction should aim not only at the identification of structural specificities in agricultural production (i.e. constraints, bottlenecks and complementarities) but, also, at addressing the various mechanisms of intersectoral learning which are responsible for the massive increase in agricultural production in many regions of the world over the last two centuries.

3. Looking 'under the surface': agricultural work, biological production and biological reproduction.

The fundamental structural feature of the agricultural sector is that its output result from three distinct (although interdependent) processes of production: agricultural work, biological production and biological reproduction. Each of these production processes is organised according to different rules/conditions (socio-economic, biological and

[16] See Romagnoli (1996) for a review.

environmental) and thus functions according to different dynamics in 'historical and seasonal' time. The existence of structural interdependencies amongst these processes generates constraints, but also opportunities for change.

Agricultural work consists of a set of interrelated tasks such as ploughing, planting, fertilising, inspecting, harvesting, storing and transporting. Each of these tasks is performed by coordinating productive capabilities embedded in workers and various 'cooperation instruments' (e.g. mechanical equipment, engines and animals)[17]. Cooperation instruments complement and empower workers by (i) enhancing the performance of particular tasks in specific ways (e.g. increasing accuracy, strength or intensity); (ii) allowing different tasks to be executed at the same time; finally, (iii) increasing the speed of production operations or reducing idle times (Georgescu-Roegen, 1969). Expressed more succinctly 'cooperating instruments' aim to increase the productivity of labour. Unlike manufacturing production where productive capabilities transform and recombine materials into goods, agricultural work "has only the task of creating the more suitable environment for the life of the cells (…) and of picking up the result of their work at the end" (Bolli and Scotton, 1987:19-20).

Biological production is occurs in land and consists of processes of transformation of biological materials triggered and fostered at appropriate intervals by agricultural work[18]. In order for land to perform a specific biological production process agricultural work and flow inputs are both required. Specifically, land can be thought as a 'photosynthetic machine' which requires solar energy, water, carbon

[17] See the following subsection for a definition of productive and technological capabilities.
[18] As observed by Romagnoli (1996:244) "in agriculture it is impossible to identify the materials in process, that is materials coming from one work to another which may be decomposed at each stage of transformation and rearranged according to other sequences. This is due to the fact that agricultural production processes are characterised by the continuous activity of the land, which may be stopped only at the end of the process".

dioxide and other nutrients from natural soils (i.e. flow inputs) to function. As land is part of an ecosystem, biological production "can be controlled by human beings only partially because it consists of a sequence of operations whose *order*, *duration* and *respective distances* are significantly dependent on weather conditions" (Romagnoli, 1996:234).

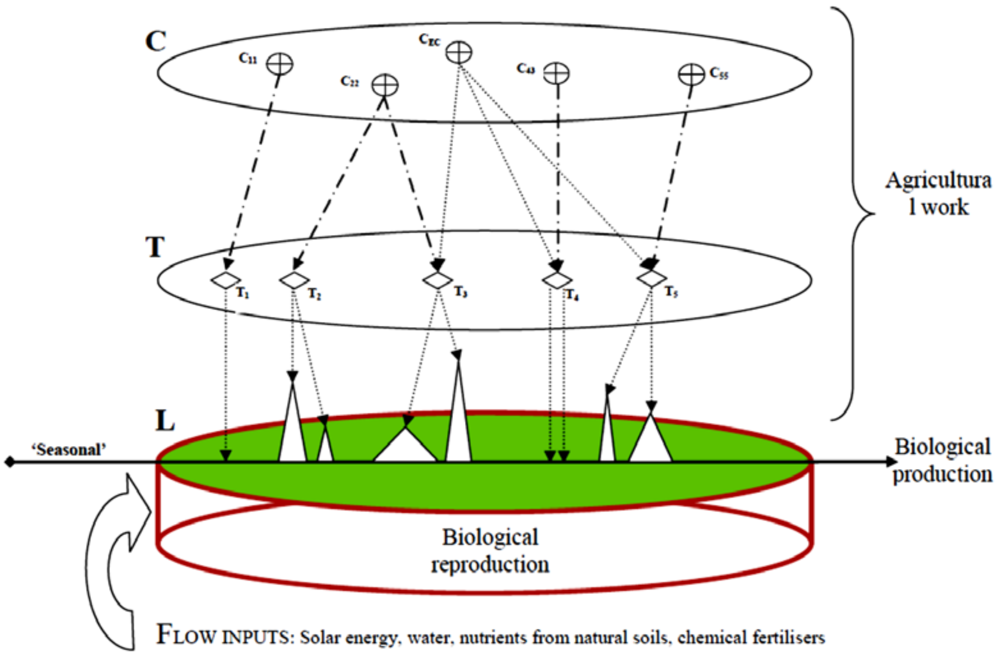
Just as *biological production* is dependent on seasonality and affected by soil differences, the organisation of *agricultural work* is be constrained by seasonal patterns (i.e. time constraint) and by the specific local conditions and geographical dispersion (i.e. space constraint). As we will see below, by relaxing these constraints through various social and bio-technological innovations it has been possible to increase land productivity (i.e. biological production).

Biological reproduction is the last constituent process in our decomposition of agricultural production. This process is necessary to restore the land capacity's to perform biological production. As discussed in Romagnoli (1996:230), from an agronomic point of view crops may be classified as: (i) *impoverishing* (when biological production reduces land fertility), e.g. wheat, rice and barley; (ii) *improving* (when biological production increases land fertility), e.g. leguminous and graminaceous crops; (iii) *preserving* when biological production maintains good standards of fertility. This last possibility derives from specific agronomic properties of certain crops such as potatoes, tobacco, tomatoes, maize, but also from the specific tasks that their cultivation requires (e.g. deep ploughing and fertiliser use).

One of the most effective answers to these agronomic constraints has been the development of rotation schemes. The well-known Norfolk four-year rotation scheme was introduced in England in the eighteenth century. However the need to follow a particular time sequence of crops in the same plot of land in order to allow biological reproduction introduces further (time) constraints in agricultural production. Historically the introduction of a rotation scheme actually induced technological advances in agricultural techniques and tasks organisation. Specifically, adopting rotation schemes with multi-crop production not only allows the preservation of the land's fertility but also permits: (i) the diversification of the climate risk of biological production; (ii) a better distribution of agricultural work during the year; (iii) an increase in agricultural work by introducing 'inserted crops' and 'associated crops' (crops that allow biological reproduction). More recently the development of chemical industries and the mass-production and utilisation of fertilisers have allowed farms the possibility to engage in monocultivation.

Having discussed and analysed these three agricultural production processes we are now in a position to examine the interdependencies that exist between them. These can be visualised as follows (see Figure 1). Given a certain amount of productive capabilities **C**, a system of interrelated tasks **T** will be organised in agricultural work according to the set of constraints imposed by biological production and reproduction in land **L**.

Figure 1: The analytical map of agricultural production



For any given amount of land **L**, the 'crop-growing technique' is defined by:

(i) a certain combination of productive capabilities **C**

(ii) a set of interrelated tasks $\mathbf{T = [\ T_1; T_2;...T_J...; T_r]}$

(iii) a certain amount of flow inputs $\mathbf{F = [\ F_1; F_2;...F_J...; F_m]}$

For each 'crop-growing technique' we can represent the set of productive capabilities with a matrix $\mathbf{C = [c_{ij}]}$ in which any element $\mathbf{c_{ij}}$ denotes the relationship between the productive capability **i** and the task $\mathbf{T_j}$.

$$\mathbf{C} = \begin{pmatrix} c_{11} & & & c_{1J} \\ & \cdots & & \\ & & c_{ij} & \\ & & \cdots & \\ c_{q1} & & & c_{qJ} \end{pmatrix} \quad \mathbf{F} = \begin{pmatrix} f_{11} & & & f_{1J} \\ & \cdots & & \\ & & f_{ij} & \\ & & \cdots & \\ f_{q1} & & & f_{mJ} \end{pmatrix}$$

'Crop-growing techniques' are by definition context-dependent. This is because land differs in its biological capacity to produce, environmental conditions are distinct and finally divergent socio-cultural and economic contexts obtain. These differences determine if a certain task is going to be performed by exploiting the productive capabilities embedded in one factor or another – e.g. labour, animals and machines.

Using the 'analytical map of agricultural production' we can identify a series of fundamental tensions arising from organising agricultural production in seasonal time, and given certain scale constraints and given certain endowments of technological and production capabilities:

- problems relating to the arrangement of production in seasonal time;

- problems relating to the scale of production and agricultural mechanisation as a way to perform certain production tasks;
- problems related to reconfiguration of the analytical map of production in agriculture as a result of capabilities building and different forms of learning.

We will deal with each of these problems in turn, in the following sub-sections.

3.1 Arrangement of production in 'seasonal time'.

To begin, biological production imposes a 'time-rigid' structure on agricultural production (Frisch, 1965). In particular, as biological production is performed on land in 'seasonal time', the entire process will be affected by seasonal bottlenecks. As a direct consequence of this, agricultural work in farms is characterised by a series of discontinuities and unexpected exogenous natural events.

When dealing with the first issue (discontinuities in agricultural work) it is extremely important that productive capabilities and flow inputs are available in the right place and at the right time. As has already been stressed, "even though the available labor pool might be more than adequate to provide the required number of workers per hectare over an entire year for all the crops being grown, if certain tasks must be performed very quickly at specific times to ensure maximum yields, important labour bottlenecks might occur in the midst of an average surplus labour pool"(Timmer, 1988:295). Even when the right amount of productive capabilities are provided the time setting of biological production means most tasks in agricultural work can only be be organised in parallel, not sequentially (as is normally possible in manufacturing production, Georgescu-Roegen, 1969). In other words, there is a rigidity in the sequential ordering of tasks in agricultural work.

With respect to the second problem (the existence of unexpected and uncontrollable natural events) farm organisations have to develop a high flexibility and responsiveness to situations such as shifts in climatic conditions or alterations in cropping patterns. In many regions even a one or two day delay in harvesting may expose biological production to the risk of destruction by climatic change (such as hail) or by pests. This situation can provoke direct value destruction as well as market prices variations up to 30% - 40% (Parker and Zilberman, 1993).

The use of pesticides or modified seeds in the sowing time, as well as the creation of warehouses, are all common measures adopted to prevent these unexpected and uncontrollable events. History shows that farms have also coped with these events by maintaining a certain level of excess capacity for performing vital activities exactly when required ($C_{EC,}$ see Figure 1) as well as through the development of collective institutions. In peasant communities the development of institutions for mutual aid in situations of emergency or breakdown of equipment reduces the need for excess capacity, both individually and collectively[19].

Other ways of assuring the availability of productive capabilities in the right time and in the right space, include increasing the scale of agricultural production (see the scale section below) and developing in-farm technological capabilities which increase the degree of flexibility in the crop growing techniques adopted (see section 3.3).

[19] The need to cope with these and other specific structural characteristics of agricultural production is one of the factors that has to be taken in consideration when an analysis of peasant communities is attempted. An illuminating example is the study of the 'anatomy of the peasant village' by Georgescu Roegen (1976: 206) in which the agricultural community (i.e. the village rather than the individual household) is described as an organised and self-contained 'unit of production'.

3.2 Scale of production and agricultural mechanisation

Given a certain 'crop-growing technique', the scale of agricultural production is determined by the extent of cultivated land. The amount of flow inputs **F (**such as water or fertilisers) can be determined simply by multiplying the unit amount of **F** by the land extension. These are *divisible inputs*. However other fund inputs (and also tasks performed by them) are not scale invariant. Fund inputs such as tractors, water pumps and mechanical equipment are *indivisible inputs*. This implies that having access to their productive capabilities requires an initial investment, which is affordable and economically reasonable only at a certain scale of individual farm production or by collective action between farmers.

The same problem also arises with those flow inputs such as fertilisers, pesticides or high yield varieties (HYVs) that, in spite of being divisible inputs (and thus scale neutral), are not easily adoptable in small production units due to credit constraints. As Martin notes (1982:3), "even if this argument [scale neutrality of land-saving modern technologies] as applied to rice cultivation makes some technical sense, it is obvious that the new inputs of the Green Revolution call for financial resources beyond the reach of the poorer peasants". This point illustrates both the necessity of complementary services and also of specific technological capabilities for adopting new inputs (both divisible and indivisible) to manage production/innovation related risks.

Scale is also strategically important for managing production/innovation related risks and for developing specific in-farm capabilities. As Sunding and Zilberman (2000:56) clearly state that "one of the main advantages of large farming operations is their in-house capacity to handle repairs, breakdowns, and maintenance of equipment. That makes them less dependent on local dealers and repair shops, and reduces the risk of having to purchase (in many cases) new products". In other words, overcoming certain scale thresholds can be particularly important for enabling processes of in-farm learning and technological capabilities development. Mastering these latter capabilities becomes of greater importance with the mechanisation of agriculture in modern agro-industries.

Throughout the last century agriculture has experienced a profound process of mechanisation due to push factors from manufacturing development as well as pull factors from agriculture itself. Crucially productive capabilities have been increasingly provided by mechanical equipment developed by industries. The theory of *induced innovation* formulated by Hayami and Ruttan (1971; 1985) is useful here to explain how technological change gets around the problem of factor constraints. Thus mechanisation eases labour constraints while chemical fertilisers, HYVs and pesticides ease land constraints.

According to this theory the transformation of agricultural production has been led by a "continuous sequence of induced innovations in agricultural technology biased towards saving the limiting factors" (Hayami and Ruttan, 1970:1115)[20]. Thus "changes in input mixes represent a process of dynamic factor substitution accompanying changes in the production surface induced by the changes in relative factor prices" (Hayami and Ruttan, 1970:1135). This theory has been tested empirically by comparing the process of agricultural development in Japan and U.S. in the period 1880 – 1960 (Hayami and Ruttan, 1970). It also finds support in other historical/empirical contributions (Binswanger and McIntire, 1987; van Zanden, 1991; Romijn, 1999)[21].

[20] This hypothesis was originally formulated by Hicks (1932:124) in his *Theory of Wages* where he claims that "a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind—directed to economising the use of a factor which has become relatively expensive".
[21] For a review of IIT and its empirical testing, see Pardey, Alston and Ruttan (2010).

One way of formalising the problem of mechanisation is to consider the labour/land ratio, that is, the ratio between the availability of farm labour and land to be cultivated.

Given a certain 'crop-growing technique':

W is the amount of labour required to cultivate a certain unit of land;

A is the availability of farm labour per unit of land **L**

X is the output per unit of land **L**

w* = W / X is the 'labour coefficient' (labour used for unit of output)

a* = A / X is the 'available labour coefficient' for each unit of output

If **W > A,** we are in presence of a shortage of labour so mechanisation will be introduced in order to reduce w*. When increasing the capital/labour ratio, the 'degree of mechanisation' will increase (Pasinetti, 1981:182). In contrast, if **W < A** , that is if there is a relative abundance of labour, the farmer will introduce new 'crop-growing techniques' which requires a growth in labour needs per unit of land (i.e. land-saving technology). A typical example is the introduction of chemical fertilizers or HYVs.

Clearly, factor-supply conditions (i.e. scarcity of one or more factors), as well as economic opportunities, are important inducing factors, as they create a potential demand for new technologies (e.g. land-saving or labour-saving). However, they are not sufficient conditions for explaining technological change in agriculture. Historians of technology and development economists inspired by evolutionary approaches (Rosenberg, 1969; 1976, 1979; Lall, 1992; Romijn, 1999; Chang, 1994, 2002, 2009a; 2009b) have shown how technological innovation does not simply come from providing the 'right' answer to the 'right incentive'.

As Chang (2007b:8) notes, "giving producers the right incentives is not enough to make them more productive because they may not have the capabilities to productively use advanced technologies that ultimately lie at the heart of higher productivity". This implies, for example, that even if the introduction of tractors in a labour-scarce country is consistent with induced innovation theory, without a manufacturing sector that is able to produce, adapt, repair and improve tractors, the agricultural sector will not be able to benefit from this labour-saving technology (see more below). Thus to properly understand technological change in agricultural production it is necessary to investigate the role that processes of technological capabilities building within and across sectors play in agrarian change dynamics.

3.3 Inter-sectoral learning, technology transfer and intersectoral commons

From the moment of the 'First Green Revolution' (which occurred in the period 1879-1914 according to van Zanden 1991: 229) the agricultural sector has undergone a tremendous process of technological and organisational change triggered by in-farm learning. Although changes have not been homogenous, many countries have experienced a massive increase in productivity as a result of significant changes in crop-growing techniques, commercialisation models and productive/technological capabilities building. Different patterns have been followed which focus on mechanical (tractors, combines, equipment), biological (new seeds varieties), chemical (fertilisers and pesticides), agronomic (new management practices), biotechnological and informational innovations (Sunding and Zilberman, 2000; Pardey, Alston and Ruttan, 2010).

In agriculture in-farm learning processes and technological change are triggered by the need to respond to multiple constraints and bottlenecks in production (i.e. *endogenous dynamics*) or by transfers of technologies and organisational models within and across sectors (i.e. *exogenous dynamics)*. However, even in the case of a technological innovation coming 'from outside the farm gate', a certain level of basic technological capabilities have to be present inside the farm. This is necessary if farms are to successfully to adopt and apply a new agricultural technology, such as a mechanical equipment or a chemical fertiliser to its specific context.

The reason why farms have to develop technological capabilities internally is twofold (Hayami, 1974:131). Firstly, because 'there is a tendency for agricultural technology to become location-specific' and, secondly, since the 'direct transfer [of agricultural technologies] is limited within a small area of similar environmental conditions'. The existence of highly contextual interdependences between agricultural work and biological production/re-production has profound consequences including the impossibility of fully standardising the production process and the need for continuous adaptation, monitoring and improvements after each seasonal cycle.

In other words, as Clark (2001:11) notes "in terms of the production and dissemination of usable knowledge, it is on the whole much more difficult to develop generic technology with universal applicability that is the case with industry". Given these factors, technological change in agriculture can be even more complex than in manufacturing thereby making the development of technological capabilities by the users even more important (Biggs and Clay, 1981).

However, to properly understand agrarian change we cannot limited our analysis of processes of technological capability building to the farm level as is usually done. Instead we require a specific focus on processes of technological change at the intersectoral level as well as processes of technology transfer at the intrasectoral level.

Intersectoral learning

As Rosenberg (1979:26-27) stresses in his analysis of technological interdependence in the American economy 'inventions hardly even function in isolation'. Instead they "depend upon one another and interact with one another in ways which are not apparent". As a result the productivity of one technology or organisational innovation depends on the availability of complementary innovations.

Complementarities have been crucial focusing devices in the process of choice and exploration of new techniques across history (Rosenberg, 1969; Richardson, 1972). In the second essay, the concept of *structural learning* was introduced to identify the continuous process of structural adjustment 'triggered' and 'orientated' by existing and evolving production structures. Static and dynamic complementarities, as well as similarities and indivisibilities were identified as essential focusing devices for activating compulsive sequences of technological change as well as for *discovering new productive possibilities* at the firm and inter-firm level. In agricultural production, constraints as well as opportunities arise from the necessary coordination of the three interdependent processes in which agricultural production has been decomposed (i.e. agricultural work, biological production and reproduction).

Many stylised facts in the history of agrarian change support the existence of these processes of learning in the agricultural sector. For example, the introduction in California of a new harvesting technique was accompanied by the need to introduce a new complementary tomato variety (de Janvry, LeVeen and Rusten, 1981). Another documented case can be found in the Punjab region where, during the 'Green Revolution', farmers realised how the full exploitation of new

HYVs was constrained by irrigation and fertilisation practices. The intensification of the latter, in turn induced farmers (as well as providers of 'extension services') to focus their attention on discovering more adequate crop-growing techniques and the introduction of new organisational forms (McGuirk and Mundlak, 1991).

This latter issue (i.e. the redefinition of organisational forms) typically emerges every time farmers have to coordinate themselves in the building of common infrastructure such as roads and canals. '[B]ecause of their network nature' and 'public good character' (Chang, 2009a:499) these projects require institutional engineering and innovative organisational design that will overcome the difficulties inherent in the provision of goods with such characteristics.

A further example of structural learning can be found in the early nineteenth century US agricultural sector. Before tractors were introduced, John Deere, a farmer from the Illinois, invented the steel plough. A 'biological constraint' was at the very basis of this innovation, as well as a series of complementary ones. Traditional wood ploughs were unable to deal with the rich soil of the Mid-West and kept breaking. John Deere made his first plough out of an old blade saw because of the scarcity of steel and the need to import it from Great Britain. After a series of tests on different types of soil the new steel plough was ready to be absorbed into the crop-growing techniques adopted at that time.

In turn, the introduction of the steel plough triggered new complementary discoveries. As Rosenberg (1979:37) recognises, "the substitution of new materials (e.g. aluminium and rust-resistant steels) for old ones and improved techniques of friction reduction (lubrication and roller bearings) have led to a considerable extension of the useful life of a wide range of capital equipment' as well as to other 'cumulative improvements'". The John Deere Company was able to 'internalise' this process of learning and qualitative improvement of mechanical tools by establishing its own research and development infrastructure. As a result, it became the world's leading manufacturing firm specialised in innovative mechanical agricultural equipment (Sunding and Zilberman, 2000).

As this last case shows, the process of structural learning in the agricultural sector has gradually developed an intersectoral character. In other words it has moved 'from the farm to the firm' and then to other science-based organisations. As a result, technological complementarities have spread from one sector (i.e. *intrasectoral complementarities*) to the space of intersectoral interdependences (i.e. *intersectoral complementarities*)[22].

In this respect, there is strong historical evidence that the emergence of technical and organisational innovations in agriculture have been triggered by the expansion of metallurgic, mechanical, biotechnological and energy industries (van Zanden, 1991; Olmstead and Rhode, 1993). Indeed innovations in power generation and, in turn, the cost of transportation have been identified by Rosenberg (1979) as the main drivers of increasing productivity in American agriculture.

A series of possibilities were opened up. Firstly the agricultural sector was able "to engage in a greater degree of regional specialisation [by] devoting heterogeneous agricultural resources to their best uses". Secondly farms could "concentrate output in a smaller number of more efficient units" (1979:27). Finally it became possible to develop "a truly world-wide agricultural division of labour (…) as a result of refrigeration techniques" (1979:28). Furthermore, 'the introduction of techniques for the mechanical harvesting of crops was sharply accelerated by the advances in genetic knowledge which permitted a redesigning of the plant itself to accommodate the specific needs of machine handling' (Rosenberg, 1979:31). These examples show how an innovation arising

[22] As discussed before, technological interdependences are focal relationships in the intersectoral matrix of production and can provide an explanation of the phenomenon of increasing returns.

from one industry can not only reduce the cost in the receiving industry but also open up a series of opportunities for change in products and processes.

By stressing the contribution that manufacturing development has made to agrarian change these examples suggest a relationship of unbalanced interdependence among sectors. Indeed today essentially all fund factors adopted in agriculture are produced in other industries (e.g. manufacturing, chemical, biotech, ICT). However even in these conditions of ever increasing interdependence the great variability and unpredictability of biological production implies that field experience and small adjustments/improvements on the field are still very important in inspiring innovations. In other words a relationship of intersectoral interdependence based on an interactive process of learning is at work.

As we saw in the second essay, intersectoral learning is defined as a dynamic process of interlocking and mutually reinforcing technological developments that link the innovative patterns of two or more sectors in a relationship of complementarity. As a result of this process "many of the benefits of increased productivity flowing from an innovation are captured in industries *other* than the one in which the innovation was made" (Rosenberg, 1979:41). Interestingly the suggestive idea of 'innovation by invasion' among and across sectors proposed by Little (1963) gets its analytic ground from precisely this concept of 'intersectoral learning'.

The process of intersectoral learning described above can link the agricultural sector to the manufacturing one, but also the agricultural sector to service industries. Going back to the previous case study "many of the marketing strategies, including warranties, money-back guarantees … were introduced by agricultural firms including John Deere" (Sunding and Zilberman, 2000:59). This is because the design of services such as credit schemes or assurances requires a profound understanding of the structural features of agricultural production – its 'seasonal timing' as well as its constraints, bottlenecks and risks. In this regard rural banks and cooperative banks have traditionally shown a particular capacity to deal with the specific needs of agricultural production. This is one of the main factors which explains their success in promoting 'productive development' in rural communities (Andreoni and Pelligra, 2009; Chang, 2009a).

With the blurring of intersectoral interfaces and the increasing importance of marketing and processing techniques in modern agriculture, new spaces for processes of intersectoral learning are emerging (FAO and UNIDO, 2009). In particular, as Chang (2009a:508) highlights, "relatively simple processing of agricultural raw materials can add significant value and in the process promote industrialisation and overall economic development". However, the development of agro-processing industries as well as the activation of processes of intersectoral learning are becoming increasingly dependent on the development and transfer of technological capabilities in the agricultural sector. We shall deal with this in the following section.

International technology transfer

Technology transfer has been one of the main drivers of agrarian change both during the 'first' green revolution' in the late nineteenth century (van Zanden, 1991) and during the 'Green revolution' proper in the middle of the twentieth century (Byerlee and Fischer, 2002; Chang, 2009a). According to Hayami and Ruttan (1973) technology transfer occurs in three main phases. During the first stage (*material transfer*) new seeds, plants, animals and machines are imported and utilised without any attempt to 'naturalise' them. As soon as adaptability problems become evident farmers, as well as public actors, start to import blueprints, designs and formulae to decrypt the new 'crop-growing technique'. This is known as the *design phase*. At the end of the process of technology transfer, that is, the *capacity transfer* phase, farmers and public actors start attracting foreign experts, creating specific research institutions, adapting foreign technologies and, finally, experiencing processes of intersectoral learning.

The transfer of tractors from the US to Russia and Japan is an interesting case which illustrates how countries can firstly follow different patterns of technological capabilities building and secondly, as a result, benefit from foreign technologies in different ways. Since the 1920s Russia invested heavily in the introduction of U.S. tractors (primarily *Fordson*) in agricultural production. The strategy followed was one of massive import of U.S. mechanical tools accompanied by a passive replication of foreign technologies. Lacking the technological capabilities necessary to repair and adapt the imported machines tractors operated at a quite low level of efficiency throughout the 1920s. In contrast, Japan introduced U.S. tractors only on an experimental scale with the specific purpose of developing the necessary technological capabilities required for mastering mechanical tools. This allowed Japan to adapt U.S. mechanical technologies and to introduce ‘mini-tractors’ (less than 10 h.p.) which were more suitable to their context.

It is not just the historical comparative analysis of Russia and Japan which points to the importance of technological capabilities. National case studies of small European countries such as Denmark or the Netherlands (Chang, 2009b) and the case studies taken from the Green Revolution’s laboratory (Byerlee and Fischer, 2002; Kay, 2009) all suggest that the development of technological capabilities has been responsible for sustained processes of agrarian change. In fact the historical and empirical record clearly shows how the speed of technological adaptation, and the benefits that technologies can generate, depends strictly on the intensity of efforts made by countries to develop technological capabilities. Specific public policies and institutional tools are required to allow endogenous processes of technological capabilities building as well as to trigger processes of intersectoral learning.

Intersectoral commons

The twin processes of intersectoral learning and international technology transfer are facilitated and triggered by intermediate institutions such as agrarian research institutes, technology centres, quality certification and standards providers (Byerlee and Fischer, 2002). Intermediate institutions are here defined as institutions bridging and transferring knowledge across different sectors and, thus, facilitating various forms of intersectoral learning. The twin processes are also facilitated by a whole range of organisations providing ‘extension services’[23].

Extension services traditionally aimed to ‘translate’ technological innovations originating in the manufacturing sector for the agricultural one. Moreover, they were meant to provide assistance to farmers - for example, in the repair of new mechanical tools or in the utilisation of chemical fertilizers. The idea of ‘itinerant instructors’ (and extension services more generally) was successfully adopted in many countries, in particular by Germany, Denmark, and Sweden in Europe, as well as by the US and Japan (Chang, 2009a). Extension services not only facilitate the application of new technologies but also proactively involve farmers in the design, experimentation and improvements of new technologies. As these activities imply farmers’ direct involvement in processes of trial and errors, reverse engineering and redesign of crop-growing techniques, they tend to activate sustained process of *in-farm* technological capabilities building.

[23] For an analysis of the central role played by institutions in the process of development see contributions in Myrdal, 1958; Chang, 2002, 2007 and 2010; Rodrik, 2004.

Public investment in intermediate institutions and extension services, as well as in vocational schools, exhibitions, fairs and specialised research centres on agro-processing techniques, tend to have an increasingly strong impact over time in the areas or regions where they function. Of course in the short term these institutions and extension services simply provide relief for farmers and farm-cooperatives who cannot afford prohibitively expensive investment in capability building, quality certification, research in agro-processing techniques etc. However, in the medium to long term, the presence of these intermediate institutions helps the accumulation of specific bundles of technological capabilities for agricultural production and technological upgrading, the latter benefitting all producers located in the same area.

These institutions, and the related technological capabilities, increasingly benefit all producers (as if they were a common natural endowment). In fact, the said institutions also play an active role in the accumulation of these common capabilities within and across sectors. The agro-technological systems in some regions in the centre-north of Italy, in particular around the Parma agro-centre, are good examples of this phenomenon (Quadrio-Curzio and Antonelli, 1988; Becattini, 2009). Since many of these technological capabilities are not limited to the agricultural sector and in fact develop through a continuous process of intersectoral learning, the concept of *intersectoral commons* is useful here to capture that specific bundle of technological capabilities which are concentrated in certain areas of strong intersectoral interdependence.

The identification of technological interdependencies across sectors as well as constraints, bottlenecks and complementarities in agricultural production needs to be achieved by intentional and selective efforts. Thus processes of intersectoral learning from which intersectoral commons derive should be incorporated into the design of agricultural policies and intermediate institutions, both at national and local-regional level. While there are many constraints and problems that these policies and institutions have to tackle, there are also many tools and institutional solutions that can be adopted, if enough policy space is allowed. The second part of the paper will provide two in-depth analyses of intermediate institutions in action and the way in which their operation allows the development of intersectoral commons.

PART II

Manufacturing Agrarian Change:

Intersectoral learning and intermediate institutions in action

1. Lessons from Latin America: intermediate institutions and transformative policies for agrarian change

Latin America is undergoing an ‘agroecological revolution’ (Altieri and Toledo, 2011). Over the last thirty years Chile and Brazil have been among the most active countries in terms of their use of policies designed to expand natural-resource-processing industries and food production. The results of these transformative policies are reflected in the remarkable results that both Chile and Brazil have achieved in manufacturing their agrarian change (Katz, 2006). Over the 1990s Chile managed to become the largest exporter of farmed salmon in the world as well as one of the main exporters of fresh and processed fruit and tomatos. Brazil is today among the top three producers and exporters of orange juice, sugar, coffee, soyabeans, beef, pork and chickens as well as having caught up with the traditional big five grain exporters (US, Canada, Australia, Argentina and European Union).

Interestingly, various types of intermediate institutions have been at the centre of the transformative policy package implemented in both countries since the 1970s. In particular, Fundación Chile (FCh) and Embrapa (EM) in Brazil have been increasingly recognised as exemplary institutions which have fostered technological change, diversification and upgrading in agriculture and farming. The following two case studies aim at elucidating the strategic role that intermediate institutions might play in fostering agrarian change. Of course in both cases other public and private actors have also played important roles in the processes of agrarian change. What is noticeable, however, is that both FCh and EM were (and remain) the key intermediate institutions facilitating and triggering processes of technology transfer, intersectoral learning and intersectoral commons development.

2. The case of Fundación Chile

Fundación Chile (FCh) is a non-profit private institution created by Decree 1528, issued on August 3, 1976 with a $50 million endowment donated in equal parts by the Government of Chile and the ITT Corporation. In the course of its existence FCh has undergone various phases of transformation with respect to its organisational and sustainability model, partners, sectors and areas of intervention. However it managed to maintain its main vocation as 'a public-private partnership for innovation' as well as its unique 'business orientation'. Specifically, as an intermediate institution FCh focuses on "the identification, adaptation and development of technologies and the diffusion and transfer of these technologies through the creation of innovative companies" (Fundación Chile, 2005:3).

2.1 From the 'daughter of the crisis' to the first 'demonstration projects'

During the presidency of Salvador Allende (1970-73), the socialist government nationalised numerous banks and industries including the Chilean subsidiary of the International Telephone and Telegraph (ITT) Company of the United States[24]. After the Pinochet coup d'état in 1973, the new Minister of Economic Coordination (engineer Raul Sáez) negotiated an agreement with the ITT Company according to which the accorded indemnity had to be reinvested in Chile for the 'joint creation of a Scientific and Technological Research Foundation'.

Behind Saez's proposal there was an explicit intention to transfer some of the technologies owned by ITT's technology laboratory in Spain to Chile (Meissner, 1988). Given the historical conjuncture, FCh

[24] The book value of the ITT subsidiary in Chile was $ 153 million with the risk insurance of the US Overseas Provate Investment Corporation (OPIC) leaving approximately $ 50 million uncovered. Alliende's government compensation accorded to ITT was equal to a 3% interest paid on the book value of the property over a 30 year period.

was initially perceived as 'the daughter of the crisis'. Indeed, two if its three main areas of focus ('Food technology' and 'Nutrition') were parts of an emergency response to the crisis (Akram 2013). The third area, 'Electronics', was seen as a way for capturing and transferring to Chile the technological and organisational capabilities owned by ITT.

With the appointment of a new general director poached from the Spanish ITT technology laboratory FCh began to introduce new business and organisational practices from 1977. Three main departments were created: 'Commercialisation and economic studies', 'Food' and 'Electronics and Telecommunications'. Major efforts were made to identify the critical areas where intervention was needed and to design and test methods of action. FCh increasingly adopted strategies to promote and intensify dialogue with the business sector, raising awareness about the services it offered. In the early years FCh provided free consultation to the private sector, only later adopting innovative marketing strategies (e.g. the organisation of 'work luncheon' at which potential clients and diplomats were invited).

In 1980 five central work areas were selected and Chilean professionals were nominated to head up them (foreign experts were asked to provide advisory services). The selected central work areas were: the *Agro-industrial area*, *Marine Resources*, *Product Development*, *Laboratory* and *Pilot Plant*. For each of them FCh implemented a number of so called 'demonstration projects' aimed at transferring foreign technologies and manufacturing agrarian change, (i.e. the adoption of industrial technologies and science-based innovations by agriculture, aquaculture and farming). Among the projects selected in 1980 was a feasibility study on the production of vegetable seeds for export. They also did an experimental test on freezing blackberries, strawberries, and vegetables for future export, a study of potato processing and an assessment of green asparagus cultivation. They also studied sanitary improvements of milk handling in industrial dairies with experiments performed on prison populations; technical post-harvest consulting in the fruit industry and quality control of fruit for export (and the utilisation of apple rejects). Research was also done on plant design for the production of dietetic rice-flour; technical assistance was given to canning plants and an aquaculture centre was established in Coquimbo. Finally, technical assistance was given on the refining of fish oil for edible and industrial uses (Fundación Chile, 2005; Bell and Juma, 2007).

Sometimes demonstration projects resulted in the creation of new laboratory (as occurred with the Marine Laboratory and Oyster Growing Station in Tongoy) and this allowed FCh to acquire the official status of 'quality certification entity' for fruits and vegetables exported (in 1985 this license was extended to other products such as meat, seafood, vegetables and housing industries). Others projects, such as the 'Asparagus Cultivation' programme (1979), resulted in massive market successes. After having identified the market opportunity represented by green asparagus (for which there was a high demand in US and Europe) FCh provided technical assistance to farmers to introduce the new variety of asparagus. With this assistance, the area planted and operated grew by 40% of the national acreage dedicated to green asparagus crops. Interestingly, given the great emphasis on agricultural technologies during this initial phase, FCh reoriented the research in electronics and telecommunications toward the design of applications for microprocessors in process control which eventually resulted in processes of intersectoral learning, that is, application of ICT technologies to quality and process control in agro-industries.

2.2 The creation of innovative companies: the 'Salmones Antártica SA' model

In 1982 the Chilean economy underwent a profound crisis characterised by a currency collapse and mass bankruptcies related to foreign currency-denominated debts. Coupled with a contraction of international demand this led to a reduction of Chilean exports. In this difficult context FCh decided to introduce a new strategy for technology transfer consisting of direct investment in 'pilot firms'[25]. These firms had to demonstrate the feasibility and applicability of their use of internationally available technologies in the Chilean context. These innovative companies were supposed to attract other Chilean companies in the sector, spreading the innovative technologies across the country. They would also become a new source of finance for FCh after their sale in the market. Often, these companies were jointly created by FCh and existing private companies which had mastered the relevant technologies and had experience in marketing the new products. The following are few examples of the most innovative companies created by FCh in the first mid of 1980s:

- 'Cultivos Marinos Tongoy S.A.', a company applying imported aquaculture techniques and dedicated to the cultivation and export of Japanese oysters (1982);
- 'Caprilac S.A.', an agro-business company dedicated to the production of fine goat's milk cheeses (1983);
- 'Procarne S.A.', a pioneer company operating in the beef industry which successfully introduced the 'vacuum packed format' and the 'deboning at origin' technique, both critically important for adding value and exporting the products;

[25] These were also used by Germany and Japan in the 19th century and were called 'model factories'.

- 'Berriers La Union S.A.', a company promoting small fruit plantations and the export of fresh raspberries and strawberries;

In 1982 FCh also acquired a company, 'Domsea Farms' (a subsidiary of Campbell Soup) which specialised in aquaculture techniques and was later transformed in the 'Salmones Antártica S.A.' (the first fully integrated company in the Chilean salmon farming industry). At the time the original company was acquired, total national salmon exports were around 300 tons per annum. In 1988, when Salmones Antártica S.A. was sold for $22 million, Chile exported more than 250,000 tons and continued growing over the 1990s approximately 17-fold reaching a world market share of 35% in 2002 (the export value was of $1.2 billion in 2003).

Other companies were sold in the subsequent years, consolidating a model according to which the invested capital was recouped through sale and re-invested in new ventures as soon as innovating technologies were transferred and disseminated through demonstrative companies. Until the end of the 1990s new three main pillars of action of FCh were Agribusiness, Forestry and Marine Resources.

As 'Salmones Antártica S.A.' became a model whose story has been widely documented (Meissner, 1988; Huss, 1991; UNCTAD, 2006; Bell and Juma, 2007), we will focus on only a few key elements that determined its success as a company:

- *In-farm learning*: FCh acquired and adopted the salmon 'cage cultivation' technology by initial experiments and by hiring national and international consultants as well as training company staff at ranch farms and fish technology centres abroad (Huss, 1991).

- *Inter-sectoral learning*: the fundamental structure of cages was locally produced and made of Chilean wood instead of steel. Additionally a new feed mixture (the highest cost item) was developed in order to employ locally cheaper resources.
- *Institution building* and *technology transfer:* during the 1980s the company built 'freshwater fish farming centres, seawater grow-out facilities, dry and wet fish feed plants, and processing installations, enabling it to produce smolts, salmon ova, and feed to satisfy its own and third-party needs, as well as fresh and frozen salmon for export'. After its consolidation it also "focused on species diversification, supporting affiliates in operation until their sale, verifying the health of salmon in laboratories, introducing more suitable species of salmon for the XII region and designing model fish culture for Pacific Salmon" (Bell and Juma, 2007:308).

2.3 Intersectoral Commons: Fundación Chile and the emergence of agro-technical clusters

Rarely were the successes of the many innovative companies promoted by FCh simply single company successes. Very often they were stories of intersectoral commons and clusters development. For example, in the case of 'Salmones Antártica S.A.', the Chilean salmon miracle would have not been possible without the original involvement of the government in salmon research from the 1960s onward and the promotion and joint development of various institutions which constituted and nurtured an intersectoral commons base, (Perez-Aleaman, 2005).

In analysing the public institutions involved we must start with the joint venture between the Chile's National Fisheries Service (SERNAP) and Japan International Cooperation Agency (JICA) while initially introduced salmon (a non native fish) to the country. Furthermore, the acquisition of the first facilities for salmon farming by FCh was financed by the regional governmental planning institution of the XI Region (SERPLAC). The first commercial farming venture in Chile able to export to Europe was partly financed by a public agency (CORFO)and was founded by professionals who had worked in government institutions such as IFOP (Fisheries Development Institute). The skills, finance, research and technologies that these institutions developed since the 1960s constituted the intersectoral commons through which in 1987 some 120 firms involved in ocean ranching were based (219 in 1997). Other firms from other industries and sectors such as those manufacturing cages, processing products, producers of refrigerators containers and providers of transport services were forward and backward linked to the salmon industry giving rise to a salmon industry cluster.

One of the main difficulties that firms in the salmon industry faced in the first stages of cluster development was the difficulty of achieving operational scale, international reputation and quality certification. The establishment of a 'Chilean brand' occurred through the constitution of an institution specialised in quality control and certification, (the Salmon Technology Institute or Intesal). This was established in 1994 thanks to the creation of a producer association (Association of Salmon and Trout Producers of Chile) supported by the government. Thus we can see that producers both benefitted from and nurtured the intersectoral commons through which the salmon industry was able to flourish.

The successful emergence of agro-technological clusters is not limited to the case of the salmon industry. FCh was very successful in establishing a 'grape technology platform' which built on genetic engineering technologies. The enormous potential impact of this project was demonstrated by the adoption in other parts of the world of genetically engineered varieties of maize, soybeans, and cotton. At that time "little effort was being expended to make improvements in perennial crop species, such table grapes", a product particularly promising in the Chilean context (Fernandez, 2007:8). Starting from these experiments the emergence of a wine cluster in Chile is a well documented story (Giuliani et al. 2010).

The tomato processing industry is another example of the process described above for the salmon industry and the wine cluster (Perez-Aleman, 2005). In the case of the tomato processing industry another public institution (the Production Development Corporation or CORFO) was centrally involved with FCh. CORFO adopted the world's best industrial tomato varieties and transferred the technologies of major established competitors (California, Italy and Portugal) to Chile. The main adaptation consisted in the creation of the 'Malloa model', a network enterprise system allowing the diffusion among SMEs of crop-rotation and cultivation-scheduling techniques.

As discussed above (section 4), rotating crops avoids soil degradation while shifting agricultural production permits the exploitation of microclimates and the extension of the production season. Local institutions for collective problems solving were created and joint ventures developed for exporting processed tomato. These institutions were financed by the state starting in 1982 through another state agency (PROCHILE, the Export Promotion Bureau of Chile created in 1975 under the Ministry of Foreign Affairs). Company associations and export committees were financed through a 50/50 scheme with the aim of improving quality to meet international standards and develop new products.

2.4 Nurturing the 'Ecosystem' for innovation: mixing selective and horizontal measures

Throughout the late 1980s and 1990s the Chilean economy underwent a drastic transformation: from 1986 to 1996, GDP per capita doubled (from US$3,400 to US$7,360) and exports grew threefold (from US$ 4.2 billion to US$ 15.4 billion). With the increasing dynamism and changing production structures, new institutions such as universities, government agencies (such as CORFO, Innova, Endeavor) and NGOs entered the innovation business that FCh had helped to develop.

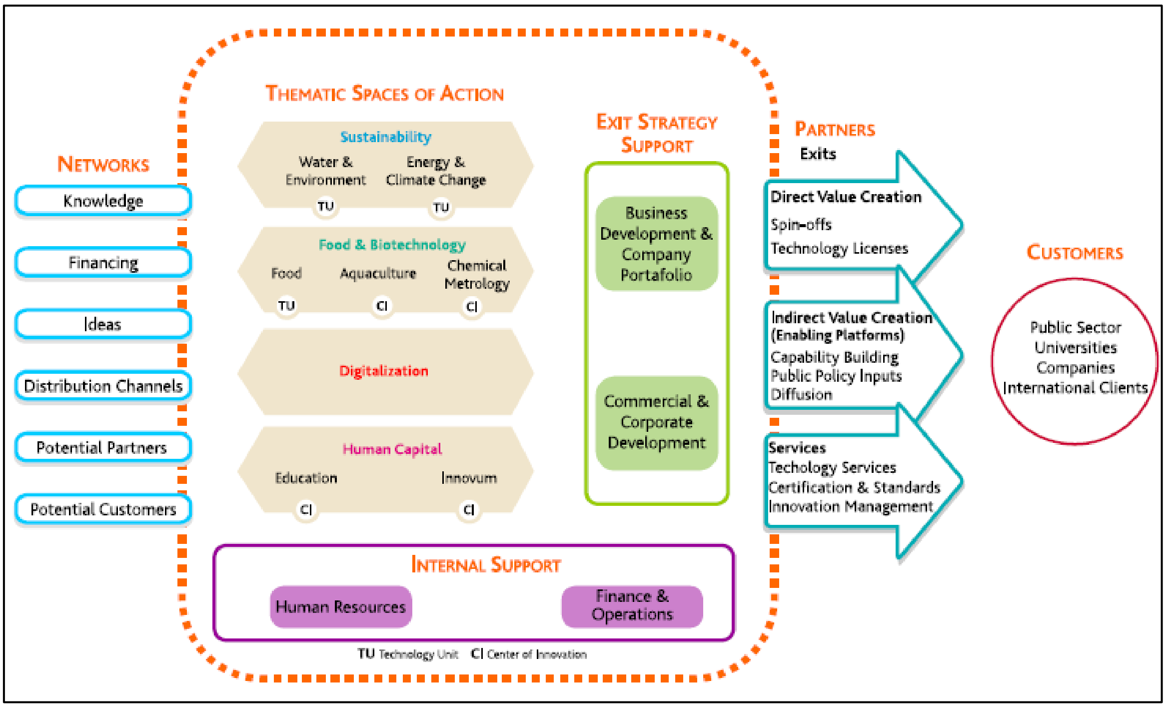
During the 1990s and early 2000s, FCh continued to promote new industries such as the cultivation of abalone and the production of extra virgin olive oil. It also carried on diversifying its portfolio investing in innovative new companies such as 'Oleotop' (2004), the first canola oil producer (replacing fish oil in feed for the salmon industry). However it also initiated the promotion of new more horizontal interventions such as fostering entrepreneurship and human capital in Chile. In 2001, together with the Ministry of Education, FCh created a portal containing 27,000 freely available educational resources and a 'Job Competencies programme' focused on three main areas: certification of job competencies, formation and job market, and management of human resources. Finally, taking stock of its successes in the last few years, FCh has repositioned itself within the 'densifying innovation and incubation ecosystem" (infoDeV, 2011:85) focusing on:

- Creating and promoting "early stage" companies while leaving the "scaling-up phase" to other organisations
- "Making things happen" i.e. operating more as a "do tank" than as a "think tank";
- Nurturing the ecosystem by articulating, coordinating and aligning the interests of key players, both public and private, at the national and international level.
- Filling in the gaps in the agribusiness value-chain and identifying where value is nested
- Development of transversal technologies (see more below)

2.5 The current organisational model and the internal operational structure

In 2002 FCh underwent an organisational restructuring that established the basis for the current organisational model. The administration was divided into three main areas: Technology Centres; Business, Investment and Companies Units; and the Corporate Centre. Whereas FCh "used to be organised according to industry sectors (e.g forestry, fruit, salmon, etc.)" it has now been "reorganised in a more transversal, matrix structure according to transversal areas (e.g. sustainability, food and biotech, ICT and human capital)" (InfoDEV, 2011:85). The matrix structure was designed in order to facilitate the collaboration among technology experts and industry specialists coming from different productive sectors (in other words intersectoral learning). The new structure was also meant to facilitate the development of those *transverse technologies* such as information technologies, biotechnologies, engineering services, human resources management and environmental technologies that are essential for upgrading and innovating different industries – i.e. intersectoral commons (see figure 2).

Figure 2: Fundación Chile matrix structure and transversal areas



Source: Fundación Chile, 2012:4.

At the core of this model are the technology centres with their current staff of 350 professionals and more than 200 international consultants. These centres perform three fundamental functions (Fundación Chile, 2005):

i. Identifying opportunities to add value through innovation by exploring market needs.

ii. Obtaining technologies by relying on internal R&D, cooperation and external sources.

iii. Scaling-up and disseminating technologies through the creation of demonstrative companies, the sale and licensing of technologies, supply of technological services, certification and implementation of standards and training.

2.6 The governance model: embedded autonomy, competence ownership and sustainability

Since its constitution FCh's governance model was inspired by three main principles:

1. A principle of *embedded autonomy* (Evans, 1996) according to which FCh's priority agenda and strategies maintain a certain degree of independence, although the Chilean government and the private partners are integral parts of its board. The first board of directors was composed by 12 members, six appointed by the government of Chile (directly by the President) and six by the ITT company. The President of the board and the vice president had to be elected from the government and ITT members respectively, every two years. Moreover, the Board had to elect a Director General (DG) for leading the administration (Meissner, 1988). In 2005, another private company BHP Billiton Escondida Mining was incorporated as co-founding member and entered the board. Furthermore, in order to facilitate inter-agencies coordination, top authorities of Chilean national development agencies CORFO and CONICYT were also included in FCh's Board of Directors as government members. The Board's activities are based on the work done by different committees. Since the constitution of FCh imposes a high quorum for approval as stated in the by-laws, this requires and encourages consensus and alignment of interests.

2. A principle of *competence ownership* was applied according to which Chilean nationals had to be increasingly involved in the management of FCh, at all levels. For this reason, from the very beginning, ITT was asked to organise in-house training programmes to prepare qualified candidates for management

positions. A formal technical assistance contract with ITT was also agreed. ITT was reimbursed for direct costs incurred and guaranteed intellectual property protection for innovations resulting from the application of its technologies. More emphasis was given to cross-pollination rather than secretiveness. The strategic interaction with ITT allowed a fast process of in-house competence building and absorption of technological, organisational and managerial capabilities. Production capacities such as physical infrastructure, laboratories, state of the art salmon smoking facilities, pilot plants for food processing were all developed under the guidance of ITT.

Technical competences were given higher priority and linked to higher management positions. Thus the first FCh staff (the so called Founding Party) were constituted by a former food industry R&D executive, a food technologist, a nutritionist, a chemical engineer and an ITT telecommunications specialist. After the first decade, Dr Anthony Wylie Walbaum who had worked in FCh since 1979 was nominated DG and Chileans officially took over the management of the institution (Meissner, 1988).

The importance of competence ownership is made clear from the following data. From 1976 to 1986, when the management of FCh was carried out by ISEC, an ITT subsidiary, FCh had access to a worldwide network of consultants and technology suppliers. In this period the staff and management was mainly composed of US citizens and, as a result, 16 of 27 projects applied US or Canadian Technologies (Meissner, 1988; Huss, 1991). In 2002 CORFO promoted the merger of FCh and INTEC in order to strengthen this organisation. Thanks to this operation, FCh expanded its internal competences on transverse technological skills such as information sciences, chemical metrology, environmental technologies and renewable energies.

3. A principle of *sustainability*, according to which FCh had to obtain balanced financial flows and achieve full-financial sustainability over time. This principle was enforced particularly strictly during the 1980s and increasingly pushed a strong shift towards more practical projects that could translate into commercial ventures and returns as well as greater concern for the market and clients. In thirty years, the application of this principle has led FCh to move from a revenue of $2.5 million and 0% self-financing to revenue of $31.5 million (including activities resulting from the merger with Intec) and 88% self-financing (Fundación Chile 2012). In order to achieve these results, FCh adopted a financial monitoring system called 'Annual Evaluation of Results of the Operations Program (AEROP) which (i) estimated private and social benefits expected to be generated by adaptation of technological improvements, the latter including social value of employment created, consumer surplus and foreign exchange earned; (ii) income of FCh, including producers and state (Meissner, 1988).

3. The case of Embrapa in Brazil

Established in 1972 via Law 581 as a public corporation under the Ministry of Agriculture, Livestock, and Food Supply (MAPA), Embrapa (*Empresa Brasileira de Pesquisa Agropecuária*) is the national agricultural research agency of Brazil. Brazil is a country with one of most well-developed and well-funded research systems in the developing world (in terms of public investment in agricultural research it is below only China and India). The Agricultural Research system involves federal and state governments as well as an enormous number of agricultural universities (around 80). There are also a very large number of agricultural research centres, (some of them have been in existence since the early 19th century). This makes the current Brazilian agricultural research system extremely complex and characterised by overlapping networks (17 state research networks in 2011). Embrapa stands as the main player within this complex system. With its 47 research centres throughout the country hosting 9.284 employees and an annual budget of over US$ 1 billion in 2011, it is the largest R&D agency in Latin America by staff and budget. The research centres are organised along three main axes of specialisation: commodities, resources and themes. In 2011 Embrapa counted 15 National 'Thematic' Centres, 16 National 'Commodity' Centres and 16 Regional 'Resource' Centres. The full list is provided in the table (Lopes, 2011; Rada and Buccola, 2012: 364).

3.1 Embrapa's Establishment and Development over forty years

In the 1960s the Brazilian military government started a profound reorganisation of the Brazilian agricultural research system. It aimed to increase national agricultural research capacities, trigger farm modernisation and enhance food production (partially as a response to the food crisis generated by urbanisation and partially to boost exports and earn additional foreign revenue). One of the main Brazilian public agencies, the Department of Agricultural Research and Experiment (DPEA), renamed DNPEA (National Agricultural Research and Experiment Department) in 1971, was charged with improving the technological capabilities of Brazilian agricultural research institutes. They did this by training their researchers to the postgraduate level and conducting research projects on commodities and areas considered priorities for national development.

Embrapa was founded in 1972 as a response to the main weaknesses of DNPEA. These included “researchers’ lack of awareness of the basic needs of agriculture and the lack of intradepartmental and external interaction among researchers, extension workers, and farmers (which had led to instances of unproductive duplication of research efforts)”. Other weaknesses involved “the lack of incentives for researchers (particularly indicated by low salaries), the low level of postgraduate training (12 percent the scientific staff at the time), and finally the insufficient, and often irregular financial resources available” (Beintema et al., 2001:16)[26]. Embrapa took over DNPEA’s extensive network of research institutes covering the main agricultural commodities and regions, experiment stations, and existing projects. Agricultural extension services were outside Embrapa’s area of intervention and were assigned to another agency, Embrater, which operated until 1991.

During its first decade, Embrapa created its network of national commodity centres and regional centres that focused on major cropping and animal production systems as well as on eco-regional and national themes. It also increased its internal capabilities by signing partnerships with US universities such as Purdue and Wisconsin, which allowed Embrapa’s staff to receive postgraduate training. By implementing a ‘Concentrated Research Model’ Embrapa also operated as a ‘capacity building coordinator’ by stimulating the creation of state corporations for agricultural research. Total government investment in the first twelve years of Embrapa’s life was around six billion dollars in 2008 value (Alves, 2010).

[26] As documented in Sanders et al. (1989:1209), “in the early days of graduate program formation (1963-1978) agricultural economics theses tended to be either production functions or linear-programming exercises…not noticeably related to resolving any real problems of Brazilian agriculture”.

By the mid 1980s the severe financial crisis dramatically reduced Embrapa's funding (its performance was criticised as the immediate impact of agricultural research on the Brazilian economy were hard to pinpoint). As a response to the crisis Embrapa decentralised its operational model. The new 'Circular Programming Model' promoted inclusive strategies for the definition of research programmes and facilitated greater interaction with farmers and federal states to better capture the local needs of Embrapa's clients and end users.

Furthermore greater emphasis was now given to research with short-term returns, multidisciplinary in scope and intersectoral relevance, while more efforts were made to disseminate existing results (Silva and Flores, 1993). Also, at the level of administration, research centres were accorded more freedom on matters of budget and resource allocation (although major policies continued to be set centrally). The reorganisation process was concluded in 1993 when a five years strategic plan (called a Director Plan) was started to be implemented. The establishment of the Embrapa Planning System (SEP) introduced for the first time a systems approach to R&D planning for the first time. This allowed a redefinition and reintegration of the centre's mission, objectives, programmes, human resources, infrastructural needs and priorities.

Agricultural research started being ever-more cross-pollinated by research in advanced manufacturing. A good example of this is the satellite monitoring services for the acquisition and processing of remote sensor images and field data. The Satellite Monitoring Centre was created in 1989 in an area of 20,000 sqm in Campinas (Sao Paulo state) assigned by the Brazilian Army to Embrapa for the development of a special unit focused on territorial management systems and electronic networks for modern agriculture.

Throughout the 1990s "Embrapa was involved in a wide range of activities related to agricultural research and technology including plant breeding, pest management, food safety, satellite monitoring, sustainable agricultural development, and hunger relief. Soybean breeding and pest management activities are headquartered at the Embrapa facility in Londrina in the state of Paraná, but crop research activities are carried out at locations around the country to develop crops and varieties that are suited for local conditions" (Matthey et al. 2004: 10).

The trend started in the 1990s continued during the next decade, in particular in 2005-2006, when Embrapa made a massive efforts to improve and renovate its infrastructure. A R$ 21 million investment was designated to the labs. However, if we include the full range of funding provided for facilities, equipment, tractors and vehicles we reach R$ 90 million. Included among these investments, at the interface between agriculture, biotechnologies and advanced manufacturing were:

- Facilities for quality improvement in the meat production chain.
- An aquaculture lab prioritising water quality control, fish feeding and health.
- A new Enology Lab to boost wine production in the Northeastern Semi-Arid Region.
- The construction of a worldwide unique National Agribusiness Nanotechnology Lab focused on the development of sensors and biosensors for food quality control, certification and traceability. The Lab was also dedicated to the synthesis of new materials such as polymers and nanostructured materials or thin films and surface to manufacture smart packages.
- Six new walk-in freezers to increase the storage and preservation capacity of the Embrapa Germplasm Bank (from 120 to 240 thousand seeds).

According to information provided by the Brazilian government, Embrapa has generated and recommended more than nine thousand technologies for Brazilian farmers since its inception in 1973. This includes developments in tropical agriculture that have developed an extraordinary network of intermediate institutions, research centres, labs and other facilities. In 2007 it was estimated that Embrapa's lab infrastructures encompass 215,500 m^2, 33,000 m^2 of canvas covered facilities and 35,000 sqm of greenhouses (Embrapa, 2007; see also Embrapa 2012). This demonstrates the massive investment that the Brazilian government made in order to provide an appropriate scale for the intermediate institutions.

3.2 Embrapa and the Cerrado miracle

Probably the most remarkable achievement of Embrapa has been the reclaiming of the *cerrado* (the Brazilian savannah) for modern agriculture. Before Embrapa achieved this, "nobody thought these soils were even going to be productive" declared by Norman Borlaug, the famous Green Revolution plant scientist.

The *cerrado* constitutes a major portion of the almost 400m hectares of arable land in Brazil (only 50m of which is in use according to the FAO's estimates). The *cerrado* is concentrated in the centre of Brazil, around its capital (see following table). When Brasilia was created in 1961 the federal government invested enormous resources in infrastructure to link the capital to the rest of the country. They also developed programmes to encourage the migration of farmers from the South. Coming from more agriculturally advanced regions migrants possessed technological capabilities which were critical for the application of the innovations developed by research institutes located in the Federal District of Brasilia, such as Embrapa Cerrado, Embrapa Vegetables and Embrapa Genetic Resources and Biotechnolgoy.

Embrapa was the key agency for the success of agriculture in the *cerrado*[27]. It introduced "new varieties, cultural practices, zoning, tillage, biological fixation of nitrogen, development of livestock for both meat and milk, vegetables, fruit, irrigation and knowledge of the cerrado natural resource basis" (Alves, 2010:70). Embrapa's technological efforts were also reinforced by government investment which established new universities and postgraduate courses in all states of the *Cerrado* region. The alignment of policies and programmes at the inter-institutional level eventually generated critical competences in *cerrado* agriculture which resulted in the sedimentation of intersectoral commons in the area and intense processes of intersectoral learning.

Figure 3: The cerrado regional distribution

Source: the Economist, 26 August 2010

From an agronomic point of view, Embrapa's strategy to make the *cerrado* land productive was fourfold. Firstly during the 1990s and increasingly in the early and mid 2000s, the acidity of the soil was reduced by pouring industrial quantities of pulverised limestone or

[27] It has been noted that Embrapa received fundamental support from the Japan International Cooperation Agency JICA. See Hosono and Hongo 2012.

chalk into the *cerrano* soil. At the same time Embrapa was working on a bacterium that encouraged nitrogen-fixing in legumes which reduced the need for fertilisers in the cerrado's nutrient-poor soil (Hosono and Hongo 2012).

Secondly Embrapa imported a grass called *brachiaria* from Africa. This was a new variety of grass created through crossbreeding. The higher productivity of this new variety (20-25 tonnes of grass feed per hectare) increased the amount of forage produced and thus allowed farmers to increase beef production.

Thirdly, soyabeans, a temperate-climate crop, were transformed into a tropical crop by crossbreeding and by introducing genetically modified soya seeds. The new varieties of soya require a shorter biological production cycle, allowing farmers to grow two crops a year. This manufactured transformation of the soya production process had profound impact in farmers' crop-growing techniques.

The fourth and last technological innovation introduced by Embrapa concerns the agricultural work of soil preparation and the agriculture and livestock integration. The new 'no-till agriculture' technique developed means that the soil does not need to be ploughed nor the crop harvested at ground level (the outmoded traditional manner). By harvesting the crop at a higher level the part of the crop that remains in the ground constitutes a natural input for agricultural reproduction in terms of nutrients for the next year. The new crop will be directly planted into the mat of organic material left from the previous 'not-till' harvesting (Hosono and Hongo 2012).

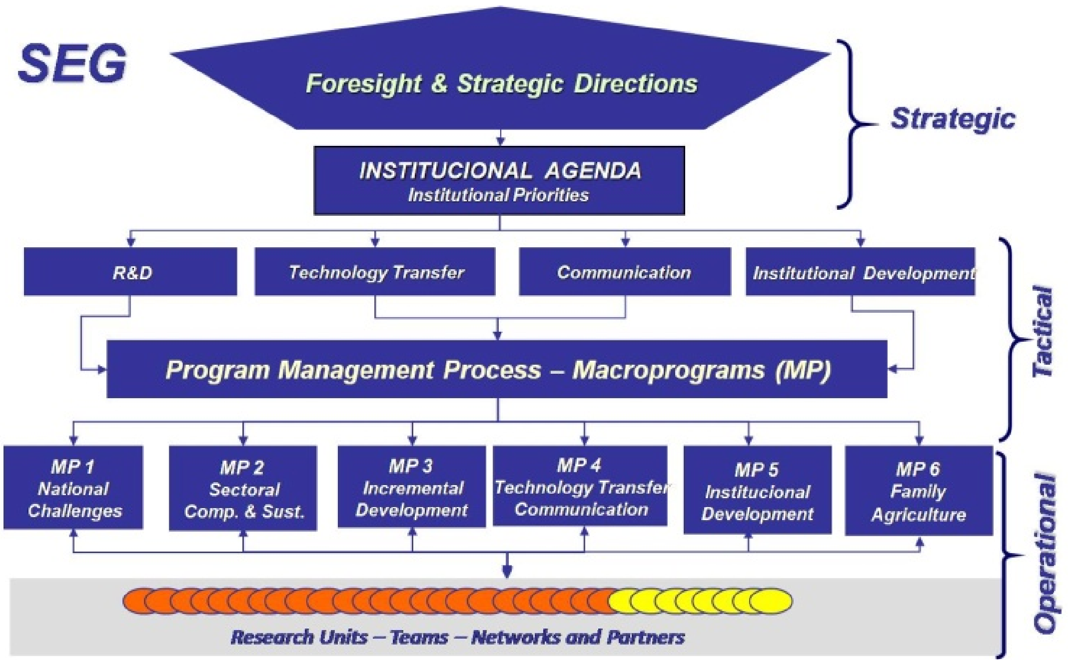
Although practiced since the first agricultural revolution Embrapa rediscovered and promoted a rotation scheme according to which fields are used alternately for crops, livestock and then tree-planting. Although possible through the use of fertilisers, this rotation scheme remains an cost-effective way for rescuing pasture lands. In sum, as a result of Embrapa's innovation, in 2010 the "unproductive" cerrado accounted for 70% of Brazil's farm output

3.3 Embrapa current decentralised model, management system and governance

Embrapa's applied research model is a decentralised one. Regional-resource (RR) centres focus on a state or region, biome or climate rather than on a national-scope product, the latter being covered by National Commodity (NC) centres. Together they account for roughly 4/5 of the total Embrapa budget and staff. The Thematic research centres provide support to RR and NC centres by concentrating on basic research problems spanning the whole the country such as soil conservation, satellite imagery, genetics and biotechnology (Rada and Buccola, 2012).

Embrapa's management model underwent four major transformations. The last one was implemented between 2001 and 2003 and involved the introduction of the *Embrapa Management System* (SEG) which explicitly aimed at aligning the R&D process with the organization's efforts in communication, technology transfer and institutional development. As the following table illustrates, the SEG system is structured so that all Embrapa's projects are aligned in the design, implementation and assessment phases and are organised within six Macroprograms, covering R&D, communication, technology transfer and institutional development. The final aim of the SEG system is to optimise the use of inputs, guaranteeing biological reproduction and the preservation of agro-biodiversity with adequate soil and water use and management.

Figure 4: Embrapa's decentralised model



Source: Embrapa website

Embrapa's governance model exhibits the characteristics of the embedded autonomy model we also discussed in the case of Fundacion Chile (section 2). As one of its leaders claimed "independence from politics does not mean isolating oneself from politicians. It means to have a close relationship with them, but putting the nation's interests first" (Alves, 2010:69). The board of trustees which governs Embrapa is composed of six members: two representatives each from the government and the private sector, the president of Embrapa, and the vice-minister of MAPA. The implementation of the board's strategies is left to an executive board of directors, consisting of a director-president and three executive directors, who are appointed following the recommendations of MAPA. Finally, the leaders of the research centres are hired through an open public selection process. Stakeholders are members of "External Advisory Boards", for all 47 EMBRAPA's Research Centres.

Concluding remarks

After two decades of neglect, the publication of the *Agriculture for Development* report by the World Bank (World Development Report, 2008) clearly reflects a renewed interest in agriculture and its role in the process of development. Although it is not explicitly acknowledged, the analytical framework underlying WB's policy recommendations is still very much grounded in the agrarianists' perspective and in the New Conventional Wisdom (Chang, 2009a and 2011; Kay, 2009). Most revealing they note explicitly that "[u]sing agriculture as the basis for economic growth in agriculture-based countries requires a productivity revolution in smallholder farming" but they do not mention *in related manufacturing*.

This last recommendation (i.e. to increase agricultural productivity) is also stated by other international organizations such as FAO, UNIDO and UNCTAD (see FAO and UNIDO, 2009: chapter 4; UNCTAD, 2009: chapter 3), which believe that technological innovations in agriculture are the only possible response to the ongoing substantial increase in global demand for agricultural products. However how to achieve this increase in productivity remains a controversial issue which calls for a political economy answer.

As Woodhouse (2009 suggests, the *Agriculture for Development* agenda presents two strong internal tensions. First of all, although the agricultural sector is positioned at the centre of the development strategy, the way in which it can interact with other sectors in a process of circular and cumulative transformation is not considered. Instead of focusing on the identification of technological interdependences in the matrix of intersectoral relationships "[t]he central question remains what agriculture can do for development. The question of what industry can do for agriculture is largely forgotten" (Kay, 2009:128). A unidirectional model of development is preferred to one in which structural change arises from a circular and cumulative process of increasing systemic capabilities.

Secondly, the WDR (2008) recognises the pervasiveness of market failures in 'agriculture-based' economies (e.g. access to credit, flow inputs such as fertilizers and HYV, various technologies). However it does so in a one-sided fashion since it assumes that solutions to inefficient market allocations has to be found in 'other markets'. The possibility that states can play a 'developmental' role is not recognised, although the history of today's developed countries testify to the effectiveness of selective public policies in fostering agrarian change (Chang, 2002 and 2009a). Public interventions, such as subsidised fertilisers, tariff protection, artificially cheap credit and price controls, are all considered as 'distorting factors'. However, as stressed by Chang (2009a:480) "if markets are not working well, distorting the prices that prevail may be a good thing, if that is done for the right purpose|[28].

The challenge is to identify the *right purpose*, and discover *how* to achieve it. We go some way towards meeting this challenge when we start to open up the black box of agricultural production and focus on intersectoral dynamics. The possibility of influencing and directing these structural dynamics through selective policies and the creation of intermediate institutions has been shown through our analytic case studies of Fundación Chile and Embrapa in Brazil. Together with an increasing reaffirmation of the role of 'selective industrial policies' (Chang, 2009c; Chang and Lin, 2009; Cimoli, Dosi and Stiglitz, 2010) this paper argues that agriculture needs a new set of 'selective agricultural policies'. These latter, named here *transformative policies,* have to start from a 'contextualised' identification of the channels through which an increase in agricultural productivity may be realised.

Going in this direction, the approach embraced throughout the paper stresses (i) how the classical vision of agriculture as a sector

[28] See also, Akram-Lodhi et al., 2007; Borras et al, 2008.

condemned to decreasing returns should be reframed, especially considering the enormous advancement in crop-growing techniques and the increasing blurring of intersectoral interfaces; (ii) how the WDR's unidirectional understanding of the relationship between agriculture and other sectors underestimates processes of intersectoral learning; (iii) how instead of focusing on incentives scheme, the design of policy measures should focus on increasing farmers' technological capabilities, as the possibility for farmers to be an active part in agrarian change depends on them.

The future of a productive agrarian sector is not only in the hands of the wise farmer, but also in those of innovative manufacturers and imaginative politicians.

Fourth Essay

PRODUCTION CAPABILITIES INDICATORS

Mapping countries' structural trajectories for the assessment of industrial skills in LDCs: The case of Tanzania.

Introduction

Over the last two decades industrial policies have gradually re-entered the policy debate among development economists and policy makers in both developed and developing countries. This process has been described by Dani Rodrik as a process of 'normalising industrial policies' (Rodrik, 2008; see also Bianchi and Labory 2006). On the one hand, industrial policies are back on the government agenda of developed economies, especially as a result of their difficulties in finding new paths to sustained growth. On the other hand, developing economies are increasingly looking at the possibility of implementing industrial policies as a way of driving structural change and catch-up processes. While the main focus of the debate throughout the 1990s was the theoretical case and historical evidence in support of and against industrial policies, this has now changed. More recently, academics and international actors such as the United Nations Industrial Development Organizations (UNIDO) have begun focusing on the specific problems connected to the design, implementation and evaluation of context-specific policies for manufacturing development. In other words the debate around industrial policies is increasingly moving from the 'why' to the 'what', 'when' and 'how' of effective industrial policy design and implementation.

The possibility for governments to achieve a certain set of macro policy goals resides in their capacity to understand, monitor and influence the production capabilities dynamics underlying the structural change in and the technological upgrading of the overall economic system. The essay identifies the methodological problems and informational limits of the various indicators currently available. Given the need for adopting multiple informational spaces to go beyond the limitations of the existing indicators, the essay follows a twofold strategy. Firstly a new methodology for mapping countries' structural trajectories of capabilities accumulation is introduced and tested for a selected group of countries. The methodology applied here is based on the distinction between three sets of factors that enter, interact and result from processes of 'learning in production'. For each of them, three direct measures of production capabilities are developed, namely capability *determinants*, capability *enablers* and capability *outcomes*. Additionally one indirect measure of country-level capability outcomes (production *outputs*) is considered.

Secondly, the essay zooms into a particular aspect of production capabilities by introducing and testing a new methodology for assessing industrial skills, in particular the existence of skills gaps and mismatches at the national level. While today's developed countries have invested widely in researching, mapping and understanding the specific industrial skills that their economic systems require, the same kind of assessment becomes extremely challenging when we approach LDCs. A large number of countries have attempted to invest in skills upgrading programmes but often find themselves unable to determine if their policies have been effective since they do not know what specific skills gaps and mismatches are affecting their economies and need to be remedied. The methodology presented here triangulates different techniques, both quantitative and qualitative, aiming at capturing these phenomena and informing skills policy design, using the case of Tanzania. As with many other LDCs, Tanzania has recently expanded its investment in skills development without yet being able to get a significant impact in terms of the transformation of its production structure. The methodology developed and tested here shows the specific areas on which the Tanzanian government should focus, and the challenges that it has to address for the future development of its industrial skills base. These challenges are common to all those LDCs that are attempting to trigger a process of manufacturing development and increase their capacities for catching up.

The essay is structured as follows: the first part of the essay identifies the methodological and analytical problems that arise from the adoption of existing national level indicators. Building on this a new methodology for the study of production capabilities at the national level is proposed. The way in which these new production capabilities indicators may be used for mapping countries' structural trajectories is shown through a series of examples. The second part of the essay highlights the challenges in scaling-down the analysis of production capabilities by proposing and testing a methodology for assessing industrial skills at the company level.

PART I

Towards a new set of production capabilities indicators

1. Measuring Production Capabilities at the Country Level

The first national science and technological (S&T) indicators were developed in the United States in 1973. Early indicators were mainly focused on input-based variables but were weaker on the output and impact sides (Grupp and Mogee, 2004). In the same period (1970s-1980s) national reports were produced by the UK, Germany, France, Japan, Austria, Italy, the Netherlands and Scandinavian countries, later followed by Eastern European countries. Among them the Japanese NISTEP (National Institute of Science and Technology Policy) developed 'cascade models' for integrating S&T indicators and also utilised factor analysis (Kodama, 1987). Among international organisations the OECD made an important contribution by ensuring statistics and indicators were comparable between member states through their celebrated *Frascati Manual* and later with the *Oslo* and *Bogota Manuals* (OECD 1992, 2002 and 2006).

Many of these *national level indicators* have been developed for different goals, from S&T assessment to innovation and competitiveness analysis[1]. There are two main approaches to the direct measurement and/or creation and measurement of a proxy for national-level production capabilities:

(1) The first group is comprised of country-level indicators which combine information extracted mainly from input-based variables, but also from a few output-based variables. With few exceptions these indicators tend to be methodologically homogenous and rely on similar data sources. Among them the following:

- The Summary Innovation Index (SII) – EU Commission
- The Global Summary Innovation Index (GSII) – EU Commission)

[1] For a review see Andreoni 2011 and Andreoni 2013.

- The indexes of the Science, Technology and Industry Scoreboard (STI) – OECD
- the Knowledge Economy Index (KEI) – World Bank
- The Growth Competitiveness Index (GroCI) – World Economic Forum
- The Global Competitiveness Index (GloCI) – World Economic Forum
- The New Global Competitiveness Index (NGCI) - World Economic Forum
- The Technology Achievement Index (TAI) – UNDP
- The Technology Activity Index (TAct) – UNCTAD
- The Industrial Capability Indicators – UNIDO
- The Competitive Industrial Performance Index – UNIDO
- The New Competitive Industrial Performance Index – UNIDO

Table 1 provides a synthesis of the data source and composition of the main indicators listed above.

(2) The second group of indicators comprises what we have called 'trade-based indicators'. These indicators have been recently developed as indirect measures of country-level production capabilities. Trade-based indicators classify exports and thus rank countries according to their export-basket. The different methodologies proposed share a common analytical starting point, that is:

- The complexity/sophistication of a product is a function of the production capabilities it requires for its manufacture
- Exported goods are more sophisticated the higher the average income of the exporter (assumption)

- By looking at countries' export basket we can infer the degree of complexity/sophistication of a country's technological and production structure (assumption)

The three most common methodologies/indexes are: the 'Sophistication index' introduced by Lall and associates (Lall et al. 2005; see also UNIDO 2009), the 'PRODY index' and the 'Method of Reflections' developed by the Harvard Research Group on Economic Complexity. The most important innovation of this latter group has been the 'method of reflections' which has been proposed as a way of solving a fundamental problem of 'circularity', that is, "rich countries export rich-countries products" (Hidalgo and Hausmann, 2009). This problem arises from the fact that the degree of complexity/sophistication of a given product is extrapolated from an 'income content' measure, rather than from a 'engineering content' measure

Table 1: Measuring Production Capabilities at the country level: A menu for choice

Typology	***Variable***	***Data source***	***Coverage Countries (years)***	***Included in***
	Public R&D exp (% GDP)	EUROSTAT+CIS	48 (2006)	GSII
INPUT-RELATED VARIABLES	Business R&D exp (% GDP)	EUROSTAT+CIS WEF opinion survey	48 (2006) 125 (2004-06)	GSII TechInnov
	R&D expenditure (% GDP)	WEF opinion survey	125 (2004-06)	Tech
	Firms' capabilities in adopting new technologies	WEF opinion survey	125 (2004-06)	TechRead
	Electricity consumption	UNDP ArCo (2004)	72 (1995 – 2000) 162 (1990&2000)	TAI ArCo
	ICT expenditures (% GDP)	EUROSTAT+CIS	48 (2006)	GSII
	Land lines per 100 population Land lines per 100 population Telephone mainlines Land lines per 1000 pop	K4D WEF hard data UNDP ArCo (2004)	132 (2006) 125 (2004-06) 72 (1995 – 2000) 162 (1990&2000)	KEI Tech TAI ArCo
	Mobile phones per 100 pop Mobile phones per 1000 pop	WEF hard data WEF hard data ArCo (2004)	125 (2004-06) 125 (2004-06) 162 (1990&2000)	Tech TechRead ArCo
	PC per 1000 population PC users per 100 population	K4D WEF hard data WEF hard data	132 (2006) 125 (2004-06) 125 (2004-06)	KEI Tech TechRead
	Internet users per 1000 pop Internet hosts per 10000 pop Internet hosts per 10000 pop Internet users per 10000 pop	K4D WEF hard data UNDP WEF hard data WEF hard data ArCo (2004)	132 (2006) 125 (2004-06) 72 (1995 – 2000) 125 (2004-06) 125 (2004-06) 162 (1990&2000)	KEI Tech TAI Tech TechRead ArCo
	Institutional capacity to create a propitious environment for the diffusion and efficient use of ICTs	WEF opinion survey	125 (2004-06)	Tech
	ICT laws	WEF opinion survey	125 (2004-06)	TechRead
	IPRs	WEF opinion survey	125 (2004-06)	TechInnov
	Receipts of royalty and license fees	UNDP	72 (1995 – 2000)	TAI
	Secondary school enrolment	K4D UNCTAD	132 (2006) 117 (1995&2001)	KEI UNICI
	University enrolment Tertiary enrolment rate	K4D WEF hard data	132 (2006) 125 (2004-06)	KEI Tech
	Literacy rate as % pop	UNCTAD ArCo (2004)	117 (1995&2001) 162 (1990&2000)	UNICI ArCo
	Years of schooling	UNDP ArCo (2004)	72 (1995 – 2000) 162 (1990&2000)	TAI ArCo
	Tertiary Science enrolment	UNDP UNCTAD ArCo (2004)	72 (1995 – 2000) 117 (1995&2001) 162 (1990&2000)	TAI UNICI ArCo
	Scientific & engineering graduates (% labour force)	EUROSTAT+CIS	48 (2006)	GSII
	Researchers per million population	EUROSTAT+CIS K4D UNCTAD	48 (2006) 132 (2006) 117 (1995&2001)	GSII KEI UNICI
	Scientists and engineers availability	WEF opinion survey	125 (2004-06)	TechInnov
	Public demand for high-tech products	WEF opinion survey	125 (2004-06)	TechInnov
	Research cooperation activities between universities and firms	WEF opinion survey WEF opinion survey	125 (2004-06) 125 (2004-06)	Tech TechInnov
	Quality of research institutions	WEF opinion survey	125 (2004-06)	TechInnov
	FDI	WEF opinion survey	125 (2004-06)	TechRead

OUTPUT-RELATED VARIABLES	Patents per million pop. (USTPO) (EPO for GSII) National patents	EUROSTAT+CIS K4D WEF hard data WEF hard data UNCTAD ArCo (2004) UNDP	48 (2006) 132 (2006) 125 (2004-06) 125 (2004-06) 117 (1995&2001) 162 (1990&2000) 72 (1995 – 2000)	GSII KEI Tech TechInnov UNICI ArCo TAI
	Medium and high tech exports	UNDP	72 (1995 – 2000)	TAI
	Scientific articles per million population	EUROSTAT+CIS K4D UNCTAD ArCo (2004)	48 (2006) 132 (2006) 117 (1995&2001) 162 (1990&2000)	GSII KEI UNICI ArCo
	Share of exports in high tech industries (% total exports)	EUROSTAT+CIS	48 (2006)	GSII
	Share of VA in high-tech industries (% TVA)	EUROSTAT+CIS	48 (2006)	GSII
	Manufacturing Value Added (Industrial Capacity-MVApc)	UNIDO	122 (2000&2005)	CIP
	Manufactured exports per capita (Mfg Export Capacity-MXpc)	UNIDO	122 (2000&2005)	CIP
	Share of MHT in MVA (Industrialisation Intensity-MVAsh)	UNIDO	161 (1990&2002) 122 (2000&2005)	ITA (TechAd) CIP
	Share of MHT exports in total manufactured exports (Export Quality-MHXsh)	UNIDO	161 (1990&2002) 122 (2000&2005)	ITA (TechAd) CIP
	Share of MVA in GDP (Industrialisation Intensity-MHVAsh)	UNIDO	161 (1990&2002) 122 (2000&2005)	ITA (IndAd) CIP
	Share of mfg exports in total exports (Export Quality-MXsh)	UNIDO	161 (1990&2002) 122 (2000&2005)	ITA (IndAd) CIP
	World Manufacturing Value Added share	UNIDO	161 (1990&2002) 122 (2000&2005)	CIP
	World Manufactures Export share	UNIDO	161 (1990&2002) 122 (2000&2005)	CIP

Note 1: SII and STI are not reported as the databases available account for less than 40 countries.

Note 2: the ArCo Index is included in the menu as it is developed by re-elaborating the TAI and the IDS indices. The variables selected allows a coverage of 162 countries for the years 1990 and 2000. See Archibugi and Coco (2004).

Source: Author

2. Measurement with or without theory[2]

If capability indicators are to be meaningful, the assumptions underlying their construction should be explicit and their informational limits clarified. In fact the more they are grounded in a thorough analytical framework the more informative and testable do the indicators become. Moreover, by comparing/integrating the information they provide with other quantitative and qualitative evidence (e.g. disaggregated data on sector-specific and/or firm-specific production capabilities), it is possible to get a stylised representation of production capabilities dynamics and the resulting competitiveness performance of different countries.

As we will see in detail in the next subsections, the dangers of building indicators 'without theory' are multiple[3]. First variables tend to be selected more on the basis of data availability rather than their informative content. Secondly overly composite indicators are generated under the assumption that 'more ingredients will provide the cake with a better taste' (Lall, 2001; UNIDO, 2002). Thirdly, indicators tend to be adopted by practitioners and policy makers in an uncritical way (i.e. *list disease*) without realising that these measures are mainly proxies of extremely complex and multilayered processes (Archibugi, 1988).

For these reasons some key methodological considerations have to be taken into account for the proper development of useful indicators. Awareness of the theoretical assumptions and methodological problems is extremely helpful for the refinement of current indicators and the identification of new industrial diagnostics

[2] The title of this section is inspired by a classic contribution on this topic: 'Measurement without theory' by T.C. Koopmas published in the *Review of Economics and Statistics*, 1947.

[3] For a discussion of methodological problems and informational limitations see also Archibugi and Coco (2005); Archibugi et al. (2009a) while Godin (2007) discusses the link between input and output measures and the functional model of production.

for policy design. The following subsections elaborate on a set of methodological and analytical points that are vital for the proper construction and use of production capabilities indicators. They will allow us to factor in important analytical distinctions between input and output variables, their aggregation and comparability over time and across countries. A new set of production capabilities indicators will be developed in section 2 based on these distinctions and analytical caveats.

2.1 Determinants and enablers

Firms are socially-structured production units characterised by certain technological and organisational knowledge bases. The same resources of knowledge ('know that') can provide different services, that is, may result in different production capabilities ('know how'). Indeed, given a certain amount of resources of knowledge, capabilities continuously develop in a circular and cumulative manner through learning processes (Kline and Rosenberg, 1986 and essays two and three of the present dissertation). Martin Bell (1984) has suggested at least six mechanisms of firm-level capabilities building. These include: experience-based 'learning by operating', 'learning through changing products', 'processes or production organisation', 'learning through performance monitoring', 'learning through staff training', 'learning through acquisition of external expertise, and 'learning through search for new technological knowledge outside the firm'.

Because of the variations in the ongoing learning processes even firms with the same technological and organisational knowledge base can actually manifest and develop different capabilities in production. This is why widely used variables such as expenditure in R&D, investments in capital goods and licenses and various indicators of worker quality (e.g. literacy rates) appear to be "proxies of *determinants* of capability rather than … of capability itself" (Romijn, 1999:3 italics added). Production capabilities are not simply pre-packaged stocks of codified knowledge.

Moreover, as in-firm learning processes are also affected by external factors, production capabilities indicators should not simply attempt to capture the knowledge bases of firms (i.e. *determinants* of capabilities) but also those factors external to the firm which affect learning processes (i.e. *enablers* of production capabilities building).

Crucially the recognition that the same determinants (and the same stock of technological and organisational knowledge) may result in different patterns of production capabilities building/accumulation suggests we should interpret the information provided by these indicators in a non-deterministic way. As Katz (2006: 897) notes "Unlike some physical processes, social activities are never completely deterministic nor are they completely random". Thus it becomes extremely important to identify the causal structures and set of causational chains which regulate the development processes. Indicators must be constructed on the basis of a clear understanding of an explicit theory of how these chains interact if they are to properly capture learning dynamics and the potential for capabilities accumulation. Moreover, an analytical distinction between capabilities on one side and their determinants and enablers on the other should be maintained.

2.2 Aggregation

The development of production capabilities involves many different factors which work as determinants or enablers. Thus very often capabilities indicators tend to aggregate multiple variables which act as proxies for these factors. However, capability indicators often conflate input-based variables with output-based variables which exacerbates aggregation problems (Lall, 2001; Grupp and Mogee, 2004; OECD, 2008).

Composite indicators are characterised by two fundamental aggregation problems (Kaplan, 2004).

Firstly when the importance of each component (i.e. its weight) is the result of an *ex ante* subjective evaluation, the same data set can provide completely different information. As Ravallion (2010:10) points out, it is "common practice … to identify a set of component variables, group these in some way and attach equal weight to these groups. However, little or no attention is given to the implied tradeoffs in the space of the primary dimensions being aggregated, and whether they are defensible". Crucially, equal weighting does not mean 'no weights'. Rather it implicitly implies that the weights are equal, in other words that all sub-indicators considered are 'worth' the same in the composite[4]. As well as being a courageous assumption, the equal weighting of the various sub-indicators is additionally problematic because, if sub-indicators have a high degree of correlation, various form of miscounting may be introduced in the index. For example, if two collinear indicators were included, the unique dimension they capture would be double counted in the composite index. This is why rules of thumb should be introduced to define a threshold beyond which the positive correlation is a clear symptom of double counting. Finally, although justifiable for comparability, keeping weights unchanged across time and space is problematic, especially when the composite indicator is used as a tool for defining best practices or setting priorities.

The second type of aggregation problem faced by composite indicators relates to aggregating different components under the

[4] A broad set of alternative weighting methods are provided in the literature from statistical methods such as factor analysis or principal component analysis to participatory methods that incorporate the various stakeholders involved in the process of performance assessment and policy design (OECD, 2008).

implicit assumption that they are substitutable. In, reality all determinants and enablers must be available according to a certain *degree of proportionality,* if the economy is to obtain certain production outcomes or achieve certain levels of competitiveness. For example, increasing R&D investment in order to build new labs will not have the expected impact on technological capabilities development without the amount of engineers universities can produce simultaneously increasing in the 'right' proportion.

As a result of the complementarities that exist among factors (which reveal underlying structural relationships in production) variables in composite indicators are very often highly correlated. For example, "countries with a high share of graduates have, at the same time, a high rate of scientific publications, patents and so on" (Archibugi et al., 2009a:3). These correlations suggest that capabilities determinants and enablers complement each other, even though their interdependencies cannot be read as causal links or as a set of deterministic relationships (UNIDO, 2002:59-60).

Given the ubiquity of these interdependencies it is useful to compile cross-correlation tables with different proxies for indicators for capabilities determinants and those for capabilities enablers and output-based indicators. By observing the resulting correlation matrices we might discover (for example) that at different stages development correlations between various factors such as R&D and output differ substantially. This result would suggest, for example, that at different stages of development R&D activities play a different role in determining the competitiveness performance of countries. In fact different countries' industrialisation experiences demonstrate how capabilities determinants and enablers (as well as the resulting production capabilities) can be combined in different ways, in line with different development strategies and paths. Thus we need to disaggregate the indicators and analyse the inter-relationships among factors in every context-specific situation if we wish to properly understand a country's production capabilities dynamics and growth potentials.

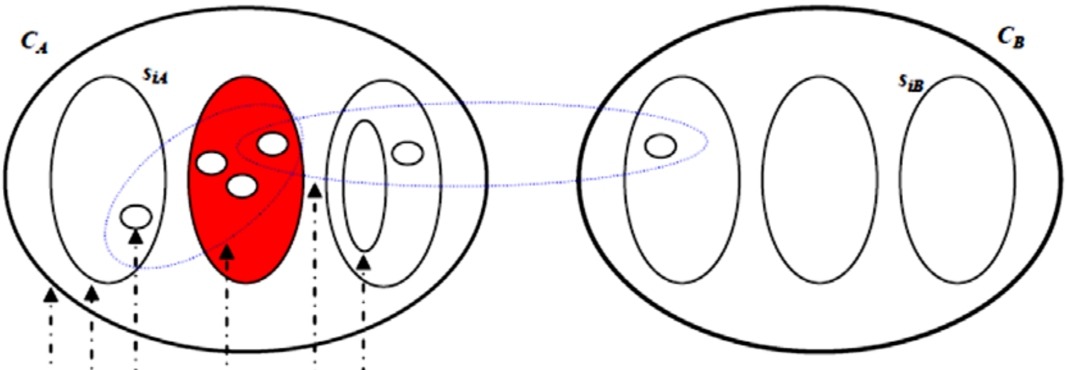
To recap, in order to respond to the many challenges posed by aggregation we recommend testing various weighting schema before we adopt one. We also recommend avoiding the use of multiple variables to capture the same dimension (i.e. risk double counting). Also, the adoption of geometric means (instead of more traditional linear aggregation) in the composite index partially addresses the problem of non-substitutability among factors. Finally, cross-correlation tables have to accompany the longitudinal analysis in order to highlight changes in production capabilities combinatorics at different stages of development.

2.3 Levels of analysis

As Jeffrey James and Henny Romijn (1997:189) have written, 'in the literature on technological capabilities there is a rather marked lack of coherence between the different levels of analysis". Production capabilities are embedded in physical agents (i.e. machines and workers) as well as in organisational configurations and institutional arrangements. According to the *loci* where they reside, levels of analysis considered (i.e. individual agent versus collective agent or organisation), and the systemic plane on which the analysis is taking place (e.g. regional or national), different capabilities indicators should be developed. This is necessary because production capabilities indicators at different levels (i.e. firm, sectoral, regional, country level) provide us with different information for industrial benchmarking and policy design. National level indicators tend to hide important sectoral and regional differences, while sectoral indicators hide important firm differences. The following figure (figure 1) is a stylised presentation of the different levels of analysis that must be taken into account:

The multilevel analysis envisaged here is made even more complicated by the fact that production capabilities at different levels (i.e. firm, sectoral, regional, country level) are interrelated with each other in different ways according to specific country characteristics. This is best understood in terms of the concept of 'social capabilities' which captures the country-specific way in which linkages among different capable entities work, develop and cluster. One crucial subset of these linkages connects firms embedded in the same regional innovation system or are part of the same global production networks (GPNs). The spreading of GPNs poses a serious challenge for the usefulness of country-level indicators. However as governments' policy-making still operates largely at the national level we cannot abandon county-level production capability indicators. Rather we should integrate them with other diagnostics that take into account the constraints and opportunities that circumscribe national economies and production systems in an increasingly globalised context.

Figure 1: Production capabilities indicators in a 3 sector, 2 country model: Levels of analysis



	Production capabilities indicators (PCI): list of possibilities
	National level PCI ➔ Cross-countries comparisons ➔ Longitudinal studies
	Sectoral level PCI ➔ Longitudinal studies ➔ Sectoral Comparisons across countries: the same sector across different countries at different stages of development
	Industry level (or sub-sectoral level) PCI ➔ Longitudinal studies ➔ Industry Comparisons across countries: the same industry across different countries at different stages of development
	Firm level PCI ➔ Longitudinal studies
	Inter-firm level PCI ➔ Longitudinal studies of industrial clusters (Bell and Albu, 1999) ➔ Knowledge flows at the cluster or inter-firm level
	Global production networks

Source: Author

2.4 Time lags and time scales

Learning processes proceed in historical time (Rosenberg, 1994; Bell, 2006). Thus indicators which fail to consider the existence of time-lags will provide a very misleading picture of the capabilities that countries' production/technological structures (and the firms which compose them) possess. For example consider a firm like Nokia in its first years of high-tech production. A capability indicator based only on output variables would show us that Nokia's is an incontrovertible story of continuous business failure since as it did not make any profit in that business for almost two decades[5].

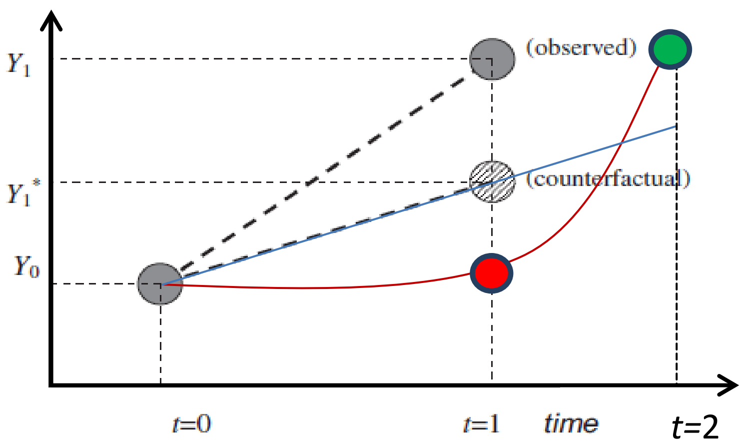
Production capabilities development takes time and is cumulative so relying only on output variables misses the ongoing learning process, which is not registered by the output-based indicator until a point further into the future. In other words "there may be [as occured in the case of Nokia] intensive processes of knowledge acquisition under way that are not yet reflected in economic outcomes, for example, in trade patterns" (OECD, 2006:201). On the other hand relying only on input-based measures does not solve the time-lag problem either. Without registering the great success of Nokia in output-terms (e.g. competitiveness performance) after 18 years of capabilities accumulation we would not have had any way to the assess if Nokia had had a *learning-rich* or *learning-poor* experience in that period.

Of course it is extremely difficult to assess and evaluate these processes and express them in an indicator *ex ante*. However one way we can partially address the problem raised by the existence of time lags would be to look at both input-based and output-based measures and to assess countries' production capabilities within a longitudinal framework instead of a static one. This approach is typically adopted for the impact evaluation of a certain programme or policy in a given context, very often relying on randomised control trial techniques (Andreoni, 2011). However, as soon as both input-based and output-based production capabilities indicators are adopted within a longitudinal framework, other problems emerge.

[5] Interestingly the learning trajectory from industry entry to the initiation of significant innovation was also around 20 years in the case of Samsung (Bell, 2006:29).

Crucially it becomes very difficult to know when the 'significant' statistical moment is in which to collect output data so we might try to have various output data points. However, even if we do this, we should not make any assumptions about the 'shape of the learning process', that is the functional form that links two observation points. If we assume (as is often done) that the relation between the input (e.g. a certain industrial policy) and a certain output (e.g. an increase in an output-based production capability indicator) is monotonically increasing and linear we might end up with a very misleading picture (see figure 2). In other words, as stressed by Woolcock (2009:3), "we know we need 'baseline' (at time t_0) and follow-up data (at time t_1), but the content and shape of the proverbial 'black box' connecting these data points remains wholly a mystery, to the development industry's peril".

Figure 2: Time lags and the 'shape' of the learning process



Source: Andreoni, 2011, based on Wolcoock, 2009.

Even if we recognise the existence of time-lags and thus of qualitative transformations, discontinuities, truncations and reversal, we are still quite far from an explicit treatment of the time/stages firms require to build certain production capabilities and, thus, to move from low to medium and high tech industries (i.e. *time scales*)[6]. Having some answers in this regard is crucial from a managerial, as well as a policy design, perspective. The most important of these urgent issues include: 'over what time period must the investment in particular kinds of production capabilities be made?' and 'when will the returns finally be realised?' and lastly 'what factors might affect the time-scales of the realisation of returns (e.g. learning faster/slower)?' Possible answers can be found in detailed long-term longitudinal studies and/or in tracking changes over time. Of course, this last option calls for the collection of time-series data. In this respect synthetic indicators should be developed in order to capture the *rate of change* of key variables more than their absolute level at any particular moment.

2.5 Comparability

International comparisons are particularly difficult when countries involved are at different stages of development. Not only are countries at different stages of development endowed with different amounts of production and technological capabilities, but often their capabilities are of *different kinds*. This is because the technologies employed in production are different and the industries in which they are specialised are also different. Thus there is considerable risk of providing misleading information if the same metrics are used to understand inherently different objects.

The use of patents as a proxy variable provide an excellent example of the problems of measuring different capabilities in different industries with the same indicators. As James and Romijn (1997:190) note, "technological efforts in most developing countries are still

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[6] See Katz (1987) for a collection of first attempts in the identification of technological learning stages and respective time-scales. Bell (2006) provides a retrospective critique of the technological capability literature arguing that it is overly concentrated on cross-sectional differences rather than an explicit treatment of time-scales.

predominantly aimed at mastering already existing imported technologies". This means that production capabilities indicators based only on patent data would be quite misleading since they would fail to pick up on the accumulation of technological capabilities occurring in terms of adaptation rather than (patentable) innovation. The data would therefore be biased against such countries and in favour of those which whose technological capabilities building was focusing specifically on activities which lead to new patentable discoveries.

Now countries at different stages of development do not just engage in different kinds of technological efforts, they also tend to be specialised in different industries. This means that using the 'number of patents' as a proxy may introduce a further bias in favour of those countries specialising in those industries for which the number of patentable products and processes is higher. Thus, for example, given that an industry like electronics allow the patenting of almost all single components of complex products, the country specialised on that subsector will appear to be much more technological advanced and dynamic in comparison to other countries whose industries do not allow this. Sectors where a large proportion of knowledge is tacit or related to processes that cannot be subdivided will produce fewer patents even though the technological capabilities present are high (for example in the case of the pharmaceutical industry or those industries whose technological capabilities are concentrated in complex assembling processes which are not patentable).

These problems of country-comparability suggest the need to benchmark countries which are at the same stage of development, in other words those which tend to have similar production/technological structures, and specialising in similar industries. The selection of various groups of countries may result either from the adoption of cluster analysis techniques or simply through selecting groups of countries on the basis of development level indicators. For example, for OECD countries very detailed and highly reliable databases are available. By creating different clusters of countries we can then develop different group-specific batteries of production capability indicators.

By following this strategy it will be possible to develop more refined measurements and, thus, perform more detailed cross-country comparative and convergence analyses (e.g. on the European integration process). This is the approach has been taken by the UNIDO (amongst others) when it stresses: “There is no optimal number of comparators, and different countries may be used for different purposes. A large number of comparators from across the world may be used (assuming that the data is readily available) to assess performance for broad issues like MVA or export performance, technology structures or inward FDI. A smaller set may be used to assess other variables like skill formation, R&D or risk ratings” (UNIDO, 2005:9).

Of course, even when we select appropriate groups of comparable countries, comparisons need normalisations. Recent work has been done showing how “a performance indicator derived from a ratio that exhibits a scaling correlation between the numerator and denominator must be scale-adjusted before it is used in comparisons” (Katz, 2006:895). Thus every time indicators rely on ratios like GERD/GDP, GDP/population or citations/paper we cannot simply assume that the indicator is normalised by the denominator even though the denominator is one measure of size.

Finally, the comparability problem is not limited to differences in countries’ stage of development or scale. Crucially as production capabilities are embedded in firms operating in different sectors and industries, differences in countries’ production/technological structures have to be factored in. Production capabilities development in some industries (e.g. manufacturing/capital goods production) is more complex than in others (e.g. process industries). This means that, to take an example we have already discussed in chapter 1, firms in certain manufacturing industries have a broad set of opportunities for in-house technical change as well as production capabilities building and accumulation because they possess the sort of machine tools with which they can also self-construct machinery for their own use, or upgrade and recondition second hand machinery (Rosenberg, 1969,1976, 1982; Romijn 1999)[7]. Thus, capability indicators have to be constructed taking into consideration the specificities of different industries.

Differences within sectors tend to be obscured by two facts. Firstly because (even in the more advanced economies) disaggregated data sets at the 3 and 4 digit levels are extremely rare for all sectors[8]. Secondly, because even when we have proper data sets there are problems in equipping ourselves with appropriate technological classifications.

Many technological classifications have been developed starting from the *International Standard Industrial Classification* (ISIC) and the Standard International Trade Classification (SITC). Further influential work in this regard includes Keith Pavitt's taxonomy (1984), Sanjaya Lall's (2001) technological classification of exports and the OECD technological classification. The latter, widely used, lists manufacturing sectors according to the level of technological complexity (see below).

[7] This is another reason why 'manufacturing development' is particularly relevant in the process of economic catch-up.
[8] The *UNIDO Industrial Statistics series* is an exception in this respect as it allows us to capture the main indicators for the manufacturing sector at the 2 and 3 digit levels. Interestingly recent innovation indicesindices have started introducing sectoral and sub-sectoral differentiations on the basis of detailed national surveys. The NESTA (2009) research work for the UK production/technological structure is a good example of this tendency.

Low technology

Division 15	Manufacture of food products and beverages
Division 16	Manufacture of tobacco products
Division 17	Manufacture of textiles
Division 18	Manufacture of wearing apparel; dressing and dyeing of fur
Division 19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
Division 20	Manufacture of wood and of wood products
Division 21	Manufacture of paper and paper products
Division 22	Publishing, printing and reproduction of recorded media
Division 36	Manufacture of furniture; manufacturing n.e.c.
Division 37	Recycling

Medium-low-technology

Division 23	Manufacture of coke, refined petroleum products and nuclear fuel
Division 25	Manufacture of rubber and plastics products
Division 26	Manufacture of other non-metallic mineral products
Division 27	Manufacture of basic metals
Division 28	Manufacture of fabricated metal products, except machinery and equipment

Medium-high and high technology (MHT)

Division 24	Manufacture of chemicals and chemical products
Division 29	Manufacture of machinery and equipment n.e.c.
Division 30	Manufacture of office, accounting and computing machinery
Division 31	Manufacture of electrical machinery and apparatus n.e.c.
Division 32	Manufacture of radio, television and communication equipment and apparatus
Division 33	Manufacture of medical, precision and optical instruments
Division 34	Manufacture of motor vehicles, trailers and semi-trailers
Division 35	Manufacture of other transport equipment

Although an analysis of sectoral classification goes beyond the scope of this paper, it is worth stressing the fundamental flaws affecting their use in the assessment of production capabilities indicators[9]. The 'original sin' of these classifications is due to the fact that they attempt to capture an inherently dynamic object in a static way. Since industries are continuously transforming, what was high-tech yesterday may well be low-tech tomorrow. In fact the problem is more serious that simply the changing nature of particular sectors. There is also no simple way aggregating sector such that their complexity level is homogenous. Thus within the same technology groups and the same division (e.g. the manufacture of electrical machinery and apparatuses) there might be production tasks of extremely different technological complexities. Additionally the most cutting-edge and innovative firms tend to do not fit into any existing category by their very nature and are not easily tracked in government statistics if they appear at all. Given these difficulties it is important that production capabilities indicators will rely on different technological classifications according to the specific level of analysis and research question.

3. Towards a new set of production capabilities indicators (PCI)

The analysis provided above has shown the numerous limitations of the country-level synthetic indicators available today. However we have also proposed possible solutions to some of the methodological problems posed. In fact, some of the shortcomings highlighted – such as the fact that using overly composite indicators or measures means time-lags and time-scales are not incorporated – might be avoided by building on the theoretical and empirical analyses provided so far. Thus this section aims to suggest a new set of indicators and methodologies

[9] For a broader discussion see Godin, 2004; Castellacci, 2008; Peneder, 2010; Hicks, 2011.

for the assessment and comparisons of country-level production capabilities that avoid the problems detailed above.

Until now the research on production and technological capabilities has not been able to come up with a comprehensive and consistent analytical framework that would permit the creation of a set of satisfactory indicators. However there is a widespread acceptance of the fact that *production capabilities result from learning processes in production.* Although it is impossible to quantify all the complex and multilayered learning processes through which the production capabilities of a given country develop, a second best strategy would be to identify, distinguish and group the most important factors that *enter, interact with* and *result from* these learning processes (provided data availability). This would then allow us to construct indicators that captured this central aspect of capabilities accumulation.

3.1 The explanatory variables

The new of set of production capabilities indicators proposed here focus on four sets of factors: capability determinants, capability enablers, capability outputs and production outputs. A stylised representation of the analytical framework describing the way in which these factors are related is provided in Figure 3.

Capability determinants

The set of 'input factors' such as spending on technical education and R&D spending are the 'knowledge ingredients' of learning processes. These knowledge ingredients consist mainly of human capital and investment in the acquisition of codified knowledge (e.g. design and engineering specifications for machinery). Before becoming production and technological capabilities, these 'knowledge ingredients' have to be processed, transformed and adapted by those actors that undertake production in firms. In doing that these actors are assisted by a broad assortment of machines, equipment and firm infrastructures (all the elements that in fact define the production capacity of a given firm).

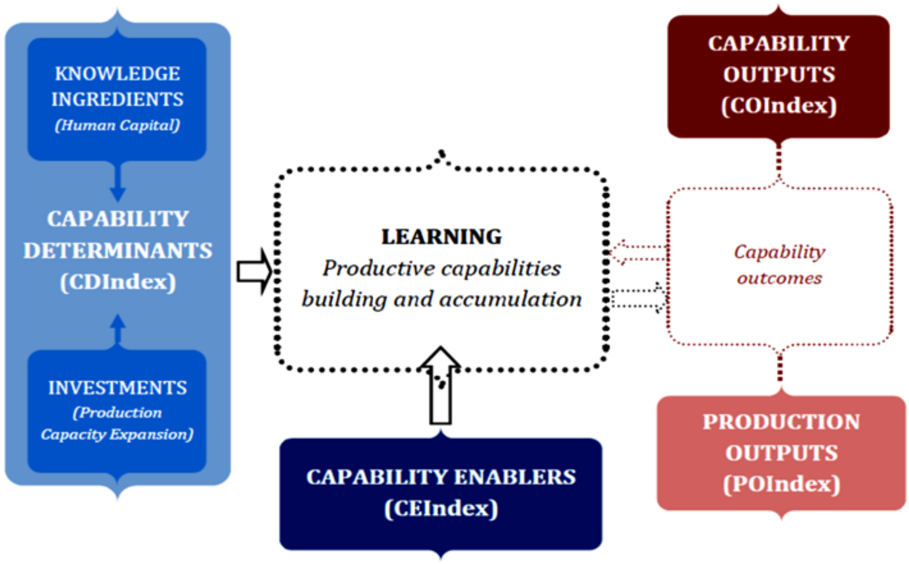
Crucially, in any give firm within a given industry, the transformation of knowledge ingredients into production capabilities would not be possible without a series of strategic investments (both individual and collective) aimed at the expansion of the relevant production capacity. Not only is the production capacity industry specific, but also its increase has to respond to specific laws of proportionality, given the existence of indivisibilities and given the production capabilities available. This means that the set of input factors entering learning processes in production must be proxied by information capturing the presence of 'knowledge ingredients' and 'production capacity' at the country level. Taken together these 'knowledge ingredients' and 'production capacities' constitute what we have called here the *capability determinants* (see Figure 3).

Capability enablers

The firm-level process of production capabilities development, its speed, effectiveness and multi-directionality, are affected by the presence (absence) of a series of 'mediating factors' that are country-specific. These mediating factors (mainly infrastructure such as roads, railways, ports network systems, public research frameworks and ICT infrastructures) do not directly enter into the firm-level process of production capabilities building but rather work as catalysts and facilitators. In other words by reducing *transaction costs* (e.g. transportation costs of machinery or technicians exchange) and *learning costs* (e.g. increasing absorption capacities and faster diffusion of production best practices with ICT) these factors enable firm-level processes of production capabilities building and accumulation. Thus they are labelled here as *capability enablers* (see Figure 3).

To recap: processes of production capabilities building and accumulation are triggered by two groups of input factors, what we have called here respectively '*capability determinants*' and '*capability enablers'* (see Figure 3).

Figure 3: A new analytical framework for country-level production capabilities indicators



Source: Author

The main reason for distinguishing these two groups of input factors resides in the fact that they play different roles in production capabilities building. Crucially these two different kinds of input factors (determinants or enablers) are linked by a relationship of complementarity rather than substitutability (see above). In fact, by developing sub-indicators for investment in production capacity, on the one hand and sub-indicators for knowledge ingredients (mainly investments in human capital) on the other hand, it is also possible to analyse the relationships of complementarity existing among the input factors (see Essays 2 and 3 on the importance of complementarities in learning dynamics). Clearly, at the country level, investment in production capacity and investment aimed at increasing the amount of knowledge ingredients available to firms (typically, human capital) call for different forms of policy intervention.

Production outputs and capability outputs

According to the amount and quality of capabilities determinants and capability enablers available in a certain country, and given the ability of its entrepreneurs to identify and capture production opportunities, individual firms (or groups of firms):

- will be able to undertake production processes only in a particular combination of sectors and industries;
- will experience cumulative processes of learning and production capabilities building triggered by 'internal compulsions' in production (Rosenberg, 1969 and 1976; see Essay 2);
- will be constantly reshaped by processes of 'creative destruction' (Schumpeter, 1932).

As a result of these dynamics, a certain amount of production capabilities develop and accumulate, while others are simply transformed or even lost.

These constantly developing and accumulating production capabilities are continuously re-inserted into the production process and thus transform the very learning processes that originated them (i.e. they are feedback mechanisms). Given that the firm-level dynamics that generate capability outcomes are extremely complex and interconnected, measuring the amount of capability outcomes generated in a certain country and in certain time period is almost as difficult as measuring capabilities themselves (or triggers of capabilities building). Two strategies are proposed here.

Firstly, as the proponents of trade-based indicators suggest, the development and accumulation of production capabilities at the country level is 'reflected' in its *production outputs*, that is, in the basket of commodities produced and internationally traded. The latter may be proxied by measuring the specialisation of a given country in the production of certain commodities with a certain degree of complexity or by looking at output indices such as the MVA, also disaggregated for low- medium- and high-tech sectors[10]. These production outputs are *indirect* measures of the production capabilities developed and employed in production by the set of firms producing in a certain country.

However, there are some capability outcomes such as new products, new machinery, new blueprints that are amenable to *direct* measurement. This is because these kinds of capabilities outcomes tend to be codified and (where possible) patented. In fact, capability outcomes such as patents become part of that stock of knowledge ingredients that triggers the initial process of learning in production (i.e. feedback mechanisms). Thus there are a set of directly measurable *capability outputs* re-entering the learning in production process as new capability determinants (Figure 3).

To recap, the new methodology suggested here relies on two direct measures of production capabilities (capability determinants: CD and capability enablers: CE) and two measure of capability outcomes, one direct and one indirect (capability outputs: CO and production outputs: PO respectively). The possible variables and data sources which would enter in the construction of each composite indicator are synthesised in the following Table 2. The next section addresses the problem of constructing four composite indicators, one for each explanatory variable identified.

[10] For any given country, the patterns of specialisation and diversification followed by its firms will determine their technological and production structure.

Table 2: Composite indicators for capability determinants, capability enablers, capability outputs and production outputs.

PRODUCTION CAPABILITIES INDICATORS (PCI)				
IRECT MEASURES				INDIRECT MEASURES
	Capability Determinants CDIndex	Capability Enablers CEIndex	Capability Outputs COIndex	Production Outputs POIndex
ENDOGENOUS EFFORT	R&D expenditure by production enterprises (per capita and as a % of GNP)	R&D public expenditure (per capita and as a % of GDP)	Patents taken out in the US (per 1000 people)	MVApc
	Secondary and Tertiary education	Traditional infrastructure (e.g. commercial energy use)	ISO Certificates (per 1000 people)	MXpc
	PISA scores	Personal computers (per 1000 people)	Product Complexity and Diversification (e.g. export baskets)	Industrial intensity (as calculated for the CIP)
	Vocational students (as a % of population)	Internet hosts (per 1000 people)		Export Quality (as calculated for the CIP)
	Tertiary technical enrolments (as a % of population)	Mobile phones (per 1000 people)		Impact in WMVA (share)
	Graduates in science and engineering (as a % of population)	Telephone mainlines (per 1000 people)		Impact in WMT (share)
IMPORTED	Royalty and licences payments (per capita and as a % of GDP)			
	FDI inward per capita			
	Capital goods import per capita			
Note: The list of variables for each of the composite indicators is not definitive. According to set of sub-indicators selected, various tests (e.g. correlations among variables) have to be performed in order to confirm that these variables can be used as proxy for each of the dimensions.				

Source: Author

3.2 Crafting composite indices

The construction of a composite index 'owes more to the craftsmanship of the modeller than to universally accepted scientific rules for encoding' (OECD, 2008: 14).

Normalisation

Normalisation is required prior to any data aggregation as the indicators in a data set have different measurement units. From the various normalisation techniques available we propose adopting the commonly used Min-Max standardisation technique. This normalises indicators so they have an identical range [0, 1] by subtracting the minimum value and dividing by the range of the indicator values. The general formula follows:

$$I_{ij} = \frac{X_{ij} - Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})}$$

where I_{ij} is the index value i for country j. X_{ij} is the indicator value i for country j. Min is the smallest value in the sample and Max is the largest. The top country in the sample gets the value 1, while the worst performer gets the value 0. Of course using this method carries with it the risk that extreme values or outliers could distort the transformed indicator. However, Min-Max normalisation widens the range of indicator results lying within a small interval, increasing the effect on the composite indicator more than the z-score transformation (OECD, 2008).

Aggregation

According to standard practice a composite indicator I can be considered as a weighted linear aggregation rule applied to a set of variables (OECD, 2008):

$$I = \sum_{i=1}^{N} w_i x_i$$

where $\boldsymbol{x_i}$ is a scale adjusted variable normalised between zero and one, and $\boldsymbol{w_i}$ is a weight attached to $\boldsymbol{x_i}$ usually with

$$\sum_{i=1}^{N} w_i = 1 \quad \text{and} \quad 0 \le w_i \le 1,\ i = 1,2,\ldots, N.$$

There is a well-known problem with this method in that additive aggregations imply full compensability among variables. In other words poor performance in one sub-indicator can be compensated for by high values in other sub-indicators. In contrast, geometric aggregation (i.e. 'derivational index') is better suited if we want to maintain a certain degree of non-compensability between individual sub-indicators (OECD, 2008: 103). Moreover, while linear aggregation rewards base-indicators proportionally to the weights (so compensability is constant), geometric aggregation rewards countries with higher scores (so compensability is lower for the composite indicators with low values).

$$CI_c = \prod_{q=1}^{Q} x_{q,c}^{w_q}$$

where

$x_{q,c}^{t}$: raw value of individual indicator q for country c at time t, with $q=1,\ldots,Q$ and $c=1,\ldots,M$.

$I_{q,c}^{t}$: normalised value of individual indicator q for country c at time t.

$w_{r,q}$: weight associated to individual indicator q, with $r=1,\ldots,R$ denoting the weighting method.

CI_c^t : value of the composite indicator for country c at time t.

The policy implications of adopting different aggregation techniques are manifold. Specifically, given the fact that (OECD, 2008: 33):

- "a country with low scores on one indicator will need a much higher score on the others to improve its situation when geometric aggregation is used", we can expect that such countries will pressure for the adoption of a linear rather than a geometric aggregation technique
- "the marginal utility from an increase in low absolute score would be much higher than in a high absolute score under

geometric aggregation”, a country would have a greater incentive to address politically those dimensions with low scores if the composite index adopts a geometric rather than linear aggregation technique

Given these considerations and the advantage offered by the geometric mean in avoiding factor substitutability, the composite indices will recur to non linear aggregation. The weighting schema proposed here is that of simple equal weights, provided that disaggregated statistics included in each composite indicator are also shown and that indicators are used both as composite and as disaggregated diagnostics.

3.3 Benchmarking, ranking, cross-countries comparisons and the analysis of trajectories

Given the fact that the four production capabilities indicators proposed here are modular, it is possible manipulate the composite indices in a number of ways according to the specific research questions in the following ways:

(i) add variables into each indicator (i.e. capability ‘determinants’, ‘enablers’, ‘outputs’ and production ‘outputs’).

(ii) consider the interaction among different sets of variables inside each group of indicator. For example the CDIndex might be disaggregated in order to analyse the ‘knowledge ingredients’ component and the ‘investment in production capacity’ component separately and in terms of their interaction. This would allow us to discover the existence of mismatches between the two sets of complementary input factors. It would also permit us to evaluate if, for example, a given industrial policy has been oriented overly towards one component or the other.

(iii) to aggregate input factors according to their origin. Crucially we could then distinguish between capability determinants that are endogenously generated from those which are imported from abroad (the latter typically being technology acquisitions of codified knowledge measured by royalty payments or production equipment measured by capital goods imports).

(iv) to integrate the set of indicators developed with others available. Given its theoretical and methodological premises, the most obvious integration would be with the UNIDO *Industrial Development Scoreboard*. Specifically, if we substitute the production output index (POI) with the index of competitive industrial performance (CIP), we obtain an updated version of the IDS. This would combine the CIP as an output measure with the three composite indices for capabilities determinants (CDI), capabilities enablers (CEI) and capabilities outputs (COI).

The set of possibilities listed above effectively refers to *benchmarking* and *ranking* countries as well as to performing *cross-countries comparisons* at discrete moments in time. However the Production Capabilities Indicators (PCI) can be combined with time-series data in order to perform longitudinal analyses and cluster analyses (see also Andreoni 2013)[11]. The possibilities offered by such combinations include:

[11] Cluster analysis is a statistical technique for identifying relatively homogenous groups of cases (e.g. countries) according to their quantitative features (e.g. a certain level of capability determinants).

(i) PCI can be used for evaluating *industrial development precursors*, that is the 'initial conditions' in terms of production capabilities shown by a given country at a certain stage of development. Interestingly, the latter can be proxied by levels of income per capita but also by more production-based measures such as the composition of the export basket as well as the stage of industrial development measured by MVA.

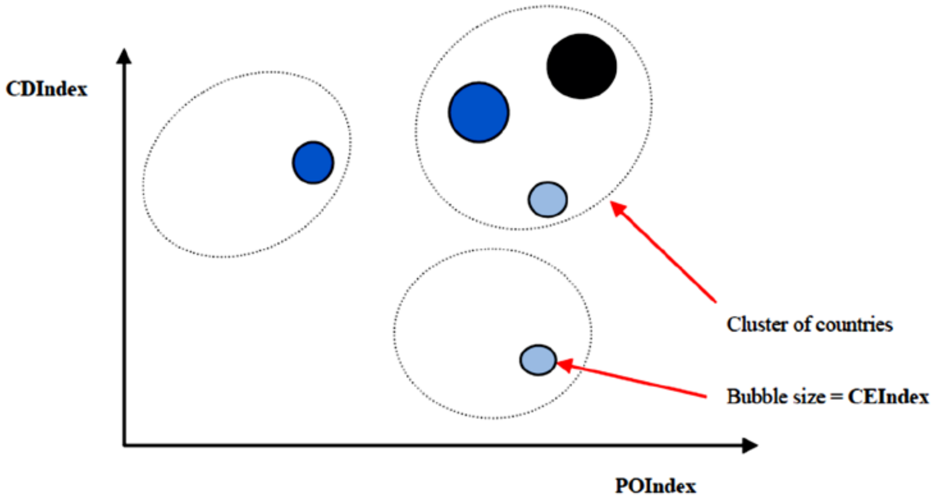
(ii) Given certain initial conditions PCI can be used as a focusing device for the identification of those cluster of countries that experience 'learning rich' *versus* 'learning poor' developmental process (e.g. fast growth of POI with a relatively slow growth of CDI).

(iii) PCI can be used for tracking the process of production capabilities accumulation in one country over time (as sketched in Figure 4). In other words it is possible to track how the relationships between CD, CE, CO and PO change over time.

(iv) PCI can be used as a focusing device for the identification of those clusters of countries that experience unbalanced patterns of production capabilities accumulation (e.g. high-sustained CEI and low/discontinuous CDI).

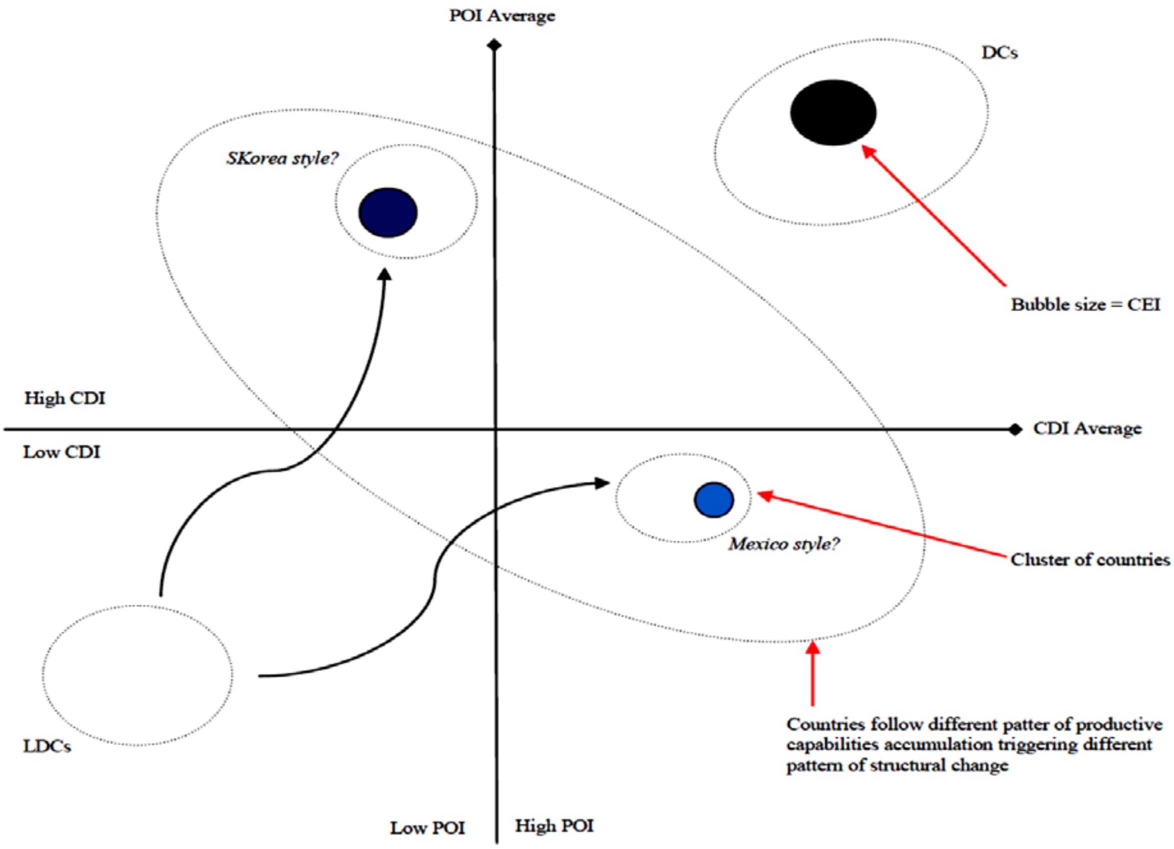
(v) PCI can complement structural change analysis by showing the different patterns of production capabilities accumulation underlying the transformation of the production/technological structure of one country over time (see Figure 5).

Figure 4: Tracking the relationships among different factors over time



Source: Author

Figure 5: Patterns of structural change and production capabilities accumulation



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PART II

Industrial Skills in LDCs:

A new methodology for assessing skills mismatches

and its application to Skills Policy in Tanzania

1. Industrial skills: opening the 'black box' of capability determinants

Different kinds of production capabilities indicators are increasingly being adopted by analysts and policy makers interested in understanding which specific structural trajectories different countries have been following. As we have seen in part I, production capabilities indicators can be customised with a high degree of flexibility in order to address specific research or policy questions. This is made possible by the fact that the composite indices constructed here have a strongly modular character. Indeed we assigned particular importance to the transparency of the composite indices in the above discussion of indicator design precisely in order to facilitate the valuable exercise of looking 'within' each of them to reduce their methodological problems and limitations.

From a policy perspective, opening the black box of what we have called capability determinants and developing an industrial skills assessment tool are particularly important tasks. This is because "the most important single determinant [of industrial competitiveness] is the level and improvement of workforce skills at all levels" (Lall, 1999:2). In particular, least developed countries cannot simply rely on natural resource abundance or traditional competitive factors (e.g. low cost unskilled labour) if they want to increase productivity in the traditional agricultural sector and catch-up in manufacturing industries. In the new global competitive landscape these factors can be used as part of an entry-level strategy for the short term. However, only by increasing their industrial skills (and complementary production capacities), will countries become able to process natural resources and to diversify into higher return agricultural and industrial products (Chang and Lin, 2009; Noman et al., 2012; MKGI, 2012).

As soon as we open up the black box of capability determinants with a specific focus on industrial skills, two orders of problem emerge. Firstly, we need to develop a way for assessing countries' current endowment of industrial skills which takes into account their sectoral distribution and differences (as well as bringing in qualitative aspects such as their adequacy and availability for companies). Secondly, we need to check in which industries companies are suffering from the existence of skills gaps and skills mismatches. In other words, we need to ask *how does the current supply of industrial skills match (both qualitatively and quantitatively) the current skills demand expressed by companies in a given country?*

The methodology developed here to answer this question is mainly based on industrial skills survey analysis and in-depth interviews with key institutional actors. Thus the assessment of industrial skills is done by triangulating and integrating different sets of information, both quantitative and qualitative, coming from companies and other actors involved in skills formation such us university and vocational schools. The methodology is presented and tested within the Tanzanian context with the specific aim of identifying areas and challenges on which the Tanzanian government should focus.

As is the case with many LDCs, Tanzania has increasingly invested in skills upgrading programmes but has been unable to determine if the skills policy implemented has been effective. In fact most LDCs do not know what specific skills gaps and mismatches are affecting their economies and need to be remedied. Although the results that we are going to present are specific to the Tanzanian context, the methodology developed here is particularly suitable for these LDCs. Although the magnitudes of the problems identified are different among LDCs, given their institutional and structural features, the Tanzanian case sheds some lights on common challenges that governments in LDCs are facing.

In attempting to evaluate the extent to which the current skills supply matches current skills demand, our methodology provokes further questions. Most crucially we are left asking: *to what extent is the current supply of industrial skills able to match companies' future skills demand?*

From an analytical point of view, this second question stresses something implicit in the first question and vital for its satisfactory resolution: the inherently dynamic character of the above-mentioned 'industrial skills matching problem'. The fact is that skills supply and demand have to be coordinated over time responding both to current needs (expressed by domestic and foreign companies) and also keeping in mind the need to match future skills requirements. Skills cannot be built in a day: their development requires long-term investment in learning processes and institution-building. Thus today's skills supply has to match today's skills demand and also respond to tomorrow's skills demand, as the Singaporean and Korean success stories have shown (Ansu and Tan, 2012; see also Toner, 2011 for a review).

The methodology developed here allows us to capture companies' perceived need for different kind of skills on the basis of their current production activities and forecasting about production expansion. This information constitutes the necessary first step for an in-depth analysis of future skills gaps.

However, future transformations of the industrial landscape in a given country are not only the result of quantitative expansions of existing activities. New production activities will need to be performed, so companies' perceptions of needs will not pick up on industrial skills that will become necessary in the future. A way to prepare the country for both these quantitative (more skills) and qualitative (different and higher skills) transformations is to develop *skill profiles benchmarks* (Andreoni, 2011). Industry-specific skill profiles are stylised representations of the kind of skills that the generic firm in a specific industry has to be equipped with in order to perform certain productive activities. Of course defining specific skill profile benchmarks for each industry should not make us forget that the same production process can actually be performed by different combinations of production capabilities. Nor should we be tempted to ignore the fact that these skills have to be complemented by appropriate investment in the expansion of firms' production capacity. Nevertheless skill profile benchmarks complement the assessment of industrial skills gaps and mismatches by suggesting the specific kind of industrial skills required by countries which want to enter into certain structural trajectories.

1.1. Structural transformation: *More* skills, *higher level* skills and *different kinds of* skills

More skills, *higher levels* skills and *different kinds of* skills have to be developed if countries are to be able to enhance their industrial competitiveness. In other words if they wish to increase their presence in international and domestic markets whilst developing industrial sectors and activities with higher value added and rising wages, then they cannot ignore skills policy.

The reason why skills development is one of the main drivers of countries' structural transformation becomes evident when we look at companies' technological efforts at the shop-floor level. For firms the possibility of capturing new production opportunities arising in global markets, introducing new production practices, or selecting alternative technologies critically depends on the domestic availability of relevant industrial skills. Workforce skills constitute the know-how base on which firms rely for absorbing and adapting technologies to local conditions as well as modifying organisational practices. They are also crucially important for the development of new work methods from the simple re-arrangement of production tasks up to the introduction of information technologies for process control, inventory systems and quality management.

Firms engage in costly and prolonged learning processes whereby production activities are eventually upgraded, the value of production output is increased and, ultimately, overall firm-level technological capabilities are developed (Lall, 2001; Andreoni, 2011; Toner, 2011). This depends crucially on the skill-level of their workforce so skills become the main determinants of production and technological capabilities development at the firm level (and the main complements to firm's investments in equipment, machines and other capital goods). And of course, in order to be used and maintained properly, complementary investments require specific technical and engineering skills.

Thus, skills perform two roles. Firstly the expansion of a firm's production capacity has to be accompanied by up-skilling and multi-skilling processes. Secondly capital investment in strategic physical infrastructure (e.g. roads, power supply, water and sanitation systems and telecommunications) require a skilled workforce able to plan, build, operate and maintain them (ADEA, 2012).

From the country-level perspective, the importance of skills for technological development is just as clear as at the shop-floor level. Crucially, increasing skills changes the structural trajectories of countries: they move from simple to difficult technologies, and within them, from basic production functions (production of simple components and assembly) to complex ones (improvement, design, innovation). Engaging in more complex production activities generally leads to the capture higher value and generate spillover benefits to local input-supplying companies, within and across industries (Chang, 2002; Cimoli, Dosi and Stiglitz, 2009).

In order to get the benefits of capturing higher value (by engaging in production activities that are complex and involve technologies which are difficult and costly to master) countries have to boost skills development. In other words they have to provide companies with an appropriately skilled workforce to engage in the technological upgrading described above. Thus, the need for increasing the quantity, quality and variety of skills domestically available goes hand in hand with the structural transformation of the national production system (in particular the manufacturing base). In other words, industrial skills development and the structural transformation of an economic system continuously interact in a process of circular and cumulative causation (Myrdal, 1958).

In fact the improvement of workforce skills is a main trigger of countries' structural transformation as well as one of its main outcomes. Specifically, technological deepening processes within domestic and foreign companies create new demand for an increasing number of higher-skilled workers and also generate new resources for improving the education and vocational school system. The government, in partnership with companies, has a fundamental role to play here. By investing increasing tax revenues in the education and vocational school system, it helps drive the cumulative self-reinforcing process of skills development and structural transformation (Noman et al, 2012; World Bank, 2012a). The education system, from primary up to tertiary education (as well as technical and vocational schools), is the main suppliers of skills. However, various forms of learning at work and re-skilling, particularly in manufacturing industries, are also important for building 'experience-based technical skills' as well as for the transformation of 'formal education-based skills' into production capabilities.

Understanding if and to what extent the current *skills supply* of a country is currently matching the *skills demand* expressed by foreign and domestic companies, especially in manufacturing, is a critical policy question. To be effective, skills policies require evidence-based judgments and, although very difficult to capture, information on the current workforce skills, specific skill needs and gaps, production and technological capabilities availability within firms (Borghans et al., 2001; Andreoni, 2011).

Countries with similar levels of investment in skills development may vary in their production and export performances according to their capacity to solve these skills-matching problems. Once identified through an appropriate methodology, each of them calls for policy action and rethinking current education policies as a fundamental lever in the broader industrial policy agenda.

1.2 Industrial skills: a matching problem

The *industrial skills matching problem* is particularly difficult to tackle, in particular for the least developed countries. There the education and vocational school systems are still in the early stages of development and thus are still not fully responsive to skills demand (Barro and Lee, 1996; Oyelaran-Oyeyinka, 2006). In order to address this problem by better guiding policy-makers in their allocation of public resources we propose the following three-step methodology:

- **Step One** consists of the identification of a set of *forms* and *dimensions* of potential mismatches that could affect companies in different sectors and industries.
- **Step Two** consists of the design of an appropriate company-level industrial skills survey covering the forms and dimensions of

analysis. The data collected has to be integrated with in-depth interviews aiming at characterising not only companies' skills demand, but also skills supply

- **Step Three** entails data analysis and the triangulation and integration of quantitative and qualitative information gathered in the previous steps.

Mismatches between skills demand and skills supply manifest themselves in three main forms:

(i) *Skills quantity and quality*: shortage of skills within companies, both in quantitative and qualitative terms;

(ii) *Skills misallocation and skills gap* within companies;

(iii) *Skills availability and formation*: lack or under-production of relevant skills by the education system and lack of coordination between the education and the production system.

In order to assess these different forms of mismatches we have distinguished them according to certain key dimensions:

(i) *Skills quantity and quality*: On the one hand the mix of high, medium and low skills within a company's workforce (or within the workforce of a group of companies with similar characteristics) reveals its ***skills intensity***. On the other, the presence in the workforce of education-based skills such as literacy, numeracy and IT skills informs us about the workforce's ***skills content***. Although skills in the workforce might be quite low, they might be sufficient for performing production activities within companies (***task sufficiency***). Finally, in terms of higher-skills, these might or might not match companies' expectations depending on whether they are adequate to perform certain production functions (***skills adequacy***). The 'skills adequacy' of certain workers goes beyond their formal 'higher skills' status.

Graduates might have achieved higher level education (typically graduate courses) but be inadequate to perform production tasks as they lack appropriate practical knowledge.

(ii) *Skills misallocation and gaps*: the fact that workforces of different skill levels might be employed by firms in such a way that they are not fully exploited given their specific job requirements (***skills misallocation***) is extremely problematic. This is particularly the case in countries affected by a significant gap between the share of graduate workers within companies and the desired share of graduate workers (***higher-skills gap***). The higher-skills gap signals both a quantitative lack of graduates, but also a qualitative lack of specific kind of graduates, that is, those in Science, Technology, Engineering or Mathematics (STEM).

(iii) *Skills availability and formation*: companies might find it particularly difficult to find specific higher-skilled workers (***skills availability***) either because there is lack of supply of appropriate skills or because there is not enough collaboration with universities and, thus, university curricula tend to do not match job requirements. Thus, in this latter case, there is a fallacy in the process of generation of skills (***skills formation***).

2. Industrial skills: driving the structural transformation of Tanzania

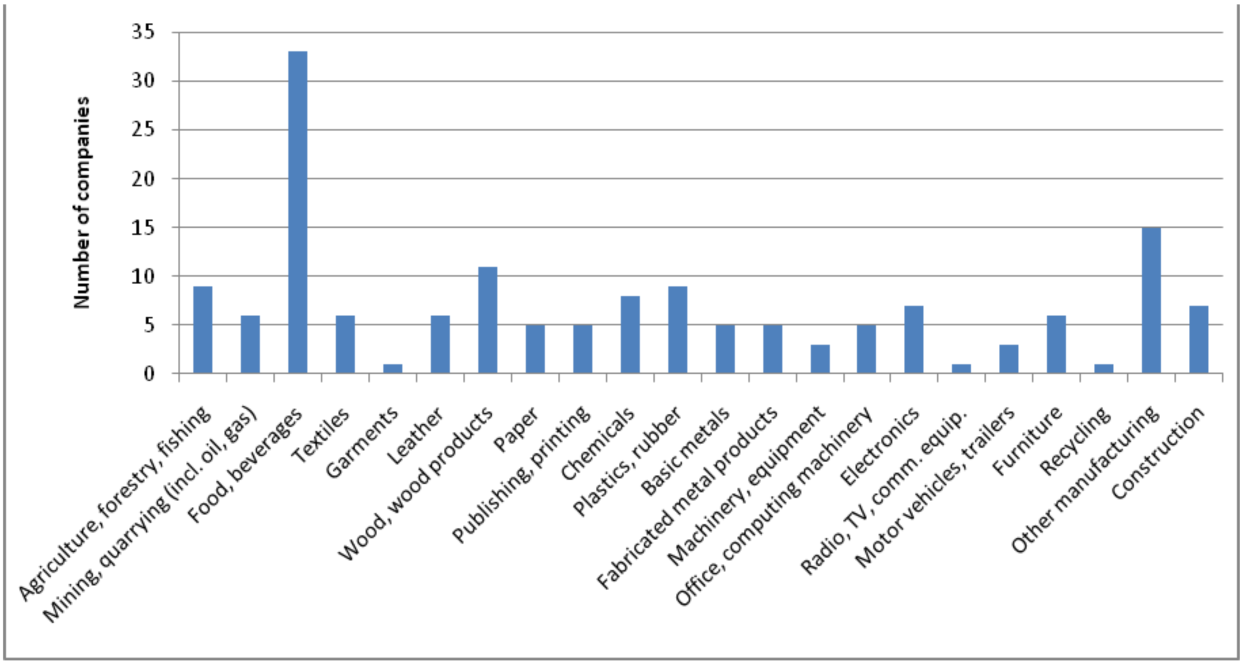
As with many other LDCs, Tanzania has recently expanded its investment in skills development without having been able to get a significant impact in terms of the transformation of its production structure. The methodology developed here was applied in the Tanzanian context in order to identify the specific areas and challenges on which the Tanzanian government should focus if it wants to develop its industrial skills base.

2.1 The data[12]

In 2011 UNIDO ran an *Industrial Skills Survey* that covered 167 companies in Tanzania (86% in the manufacturing sector)[13]. Based on a technological classification adopted from Lall (2001: 364-366), the survey sample consisted of 45% resource-based manufacturing companies, as well as 20% low tech and 19% medium-high tech manufacturing companies[14]. The technological composition of the company sample seems to reflect the sectoral composition of the Tanzanian economy (see Figure 6; see also UNIDO 2011). The companies are in great majority domestically-owned (almost 80%), tend to be small in size (the median company has 50 employees)[15] and are oriented towards the national market (60%), although almost one third export to the regional market. In terms of their innovation propensity, almost all (41%) of them are somehow involved or highly involved in innovation (50%). On the supply side, the skills matching analysis was supported by a curriculum survey previously conducted by UNIDO (2010) and a set of interviews conducted in the main educational institutions.

[12] The data were collected by UNIDO Staffs and made available by Florian Kaulich, UNIDO Consultant, under the project: Tanzania Industrial Competitiveness Report. UNIDO support is thus acknowledged. The author of this Essay also produced chapter 6 of the Tanzania Industrial Competitiveness Report. The chapter is called 'Modern Skills for Industrial Development'.
[13] Among manufacturing companies 64% would be classified as *light-manufacturing* according to the World Bank (2012b).
[14] In Lall (2001) the technological classification maintains a distinction between medium and high tech manufacturing industries. Given the structural characteristics of LDCs, the technological classification adopted here conflated medium and high tech manufacturing activities.
[15] The number of employees ranges from 4 to 1240 and its distribution is highly skewed towards large companies. The median company has 50 employees. The median is more meaningful than the mean in case of skewed distributions. The mean value of employees would be 99.

Figure 6: Sectorial distribution



Source: Author

3. Skills quantity and quality

3.1 Skills intensity

The skills intensity reveals the mix of high, medium and low skilled workforces within companies[16]. For any given company, the higher is the portion of workers with higher skills, the higher is its skills intensity[17]. In Tanzania, more than half of the workers of an average company are low skilled, almost one-third are medium skilled, and only 16% are high-skilled. These shares differ, however, if we consider different company groups (see Figure 7). For example when companies are split according to their market orientation (namely whether they

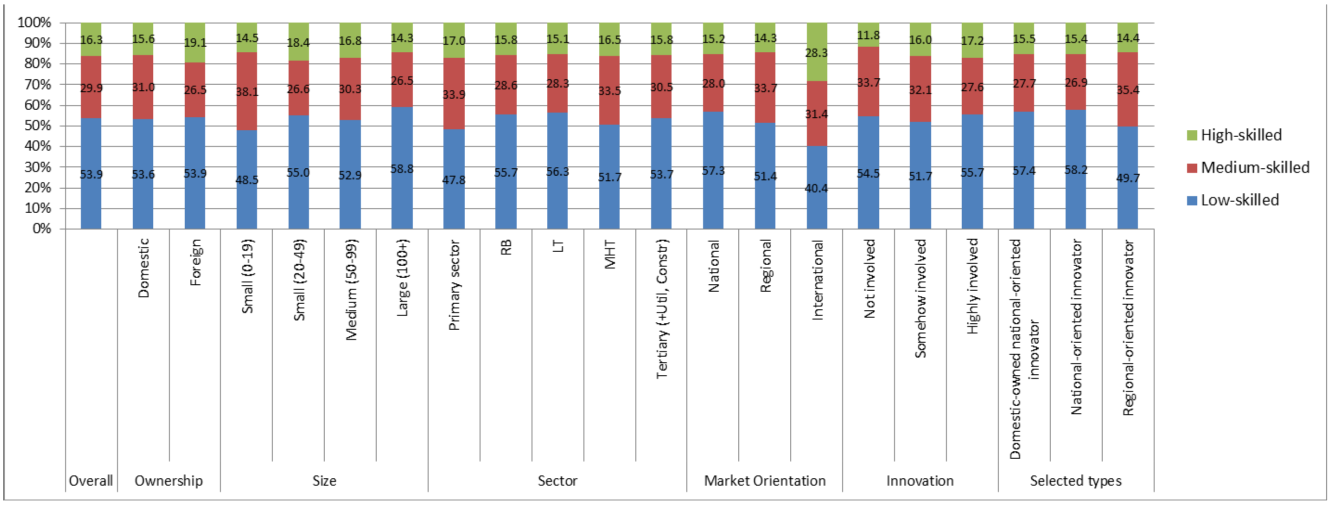
[16] Skill intensity is generally measured by the sum of managers, professionals, technical, clerical and supervisory personnel and skilled production workers divided by the total labour force (UNIDO 2009: 32).

[17] At this level of the analysis, the skills intensity is a perception-based measure, that is, relies on respondent's evaluation of the amount of skills currently owned by the firm's workforce. The possible existence of biases is controlled by reporting objective indicators such as the number of graduates or the real skills content (see below).

serve mainly the national, regional, or international markets) it becomes evident that the firms which serve foreign markets have a larger share of medium and high-skilled workers. In this context, it is notable that those companies targeting international demand employ almost one third of high-skilled workers among their workforce.

This ‘export effect’ tends to be correlated with the ownership and the size of companies. Foreign-owned companies tend to employ slightly more high-skilled workers but the same share of low-skilled workers. When looking at size, large companies have the highest share of low-skilled workers, while in small companies more than half of the workforce is medium-high skilled. The fact that foreign owned and export oriented companies may play a key role in capturing internationally available technologies as well as in triggering up-skilling and multi-skilling processes is well known. Countries such as Singapore and Malaysia have massively benefitted from actively managing FDI-led targeted strategies. At the same time, the development trajectory followed by countries such as Korea and Taiwan has also shown how a national-led strategy fostering export-oriented domestic firms can also increase national learning capabilities (Lall, 2001).

Tab 7: Skill level distribution of workforce (means)

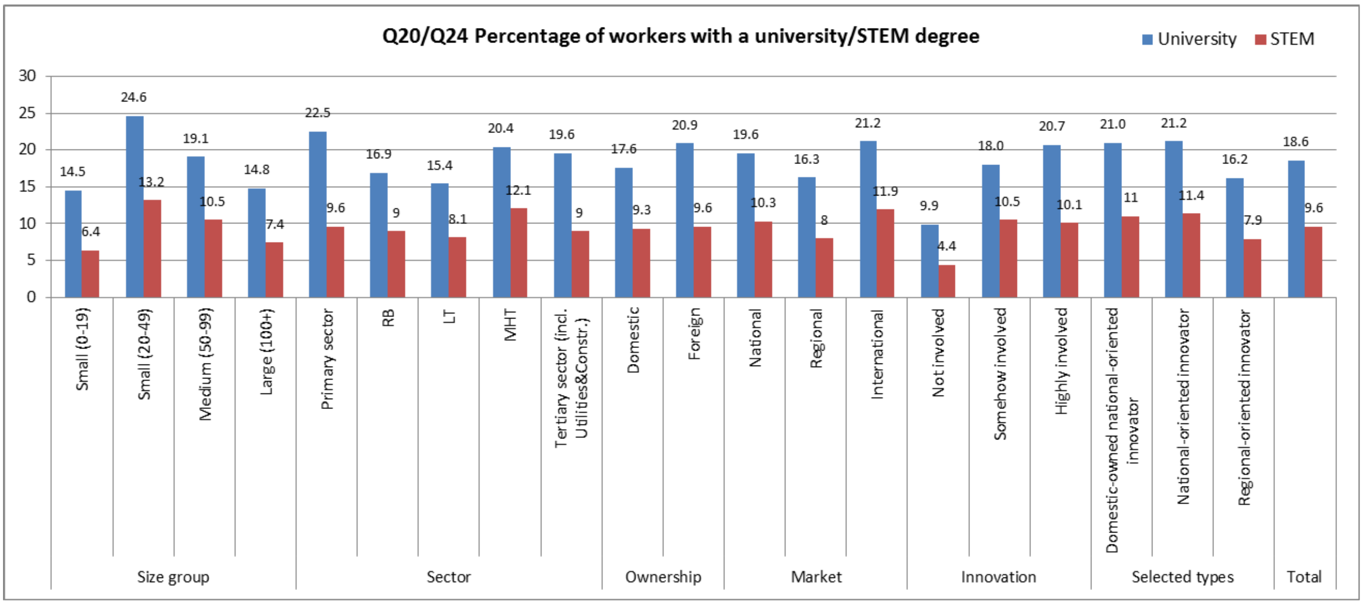


Source: Author

Surprisingly companies active in the primary sector employ the largest relative share of high-skilled workers and the smallest relative share of low-skilled workers. However this result might reveal a selection bias: a much smaller proportion of primary sector firms participated in the survey (compared with manufacturing firms) so those that did could well be the ones that invested most in upgrading their workforce skills. At any rate, within manufacturing, the lowest relative share of high-skilled workers and the highest relative share of low-skilled workers are to be found in low-technology manufacturing companies. Thus, the existence of a ‘technological effect’ is confirmed. In terms of ‘innovation propensity’, companies involved in some form of product or process innovation also employ relatively more high-skilled workers than companies that are not engaged in innovation.

The ‘innovation propensity’ and ‘technological’ effects described above can be also found by looking at the number of graduates in the workforce: innovation-oriented companies have double the number of graduates and, specifically, of STEM graduates. Medium- and high-tech companies also employ a larger share of graduates (see Figure 8). In terms of the number of graduates the export effect seems weaker: only companies exporting to distant markets (international) have a slightly higher number of graduates. Interestingly, the data reveal the existence of skills intensive small companies where the graduate/workforce ratio is one quarter (although only 13% if we consider STEM graduates). Considering that in these companies the number of employees is below 50 units, it is reasonable to imagine a quite high presence of graduates in all stages of production processes and, thus, a quite high degree of in-firm technological effort. Overall, one fifth of the workforce of the average company is composed by graduates, but only half of them have a STEM degrees.

Figure 8: Percentage of workers with a university/STEM degree



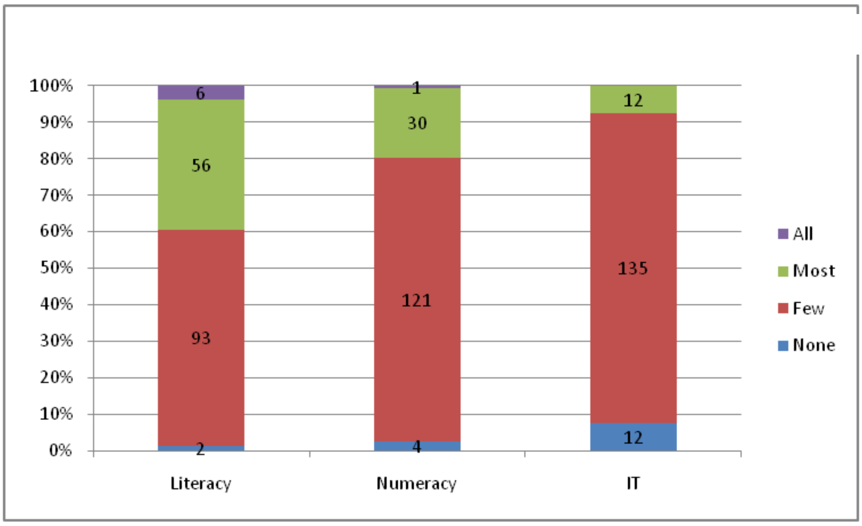
Source: Author

3.2 Skills content and task-sufficiency

Companies' skills endowment may be assessed in a more detailed and objective way by looking at the presence in the workforce of specific basic skills such as 'literacy' and 'numeracy', or more advanced ones such as 'information technology' (IT) skills. A number of worrying results emerge from the analysis of the workforce skills content in our sample of Tanzanian companies. Almost two thirds of respondents claim that none or few of their workers are literate and four fifths claim that none or few workers are numerate. Moreover nine out of ten respondents say that none or few of their workers have IT skills (see Figure 9).

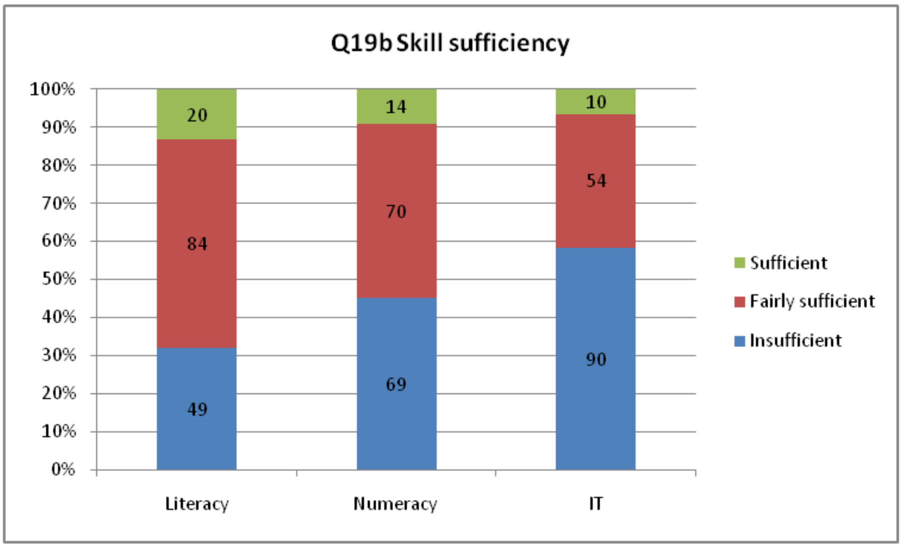
While this result is somewhat understandable for IT skills, as most manual activities do not actually require the usage of computers, the results for literacy and numeracy are surprising. Not being literate implies not being able to follow written instructions or understand blueprints, while the lack of numeracy skills at the shop-floor level makes the introduction and effective use of modern machines and equipment extremely difficult. Moreover, the lack of basic skills in the workforce tends to reduce the effectiveness of in-firm training and increase the costs that companies have to face (especially when they want to move from simple to more complex production functions). In fact skills content tends to be positively correlated to a company's degree of technological deepening (from resource based to medium-high tech manufacturing and, within them, from basic to complex production functions). In the Tanzanian case, given the fact that the great majority of the companies (65%) are resource-based and low tech manufacturing companies, it is not surprising to find that the proportion of workers mastering core skills is 'sufficient' to satisfy companies' current production needs (see Figure 10).

Figure 9 Skills composition



Source: Author

Figure 10 Skills sufficiency



Source: Author

In terms of the *task sufficiency* of workforce skills only one third of the companies consider the proportion of literate workers that they have insufficient. Task-sufficiency decreases when we move to numeracy (for almost half of companies numeracy skills are insufficient) and to IT skills, only 30% of the companies consider their proportion fairly sufficient (for only 10% they are fully sufficient). The fact that Sub-Saharan African companies can be competitive in light manufacturing industries even with a significant shortage of skilled workers is documented in a recent comparative study by the World Bank (2012b:102). As for labour productivity, Tanzania ranks higher than Ethiopia and Zambia in all products selected in this study. However it is below China and Viet Nam when it comes to wooden products.

At first glance, given the high task sufficiency indicator and relatively labour productivity figures, the very negative skills content results (in terms of literacy, numeracy and IT skills) may not matter very much. However, the fact that the existing workforce is sufficient to perform current production tasks does not mean that they will be sufficient to improve current production practices or diversify into higher value products. The latter is critically dependent on changing and increasing the workforce skills content. Thus companies have to prepare and adjust their internal skills base, keeping in mind their future business plans and market opportunities arising in domestic and international markets. This calls for various forms of collaboration with the education system and the government in defining skills needs and quality standards (on this, see section 4).

3.3 Higher-skills adequacy

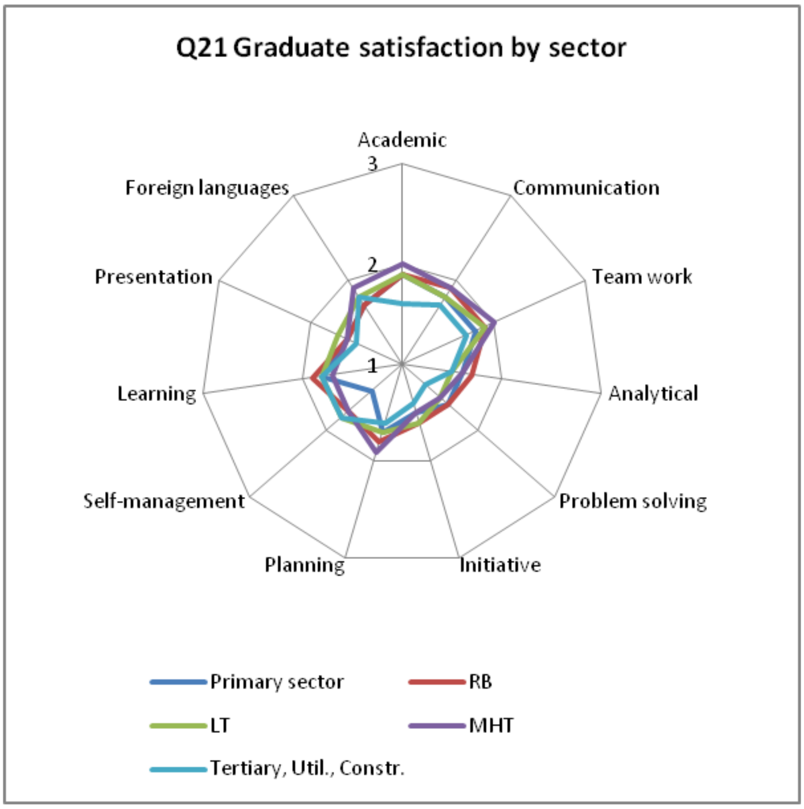
The problem of locating workers with qualitatively appropriate skills becomes even more complex for companies when it comes to higher-skills (i.e. education-based skills typically acquired through tertiary education programmes). Assessing higher-skills adequacy presents two main problems. Firstly, to provide an informed evaluation of graduate workers' skills adequacy within companies, managers and directors need to possess higher-level skills themselves. Secondly, graduate workers have to be assessed along different axes, each of them representing a specific skill typology. Identifying specific weaknesses among graduate workers allows the selection and prioritisation of specific areas that require intervention on the education side, for example in the reformulation of curricula and teaching methods.

A recent World Bank study (2012b:94) reported that on average Tanzanian company owners have just six years of education, while only 20% of them register some form of secondary education. In our company sample almost all respondents hold a top position within their company (ranging from chairmen and directors to senior managers and chief accountants) and 87% of them has graduated from a university (half of them hold a 1st degree). The high skill level of managers in our sample is encouraging for two reasons. Firstly, skilled managers can more reliably assess higher skills adequacy. Secondly indigenous firms' rate of growth is positively influenced by whether the ownerentrepreneur has a university degree or not (Ramachandran and Shah, 2007). However the high number of graduates in top positions might also reveal a certain selection bias in the sample, that is, the companies responding are actually those with a higher skilled workforce at the management as well as other levels. This might imply that the higher-skills adequacy analysis provided is relatively more optimistic than the one that would arise from a broader study. Thus measures for increasing higher-skills adequacy have to be even more robust than the data would suggest.

Respondents were asked to grade graduate workers along eleven axes, each of them representing a different skill typology. On average managers were more satisfied with academic, learning, communication and team-work skills, but less satisfied with presentation, problem-solving, initiative and analytical skills. When splitting these satisfaction ratings by company size, it becomes clear that large companies are less satisfied with their graduates in almost all aspects except foreign language skills. This type of company runs larger-scale production processes requiring organisational capabilities in the workforce. They also tend to employ bigger and, sometimes more complex, machines and equipment. Their utilisation and maintenance pose serious challenges even to higher-skilled workers who lack problem-solving and experience-based technical skills.

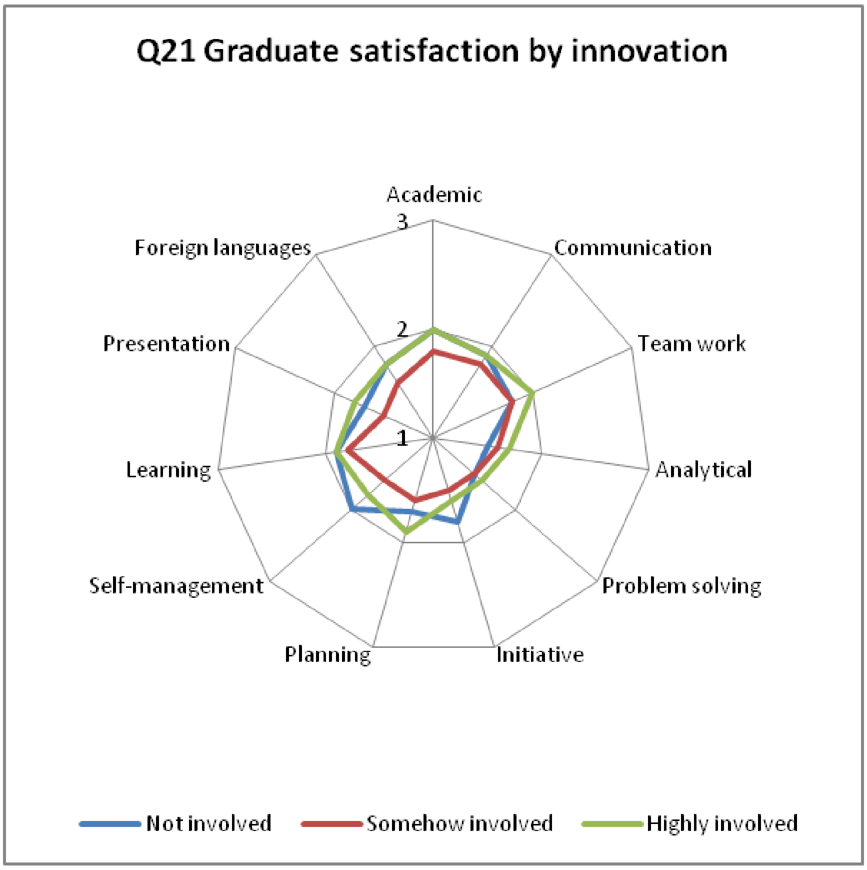
Worryingly, medium and high-tech manufacturing companies and those in the tertiary, utility and construction group register the lowest level of skills adequacy among their graduate workers with respect to problem-solving, initiative and analytical skills (Figure 11). In other words, companies operating more complex production functions or adopting information and communication technologies have greater problems with their graduate workforce. Skills are particularly limited when it comes to mastering technologies and applying formal knowledge to the solution of everyday production-constraints and bottlenecks. By controlling for the innovation propensity of firms, we find that the same set of skills are also identified as inadequate by companies who are not involved in innovation at all. However, companies who are 'somehow involved' in innovation find their graduate skills paradoxically inadequate in multiple dimensions (see Figure 12). These results can be partially explained by the fact that while companies which are 'highly involved' in innovation put more effort into selecting their graduate workers, those that are just 'somehow involved' invest less in selecting the best graduates. However they have enough knowledge of innovation challenges to perceive their graduate workers' weaknesses.

Figura 11: Graduate satisfaction by sector



Source: Author

Figura 12: Graduate satisfaction by innovation



Source: Author

When judging the background level of STEM graduates already employed in companies, most of them were rated as modest (41%) or fair (33%), while only one tenth were rated as good (almost none rates them as very good). Moreover, a quarter of managers claim that their STEM workers have no understanding of innovation, while almost three quarters report that there is just a ‘fair understanding’. In contrast, virtually no respondent attributed a ‘full understanding of innovation’ to their STEM workers. Finally companies manifest particular concern for a set of issues which make STEM graduates extremely costly. These include the need for re-training and long practical in-work training because of lack of experience and technical knowledge as well as low level of work commitment and relatively high wages.

4. Skills misallocation and gap

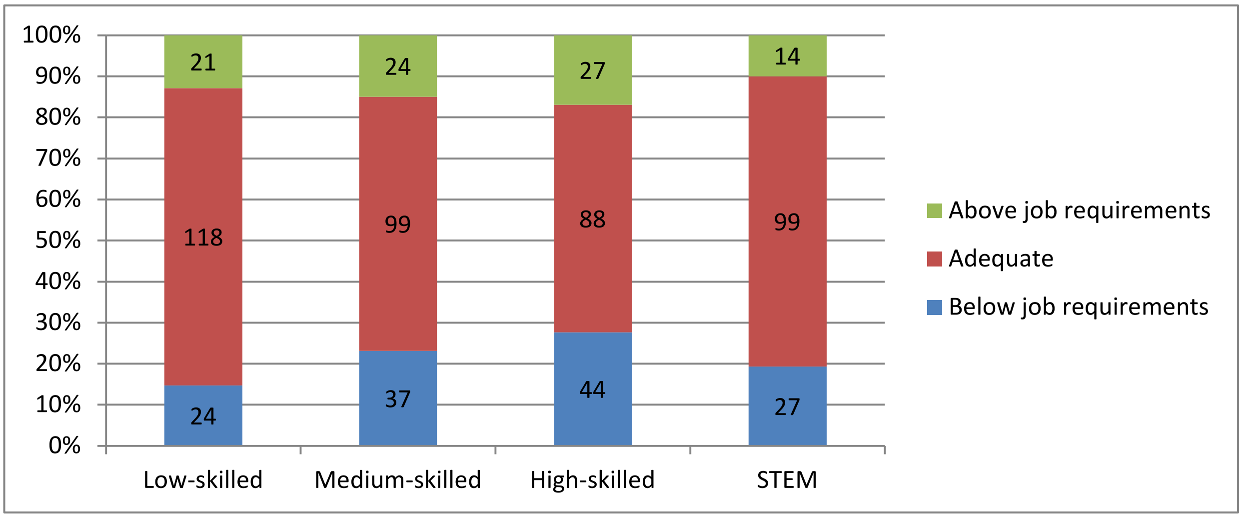
4.1 Skills misallocation

Increasing skills intensity and the overall quality of the skilled workforce is clearly the main pathway for firms to achieve higher productivity, technological deepening and diversification. However it is also important that companies do not misallocate skills in the organisation of production processes (since they are scarce and costly to produce).

This might occur for two kinds of reason. On the one hand, workforce skills of different levels might be employed by firms in such a way that they are not fully utilised, given their specific job requirements. In this kind of situation, organisational changes in production processes may result in higher production performances or operational improvements even if skills intensity did not improve. On the other hand, especially in the case of a shortage of skilled workers, the competencies of the workers might be noticeably below the specific job requirements. This might result in low productivity in certain production stages, the emergence of bottlenecks affecting overall production processes and low quality final output.

On both fronts Tanzanian companies registered mixed results (see Figure 13):

Figure 13: Skills-job requirements misallocation



Source: Author

Almost two thirds of low-skilled workers are considered to be adequately competent for their job, and only 15% are judged to exhibit competencies below the requirements of their job. However, it is disquieting that the proportion of workers whose competency level is adequate for their job becomes smaller when we come to medium and high-skilled workers,. In particular, when looking at high-skilled workers, only a half of them are considered to be competent with respect to their job requirements while more than a quarter are insufficiently competent. Notably, almost a fifth are too competent: in other words, their skills are not being utilised properly.

This misallocation is also present for the sub-group of STEM graduates, although, given their shortage, it seems that companies have managed to allocate them better. The misallocation of available medium and high skilled workers within companies is particularly severe for small and medium recource-based manufacturing companies that only serve the national market. Here a combination of size, technological and market orientation factors generate a significant amount of underutilised scarce skills (i.e. overqualified workers). In contrast, in large primary and tertiary sector companies, as well as in those manufacturing companies that undertake innovative efforts, the numer of workers whose skills are below job requirements is higher than the overall average.

4.2 Higher-skills gap

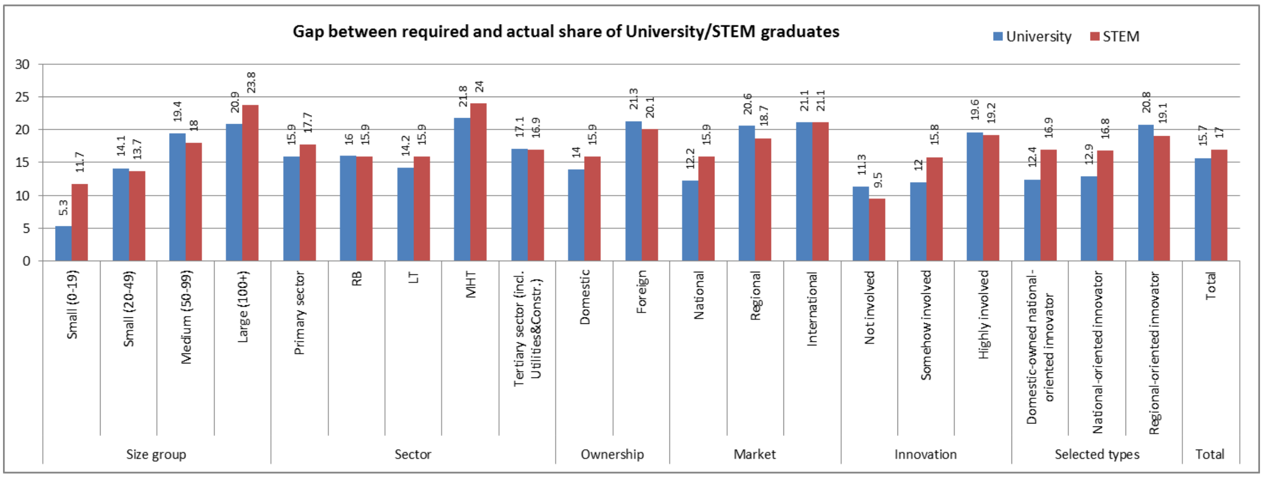
Because of the self-evident fact that higher-skills gap is much more severe in LDCs, we will now look in a more disaggregated way at the specific higher-level skills missing in the Tanzanian industries. Firms continuously struggle to improve production processes, operations and quality standards. Their chance of survival and chances for growth (i.e. their competitiveness) depends on their success in dealing with production challenges. This is why firms tend to know better than anyone else about what quantity and specific types of higher-skills they are currently lacking. In other words, they have local and direct knowledge of the 'skills gap' (i.e. those skills that they need to overcome current production constraints).

As these firm-level skills gaps directly have an impact on the industrial competitiveness of the entire economic system, it is absolutely vital that the government understands what skills companies need and wish to employ. Policy measures operate at the systemic level to an extent but they can become more selective and effective to the extent that the government has access to firms' relevant local knowledge and is able to coordinate and prioritise interventions. From our company sample the required graduate workforce share is on average 15.5% higher than the current workforce share. The higher-skills gap reaches 17% for STEM graduates (see Figure 14).

The skills gap between the actual and the required graduate workforce share varies considerably across company groups and types. The larger the company the larger the gap: small companies would like to increase their graduate workforce share by just 5%, while large companies would like to increase this share by over 20%. This 'size effect' increases with respect to STEM graduates: across company types, company size accounts for the largest variance (the larger the company, the larger the STEM recruitment gap).[18]

In sectoral terms, the skills gap is largest in the group of medium- and high-tech sectors giving us a disaggregated confirmation of the 'technological effect' registered in the skills intensity analysis. This company group stands out as having the largest STEM gap. Worryingly this means companies that are highly involved in innovation also report the largest gap, which implies that their innovative activities cannot develop properly because of lacking relevant higher-skills. Other company types with an above-average skills gap are foreign-owned companies and companies oriented to regional or international markets.

Figure 14: Gap between required and actual share of University/STEM graduates



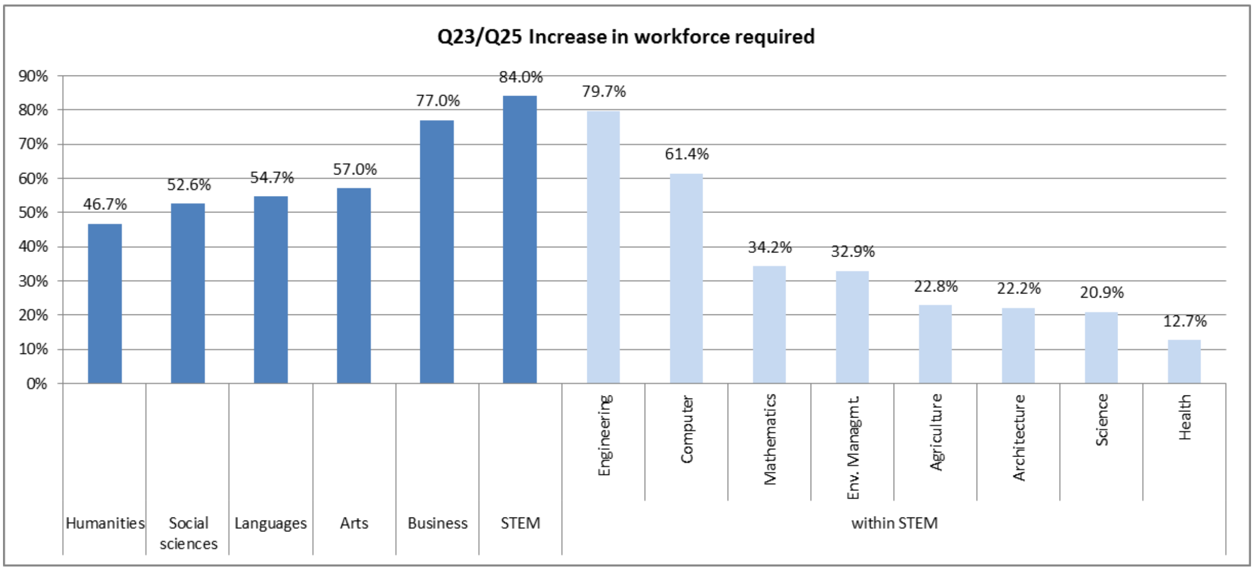
Source: Author

Observing the higher skills gap between actual and required graduates reported above, it is natural to ask what kind of graduation fields are

[18] Note that "gap" denotes the percentage point difference between the actual and the required share of STEM workers, thus the correlation with the size of the company is *not* by construction.

most in demand (see Figure 15). It turns out that the vast majority (84%) of companies want to recruit more graduates from the STEM fields, closely followed by business studies graduates. Over three-quarters of companies require engineering graduates, closely followed by computer science. Among the medium-demanded STEM graduates are mathematicians and environmental management graduates. Relatively less demanded are health sciences, applied, biological and physical sciences, agriculture and architecture. Other non STEM academic fields such as arts, languages, social sciences and in particular humanities are relatively less demanded. Nevertheless about the half of companies does want to recruit graduates from these areas.

Figure 15: Increase in workforce required



Source: Author

This skills gap analysis allows us to identify quantitative and qualitative gaps (i.e. those specific graduate types that are particularly relevant to the process of structural transformation for an economy in its catch-up phase). In this respect Tanzanian companies' demand for higher-skills reflects their ambition to upgrade production processes and to climb the technological ladder towards middle-income country status. A recent study (Moyo et al., 2012) performed a skills gap analysis showing the proportion of low, medium and high skilled workers that Tanzania would need to have across the working population if it wanted to reach middle income status. By relying on the Integrated Labour Force Survey conducted in Tanzania in 2006 and on a benchmark model of medium income countries (MMIC), the study points out similar inadequacies to those highlighted by the UNIDO Industrial Skills Survey. Unsurprisingly the occupational categories where Tanzania needs a higher proportional shift in supply are those requiring higher skills linked to STEM degrees. More specifically, taking the MMIC as a benchmark, Tanzania needs to almost triple the number of technicians as well as to increase the number of professionals of six times (as % of working population).

In order to reach its middle-income target by 2025 Tanzania needs its education system to be able to produce almost 300.000 engineers, architects and related technicians and almost 90.000 physical scientists and related technicians. It also needs 70.000 life scientists and related technicians. Of course, supporting an industrial middle-income country structure would also require a massive increase in administrative and managerial posts (by almost 430.000). Skills gap analyses (like the one presented) here have a twofold aim. On the one hand they allow us to identify current constraints and salient problems that require immediate policy interventions and on the other they reveal future opportunities and the potential benefits arising from investment in increasing skills supply.

5. Skills availability and formation

5.1 Skills availability and recruitment in the labour market

The labour market in Sub-Saharan African countries presents many complexities (Ansu and Tan, 2012). Given the relative underdevelopment of the education system at all levels, there is a significant shortage of appropriate skills in the workforce, especially of higher-level skills. Thus it is difficult for companies to find workers with skills profiles matching their job requirements. For example, companies tend to face an over-supply of graduates in humanities and social sciences, while a shortage in the supply of engineers, scientists and high-technical profiles (for the Tanzanian case details are provide in the URT, 2011: chapter 19, Annex).

Not only does the skills supply not meet the companies demand for quantitative or qualitative reasons, sometimes the geographic distribution of workers in the country does not match companies' location, as the most able among the graduates are attracted by better job opportunities and higher wages abroad and thus are not available for domestic companies. Other workers may eventually take up jobs for which their skills qualification is relatively high or end up working in the informal sector (another form of misallocation).

Paradoxically, at the early stages of countries' structural transformation or in certain cycles of economic contraction, the demand for skills may be very weak and the lack of employment opportunities may cause unemployment among higher-skilled workers. Prolonged unemployment may result in de-skilling processes or force workers to migrate. In sum, lack of skills supply may co-exist with situations of unemployment, especially among the youngest who find it much harder to enter the labour market. In 2011 unemployment within Tanzania's workforce of more than 22 million fell to 10.7%. However in the same year the level of youth unemployment reached 13.4% (14.3% for women), with a very high percentage of the youngest people forced to work in the informal sector[19].

Tanzanian companies were asked to report their perceived 'skills availability' in the country. Results show that skills availability is extremely dependent on the level of skills firms require. Low-skilled workers are easy to find for over four fifths of companies. Medium-skilled workers are much harder to find, and high-skilled workers seem to be a scarcity: nine out of ten respondents claim that it is very hard to find such workers. Low-skilled workers are particularly easy to find for small foreign-owned companies. Medium-skilled workers are harder to recruit if the companies are large medium- and high-tech companies. The scarcity of high-skilled workers is particularly problematic for large primary-sector companies, closely followed by medium- and high-tech companies.

When it comes to the market for graduates, medium-sized companies seem to be relatively more confident in all fields, while medium- and high-tech companies are 'somewhat confident' that they will find STEM workers. Finally, resource-based manufacturers are the ones that are most confident in finding business graduates. Foreign companies seem to be slightly more optimistic in assessing skills availability; however global traders are least confident about finding STEM graduates. Overall, no STEM positions are considered to be easy to fill. However it seems that small companies still find it easier to recruit STEM graduates. Domestic companies and global traders also find it easier to recruit STEM workers, albeit the difference is marginal. Interestingly, companies that are active innovators are those that find it

[19] These estimates are provided by the National Bureau of Statistics by projecting the data collected in the Labour Force Survey 2006 (the last available).

the hardest to recruit workers with a STEM degree, particularly in mathematics.

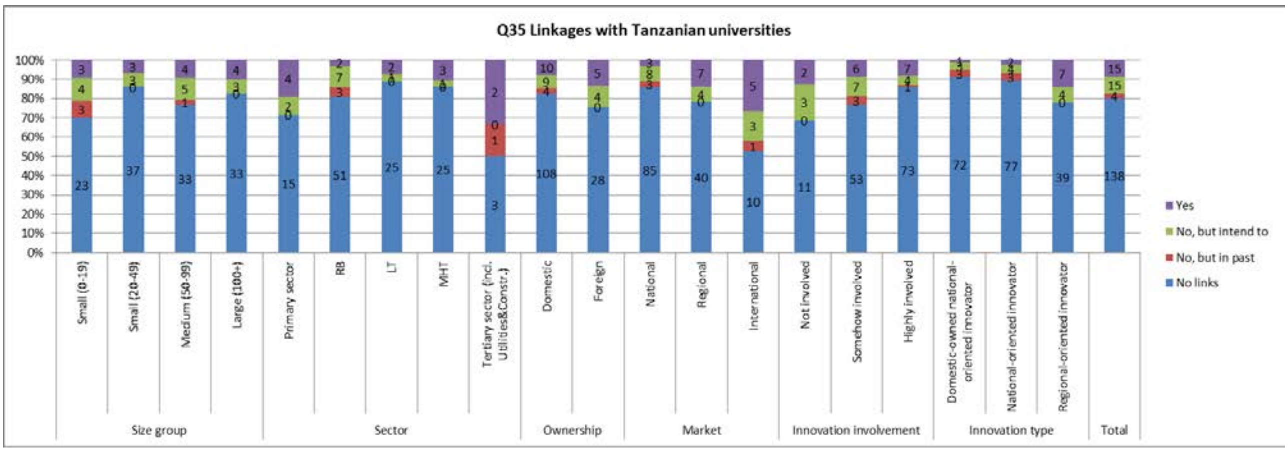
This is because innovative firms need both more specific and higher quality skills, especially in STEM fields. In order to be innovative and develop internal technological capabilities, these firms cannot simply rely on general graduate profiles: they need a specific mix of appropriate education-based skills and practical knowledge of production activities. For the group of innovative firms, the key barrier for STEM recruitment is the shortage of graduates with a relevant degree (40%) while the high salary is considered a barrier only for the 15%. For more than one third of the sample the main barriers are shortage of graduates (42%); high salary (36%), the latter being partially correlated to the shortage of supply and irrelevance of the degree (30%). These problems are particularly severe for resource based manufacturing industries and small companies (1-19 employees). Interestingly both the shortage of graduates and the difficulty of paying high salaries become less problematic the larger the company is and the more open it is to international markets.

In recruiting graduate workers three quarter of companies think that the most important factor is the presence of ‘relevant work experience’ followed by a ‘positive attitude’. Interestingly, the academic background, the degree result or the university attended are not considered as relevant in the majority of cases. This suggests a general lack of confidence among companies in the quality of the education system, and a certain concern about graduate workers lacking relevant practical experience. At the same time highly innovative companies give more relative importance to formal education-based skills. Given their higher involvement in innovation processes, these companies seem to be aware that although experienced-based skills are necessary, they are not sufficient and the skills acquired in tertiary education become an essential complement when companies want to upgrade their production processes.

5.2 Skills formation: a missing link

In order to address the skills mismatch problem currently affecting Tanzanian companies (and the economic system as whole) the firms which demand skills and the education system which supplies them need to coordinate their efforts. Specifically, the more companies interact and establish partnerships with universities the more the latter will be able to impart quality education. Most importantly partnerships will allow universities to complement theoretical knowledge with practical experienced-based skills and conduct relevant applied research (Lall, 2001; O'Sullivan, 2011; Noman et al., 2011). In this respect, a number of coordination problems have been identified in the Tanzanian context. The vast majority of companies claim that they have no links with Tanzanian universities. Only very few companies say that they do have such links, while some claim that they have not linked up with universities yet but they would like to do in the future (see Figure 16).

Figure 16: Linkages with Tanzanian Universities



Source: Author

There are two main reasons why companies-universities linkages are so weak in Tanzania. About half of all companies in our sample signal that they lack 'information about what universities offer', and one-third of companies claim that they lack 'information about whom to contact at the university'. Interestingly, controlling for companies' innovation propensity, highly innovative companies complain most about the lack of information regarding potential university offers (for almost 30% it is the main problem in this area).

Thus it seems that even those companies which are, in principle, more interested in interacting with universities find it extremely difficult to get relevant information. The 'market orientation effect' is the only one that seems to have facilitated companies-universities interactions. Overall, the results point to a serious coordination failure between universities and companies (especially since the lack of information flows could be addressed with a relatively small amount of resources).

The general lack of information flows and collaboration between universities and companies seems to have negatively affected companies' general attitude towards the tertiary education system. It is puzzling to observe that over two-thirds of respondents say that they would not benefit from linkages with Tanzanian universities in any form. Only one-tenth of the companies value the existence or the establishment of linkages with universities as highly beneficial while, on average, almost 20% find them just 'somewhat beneficial'. Interestingly, by controlling for different company characteristics it clearly emerges that the market orientation plays a key role in the relationship with universities. Half of the companies targeting international markets say they find it beneficial to collaborate with universities in order to access research and technologies, consultancy and networking opportunities.

Effectively there is a ‘missing link’ between universities and companies that make coordination between the two extremely hard to achieve. One of the main negative effects of this lack of coordination is the fact that university curricula are failing to match skills demand (in terms of both quality and variety). For example, about a half of companies feel that certain competencies should be provided in the Universities’ STEM curricula to make young graduates more aware of innovation but this has not occurred.

5.3 The education system: tertiary education and vocational schools

Over the last decade Tanzania has undergone an unprecedented fiscal effort to support its education system, including abolition of primary school fees and of enrolment-related contributions from parents (since 2004). In fact by 2011 education expenditure per capita increased 175%, compared with 2005. In 2011 spending in education reached almost 20% of the total government budget, of which half goes to primary education. Despite these big increases in spending learning outcomes are still not improving very much: pass rates in primary and secondary schools are stagnant and the dropout rate is still massive. According to the UN Tanzania, only 53% of 13 years old had completed a full cycle of primary school and almost the same number passed the primary school leaving certificate (2010). Furthermore, secondary schools are relatively underfunded and are under enormous pressure. There is some good news however: in 2010 enrolment in secondary education (form I-IV) was only 30% among the youth but the student secondary school population grew by more than 30% per year (World Bank, 2012a).

As for tertiary education, the number of graduate students is still insufficient and enrolments rates are poor in absolute terms (in

2009/10 there were approximately 120.000 graduate students distributed over 31 universities, 20 of which are private). They are also poor in relative terms as compared to countries such as Burundi, Kenya, Rwanda and Uganda (World Development Indicators, 2012).

In order to understand to what extent students were aware of companies' skills expectations and were satisfied about the tertiary education system in Tanzania, UNIDO conducted a curricula survey in 2011. Overall students expressed a medium-high degree of satisfaction with the programme in which they were enrolled. Specifically the survey registers students' positive evaluation of course programmes, their usefulness and lack of repetition across courses. However there was a negative evaluation given to study materials, physical infrastructure, didactic instruments and computers.

In terms of coverage of topics in curricula, the majority of students think that their respective programme should contain additional courses that are not currently included. The particular requests cover a wide range including numerical methods, scientific writing, eco-tourism, specific topics of chemistry, wildlife conservation, GIS, astrophysics, bioethics, and project management. In terms of integrative activities, such as laboratories and hands-on sessions, the opinions among students vary extensively. While some students are fully satisfied, others complain about the low ratio of workplaces to students which seriously obstructs the progress of their studies. Only half of the respondents declare that they received some form of on-the-job training such as internships, workshops and field trips. It is notable that these students are highly satisfied with these activities. It is also revealing to observe that three-quarters of students feel that their preparation is good enough to find a job in the field of their study, provided that the job position requires a focus on theoretical knowledge. These results reveal students awareness of a lack of sufficient opportunities for translating formal theoretical knowledge into applicable competences for addressing companies' production problems and challenges.

Formal education-based skills are necessary for using technologies effectively: literacy skills allow workers to read blueprints, or in the case of engineering skills to operate and control sophisticated machines. However, very often, basic skills acquired in primary and secondary schools such as literacy and numeracy (or even higher skills acquired in tertiary education) turn out to be insufficient as production processes also require workers endowed with *experience-based technical skills*. The latter are generally acquired in vocational training and technical education colleges. The major providers of industrial skills in Tanzania are the VETA training centres and the company based training centres. Internal training schemes are mainly provided by larger companies and parastatal companies, however their number drastically decreased as parastatals were privatised. In 2010, the total number of students enrolled in all forms of vocational and technical education was approximately 180.000 (URT, 2011: chapter 19; ADEA, 2012).

6. Rethinking skills policies in Tanzania: current constraints and future opportunities

As we have seen from previous discussion, industrial skills are among the main drivers in the transformation of the Tanzania's production structure. This is why the problems of the registered skills gap and mismatch between demand and supply of industrial skills must be urgently dealt with by the Tanzanian government. Crucially, given the dynamic nature of the skills gap and mismatch problems, skills policy must be articulated as a set of selective and aligned interventions over time.

On the one hand, skills policies must tackle 'current constraints' registered by companies in different industries and address difficult trade-offs arising in the allocation of scarce resources in the education system. Addressing current constraints would allow companies to rely on *more* skills, *higher levels* skills and *different kinds of* skills and, as a result, increase the productivity of current production processes.

On the other hand, in order that companies be able to capture 'future production opportunities', skills policies should also deal with the development of the industrial skills base that companies will require in the future stages of industrial development. Industrial skills development is an uncertain, costly and slow process as learning takes place over time and skills have to be embedded in production processes for becoming effective. However, on the basis of the skills gap and mismatch analysis, a set of area of policy interventions may be identified.

1. In order to significantly increase the overall level of industrial skills intensity within companies (especially in those companies which are less skills intensive because they are not exposed to international markets), skills policies should firstly rebalance the current allocation of public resources. *Secondary education* should be favoured (in particular numeracy skills) as should the more general development of production related skills combining formal and experience-based education.
2. Skills policy should channel increasing public resources to vocational schools and training centres and should also favour experience-based skills development in the education system overall. *Vocational schools and training centres* develop skills targeted to industry-specific production tasks and therefore

seem to offer a more appropriate and selective response to industries' needs and gaps.

3. Overall, *tertiary education* curricula should aim at the formation of analytically skilled graduates with a problem-solving and proactive attitude. Also, given the fact that the skills gap is higher for STEM (in particular engineering and computer science) and business graduates, skills policy should channel relatively more resources towards these disciplines guaranteeing the achievement of certain standards of higher-skills adequacy.
4. Skills policy should facilitate the transition from the formal education system (especially higher education) to industries. Given industries' desire to find experienced people, internships and 'bridging' programmes should be developed and supported. Institutions should be supported in the creation of mixed curricula, including both formal knowledge and practical skills.
5. Given the 'missing link' between industries and the education system (in particular universities)ff skills policy should facilitate the dialogue and the information flow by providing network services, opening and promoting the visibility of technology transfer offices within universities, enabling joint ventures between public research institutes and private companies through financial supporting schemes and the experiment with alternative legal forms.

Concluding remarks

The need for better production capabilities indicators becomes obvious when faced the problem of designing selective industrial policies for structural change. In order to be contextually viable, time-effective and structurally feasible, these policies have to be informed by appropriate production capabilities indicators. Of course most of today's industrialised countries have conducted successful industrial policies by relying mainly on the 'rules of thumbs' provided by classical development economics (List 1844; Prebisch, 1950; Hirschman, 1958; Kaldor, 1966; Chang, 1994)[20]. However, this paper has suggested that in today's more competitive global division of labour with a far greater number of players, economies in the catch-up phase can benefit from adopting other heuristics and benchmarks (specifically production capabilities indicators).

Production capabilities are personal and collective skills, production knowledge and experiences embedded in physical agents and organizations needed for firms to perform different production tasks as well as to adapt and undertake in-house improvements across different technological and organizational functions. The first part of theis essay has reviewed and compared the various synthetic indicators adopted by international organisations and independent researchers in cross-countries comparisons of production capabilities as well as industrial and competitive performance. Crucially we identified the methodological problems and informational limits of the various indicators available. The second part of the paper then developed a new set of industrial diagnostics for mapping the different drivers of structural change dynamics and measuring production capabilities at the national level.

[20] See Chang (2002) for an analysis of industrial policies in a historical perspective.

The methodology offered is based on a threefold distinction between factors that *enter*, *interact* and *result* from processes of learning in production. For each of them the paper proposes two direct measures of production capabilities (capability determinants or CD, capability enablers or CE) and two measures of capability outcome, one direct and one indirect (capability outputs or CO and production outputs or PO respectively). The paper has shown how relying on multiple informational spaces to analyse the relationships among input, output and mediating factors in a consistent causal structure is a superior fundamental starting point for the design of industrial policies.

In fact, country-level indicators of production capabilities can work as focusing devices and tools for benchmarking and ranking countries according to the process of production capabilities building and accumulation experienced. In particular, production capabilities indicators are extremely useful tools for the assessment and the comparison of different countries' production and technological structures. Moreover, by relying on time-series data, they can be employed as diagnostics for identifying the presence of *industrial development precursors* (i.e. the 'starting-point conditions' in terms of production capabilities shown by a given country at a certain stage of development). They can also show the different trajectories of production capabilities accumulation at the country level and their impact on production performance and structural change dynamics.

The second part of the paper has stressed how the design of selective industrial policies depends on the availability of industrial diagnostics at different levels of aggregation. The latter should allow policy makers to capture the specific production capabilities requirements of different industry groups. For this reason, the analysis of country-level indicators has been complemented by outlining new methodologies for the analysis of industrial skills which allow the government to promote different specific industry groups. The capability determinants black box was opened up and a specific methodology was developed and tested for assessing quantitative (skills gaps) and qualitative (skills mismatches) problems faced in particular by LDCs such as Tanzania. The detailed analysis of the Tanzanian case has allowed us to highlight the existence of multiple dimensions and forms of industrial skills mismatch. Given the difficulties in matching supply (skills availability and formation) and demand for skills (according to companies' surveys) in LDCs, skills policies need to involve different actors and operate in a selective way given industry-specific skills needs.

Fifth Essay

INDUSTRIAL POLICIES FOR MANUFACTURING DEVELOPMENT: structural dynamics and institutional transformations.

The Italian “Mezzogiorno”: A case of ‘dependent industrialisation’

Introduction

The debate surrounding industrial policies to promote manufacturing development has, since the eighteenth century, been one of the most important in political economy[1]. For almost two centuries states have played a key role in orientating and facilitating the structural transformations of their economic systems with the adoption of a wide spectrum of selective industrial, trade and technological policies.

However, with the end of the so-called 'golden age of capitalism', the idea that the state has to play a key role in the market in order to achieve systemic goals came under attack. With the rise of a neoliberal policy consensus, mainstream economists and international organisations have sustained the pro-market argument of 'getting the prices right'. According to this theory, all forms of industrial policies result in distortions of the market and in dramatic inefficiencies in resource allocation.

Many scholars have strongly criticised the neoliberal view both from a theoretical and historical perspective showing how the world's industrialised economies benefitted from the adoption of selective policies for manufacturing development in their industrialisation process just as emerging industrial giants are doing today (Johnson

[1] Even before the appearance of Adam Smith's celebrated *Wealth of Nations*, Antonio Serra's *Short Treatise* addressed the problems of underdevelopment by focusing on economies of scale and agglomeration, with a specific focus on manufacturing. Paolo Mattia Doria and David Hume investigated what they called the 'jealousy of trade', while Antonio Genovesi in Naples and Cesare Beccaria in Milan proposed a set of policies that nations should follow in order to develop their manufactures and escape a situation of dependency (Scazzieri 2011; Bagchi 2012). Alexander Hamilton and Friedrich List formulated the infant industry argument, later rediscovered by classical development economists in the second half of the XX century (Chang 2002). The *developmentalist tradition* (started by classical development economists such as Rosenstein-Rodan, Albert Hirschman, Raul Prebish, Celso Furtado and Gunnar Myrdal) is much more well known and will constitute a point of reference for this essay.

1982; Hall 1986; Amsden 1989 and 2007; Wade 1990; Chang 1994 and 2002; Stiglitz 1996; Rodrik 2004; Cimoli, Dosi and Stiglitz 2009).

Given the recent global financial crisis, policymakers are increasingly showing interest in the potential role that industrial policies can play in boosting national competitiveness and rebalancing economic structures. Thus industrial policy to promote manufacturing development is once again at the centre of the political economy debate and economists are increasingly asked to provide analytical tools for disentangling structural economic dynamics, for understanding the complex architecture of modern manufacturing systems and for designing effective industrial policies (Rodrik 2007; Chang 2009; Bianchi and Laboury 2006).

This essay aims at contributing to this renewed interest in industrial policies by analysing the relationships between structural economic dynamics and institutional transformations of economic systems. Drawing from the Anglo-Saxon and Latin American structuralist schools, the paper offers a new analytical grounding for the reformulation of current industrial policy thinking to promote manufacturing development.

Luigi Pasinetti's *structural economic dynamics approach* has been particularly important in showing "the lack of theoretical concepts concerning the structural dynamics of production" (Pasinetti 1993, 112) and in highlighting the need to better link the structural dynamics of economic systems to their institutional transformations. On the one hand, institutional forms and functions are shaped by structural dynamics originating within the production realm. On the other, the transformation of these institutions are fundamental conditions for the unfolding of structural dynamics of production in historical contexts. As stressed by Pasinetti (1993:147 italics added) "A vast programme of research is thereby opening up. But there also emerges a wide programme for action. Not only is there an *'institutional problem'* to be solved; there also is a challenge for *'institutional action'* to be met'. Industrial policies are at the core of governments' institutional action".

Disentangling the complex architecture of modern manufacturing systems, hierarchic in structure and inherently dynamic, calls for a mixture of heuristics through which both structural dynamics and institutional transformations are captured, at different degrees of granularity and for different units of analysis. The adoption of these heuristics allows the expansion of the industrial policy space currently visualised by policymakers, permitting the identification of hierarchical principles through which policies can be sequentially coordinated.

Within our new analytical framework, industrial policies are understood as a set of *sequentially coordinated selective measures addressing structural tensions, institutional bottlenecks and various forms of dualism* that impede the economic system from entering certain trajectories of manufacturing development. Framing industrial policies as measures arranged along the axes of selectivity, matching and alignment over time also leads to a rethinking of the role of the state in the practice of industrial policies to promote manufacturing development.

The analytical lenses developed in our theoretical discussion are then illustrated by reinterpreting the industrialisation experience of the Italian "*Mezzogiorno*" during two consecutive phases of industrial policy development, from 1950 to 1959 and from 1959 to 1975. In the 1950s (in the immediate aftermath of the Second World War but before the start of the industrial policy programmes we will be studying) the Italian Mezzogiorno had witnessed an agrarian reform and the first round of public investment in infrastructure. The latter had resulted in a significant increase in agricultural exports, going from the South to the fast-industrialising North where the automotive and the machine tool industries were becoming the main export strengths of the country.

During the 1959-75 period, SOEs in the South focused mainly on energy and intermediate goods, such as chemicals and steel. Crucially they were aligned to the specific needs of the manufacturing industries (such as machine tools) booming in the North. Although industrial policies delivered important results in terms of increasing income and employment in the South during the 1959-1975 period, sectoral complementarities and linkages developed in a way that may be called of 'dependent industrialisation'. In other words, they responded more to external stimuli than to local dynamics of sectoral deepening, which would have triggered industrial commons development. Thus the first attempt to deal with the dualism characterising the country since its unification failed because it did not nurture the organic creation of development blocks (or 'development poles') in the South.

The structure of the essay is as follows: section 1 addresses the renewed interest in structural economics for industrial development while highlighting the limits of the current approaches; section 2 proposes a set of heuristics for disentangling structural dynamics and institutional changes keeping in focus the structural tensions, institutional bottlenecks and dualisms impeding manufacturing development; section 3 applies these heuristics with the aim of redefining the industrial policy space along the axes of selectivity, matching and alignment over time; section 4 applies this new analytical framework to provide an novel interpretation of the 'dependent industrialisation' experience of Italian Mezzogiorno, from 1950 to 1975.

1. Renewing structural economics for industrial development: analytics and policies.

After two decades in which the development discourse has primarily focused on the 'economics of institutions' in a market economy context, more recently the 'economics of structural change' and the related 'industrial policy debate' have reacquired centrality. Evidence of this can be found in the recent World Bank's 'New Structural Economics' framework as well as in the 'New Developmentalism' agenda, promoted by economists sharing a Keynesian and structuralist development macroeconomics approach. The new contributions in the economics of structural change and industrial policy face a fundamental analytical challenge in disentangling manufacturing development as resulting from two interconnected processes. On the one hand, there are structural dynamics triggered by 'disproportional transformations' within and across production sectors (i.e. changes in the sectoral composition of the economic system that are not proportional, as production sectors transform at different speeds and with different intensity). On the other hand, there are institutional changes aimed both at overcoming structural constraints and at realising opportunities embedded in production structures. The lack of clarity in the analysis of the relationship between these two processes seems to have undermined industrial policy propositions and restricted industrial policy imagination.

The following two sub-sections review the recent contributions in the economics of structural change and industrial policy. While the World Bank's New Structural Economics framework is still intrinsically limited by its neoclassical grounding, various contributions related to Old and New Developmentalisms remain quite scattered and few of them systematically address the set of *structural tensions, institutional bottlenecks and dualisms* characterising manufacturing development trajectories. Where this has been attempted, these phenomena tend to be addressed in an ad hoc and undertheorised way, as if structural dynamics and institutional changes are one and the same, and as if they may be addressed by adopting the same unit of analysis (i.e. sectors). The final sub-section will attempt to overcome these limitations by focusing on a set of heuristics capable of disentangling these structural and institutional dynamics and proposing a broader set of units of analysis.

1.1 What's new in the *New Structural Economics* framework?

In the words of its main architect, the former chief economist of the World Bank Justin Yifu Lin, the *New Structural Economics* (NSE) framework "advances a neoclassical approach to study the determinants and dynamics of economic structure. It postulates that the economic structure of an economy is endogenous to its *factor endowment structure* and that sustained economic development is driven by changes in factor endowments and continuous technological innovation" (Lin 2012:5 italics added). Although manufacturing development is recognised to be an unavoidable step in the catching up process, a country's optimal industrial structure is derived from its comparative advantage, the latter being defined by *factor endowments at each point in time*.

As a result, the NSE framework envisages a mix of 'comparative advantage following strategies', supported by 'hard/soft infrastructures' for facilitating market functioning. This stands in a clear contrast to a fully-fledged neoliberal model, where countries should passively adhere to their comparative advantage. In the case of the new structural economics framework, the alternative idea is presented that countries should develop specific policies which aim at an effective exploitation of their comparative advantage at each point in time, that is, at each stage of their economic development (Chang and Lin 2009). "The new structural economics argues that the best way to upgrade a country's endowment structure is to develop its industries at any specific time according to the comparative advantages determined by its given endowment structure at that time" (Lin 2012:5).

Thus a certain element of economic dynamism (at least in terms of changes in factor endowments) and a certain degree of policy space seem to differentiate the NSE framework from the standard neoliberal one. The latter is essentially based on three pillars: liberalisation, privatisation and depoliticisation of market economies (Chang 2003). In order to achieve the highest level of efficiency and the fastest rate of sustainable growth, neoliberals believe that developing countries should commit to the free market (the resilience on price mechanisms for the allocation of resources and competition rules), drastically reducing state intervention. At the same time, neoliberals claim that developing countries should open up to international trade, specialising according to their 'natural' comparative advantage (e.g. relative abundance of unskilled labour or natural resources). This supposedly promotes the 'natural' (not state-led) development of the industrial sector (Pack and Saggi 2006).

According to the neoliberals, all those 'selective' industrial policies which aim to promote and nurture indigenous firms, as well as to resolve market failures, only serve to introduce distortions and inefficiencies in the market mechanism. Moreover, they argue that these policies also open the door to a series of government failures – i.e. incapacity or, worse, corruption at the political and bureaucratic level, rent seeking behaviours and protection of inefficiencies and interest groups (Krueger, 1974; Lall, 1983). In addition, the 'informational objection' proposed by neoliberals according to which "it is impossible for governments to identify with any degree of precision and certainty the relevant firms, sectors, or markets that are subject to market imperfections" (Rodrik 2007:11) seems to deny any form of industrial policy.

The NSE framework gives greater prominence to governments' provision of 'hard and soft infrastructures' to facilitate economic operations and is open to the idea that the state could address market failures with horizontal policy measures. However policies are still expected to perform essentially 'market-friendly' functions: maintaining macroeconomic stability, providing public goods (education, health and infrastructure) and creating an enabling institutional environment through functional pro-market policies (Chang and Rowthorn 1995). There is no space for pro-active structural change policies aimied at defying countries' given comparative advantage. Also, there is still a fundamental adherence to the idea that the market is the only possible institutional form for the fulfilment of essential institutional functions in the development process.

The lack of a distinction between institutional *forms* and institutional *functions* has been stressed by Ha-Joon Chang (2007:23) when he highlights how "[a]t the very general level, we may say that there are certain functions that institutions have to serve if they are to promote economic development, and that there are certain forms of institutions that serve these functions the best. However, the difficulty is that we cannot come up with an agreed list of the 'essential' functions nor an obvious match between these functions and particular forms of institutions". In fact the same institutional functions may be fulfilled by different institutional forms, the latter being developed in different historical contexts. Indeed institutions tend to serve more than one function.

Without maintaining such distinctions, the understanding of institutional transformations remains quite limited and there is a danger of confusing certain institutional forms with functions necessary for a new stage of economic development ('form-fetish'). At a deeper level the shift from one institutional form to another might allow the fulfilment of certain institutional functions but the overall mix of institutional functions might be compromised. Moreover the new institutional form might not be compatible with the other existing institutions, given the historical context.

It is not just the NSE framework's understanding of institutions that is unsatisfactory[2]. Its interpretation of structures is also limited as these are reduced to "relative abundance of natural resources, labour, human capital and physical capital" (Lin 2012:24). The upgrading of the industrial structure is treated as an aggregate growth process of upgrading of the factor endowment structure. Even when structural dynamics at a more disaggregated level are considered, the NSE framework remain rooted in the neoclassical idea that moving from a one sector-model-approach *à la Solow* to a multi-sectoral approach *à la Pasinetti* is simply a matter of disaggregation and 'transparency' and that the two are in fact 'complementary' (Solow 2012:552).

However, as the recent Pasinetti-Solow debate shows, "essentially the two approaches embody two different visions of the industrial world. The vision behind structural dynamics originates from the consideration of a *permanently* evolving economic system. The vision behind the aggregate model of traditional growth theory embodies a static, or at most a stationary, view of the economic system, and the reason is that it is inherently incapable of absorbing any change in time of the structure" (Pasinetti 2012:553 italics added). In the multi-sectoral approach envisioned by Pasinetti, both productivity (learning in production) and demand (learning in

[2] See also the debate around the contribution by Chang 2010 hosted in the *Journal of Institutional Economics.*

consumption) will grow at different rates from sector to sector and independently of one another. As a result *relative* economic magnitudes will evolve constantly through time and the ongoing disproportional dynamics will shape a certain *specific structure* of the economic system for each *specific point in time*.

In sum, the NSE framework has a limited understanding of institutional transformations and of structural dynamics within a multi-sectoral dynamic model. Therefore the problems related to their evolving relationships (structural tensions, institutional bottlenecks and dualisms) in the process of economic development are not considered.

1.2 ***New Developmentalism*** **and the rationales for industrial policy.**

The *New Developmentalism* (NDev) framework is articulated in ten theses[3]. Here, economic development is a “structural process of utilising all available domestic resources to provide the maximum environmentally sustainable rate of capital accumulation building on incorporation of technical progress [...] To achieve long term development, economic policies should pursue full employment as its primary goal, while assuring price and financial stability” (*First* and *Tenth* theses). At the core of the NDev framework there are three macro-tendencies (*Fouth, Fifth and Sixth* theses), with the latter two characterising countries at first stages of economic development:

1. The demand side is where the major growth bottlenecks unfold;
2. The tendency of wages to increase more slowly than productivity growth;
3. The tendency to cyclical overvaluation of the exchange rate caused by an excessive reliance on external savings in the form

[3] See the website for a full list of scholars supporting such vision: http://www.tenthesesonnewdevelopmentalism.org/

of foreign capital flows and the 'Dutch disease' related to excessively open and unregulated capital markets.

In this framework, the state has the role of designer of macroeconomic policies and national development strategies. Although the 'Schumpeterian side of development' is recognized as important, the NDev framework tends to concentrate on the demand side and macro tendencies in aggregate magnitudes.

In contrast, earlier contributions within the broader *developmentalist framework* assigned major emphasis on micro tendencies and the supply side: specifically to industrial policies as the main tool for shifting developing countries' production structure towards higher value added activities and those paying higher wages and salaries (Johnson 1982; Hall 1986; Dore 1986; Amsden 1989 and 2007; Wade 1990; Chang 1994, 2002 and 2009; Evans 1995; Rodrik 2004; Cimoli, Dosi and Stiglitz 2009). The starting point of this school of thought has been the reconsideration of the 'official' history of capitalism promoted by neoliberals (Chang 2002). From an analytical point of view, this requires the recognition of all those market failures and deficiencies, problems of coordination and information externalities that impede developing countries entering manufacturing development trajectories (Chang, 1994; Stiglitz, 1996 and 2001; Lall, 2004; Rodrik, 2007).

Two main sets of problems and obstacles justifying state intervention have been stressed. The first set relates to those market failures caused by information asymmetries and information externalities that lead to under-investment in new activities. The second set is related to problems of coordination and the possibility of waste of resources. The static as well as the dynamic implications of these market failures must be taken into consideration.

To begin with, we will consider the problems related to underinvestment due to information problem. In developing countries, investment in new non-traditional industrial sectors is strictly limited by capital market failures as well as by the lack of equity markets and of financing resources internal to the firm. Moreover, the market price mechanism does "not provide clear enough indication of the profitability of resources that do not actually exist (e.g. new skills and technology)" (Haque 2007:3). These market failures are particularly pervasive in developing countries since new investments are perceived by private lenders as highly risky (Seffaeldin 2005).

To deal with these problems, the state can intervene in two ways. It can become a direct surrogate for the capital market through the provision of subsidies or venture-capital schemes which help new investors, especially in sectors with high initial fixed cost (Chang 1994). In addition, the state can promote savings accumulation and investments through creating and supporting/controlling financial institutions. The East Asian experience testifies to how government intervention can drive the establishment of a system of flexible bank finance, as Stiglitz (2001) defines it (a system that promotes high saving ratios and introduces alternative forms of risk-sharing through 'bailouts'). Moreover, as Chang (2004:144) underlines, 'state control of the financial sector has been critical […] to influence private sector investment decisions and, more importantly, by giving it the power to discipline the non-performers'.

Secondly, the State can respond to the problem of under-investment through the application of a so-called 'carrot and stick strategy' (Rodrik 2004), as occurred in East Asia. East Asian governments subsidised innovators by guaranteeing them a rent for a limited period of time through trade protection or by facilitating access to venture capital. At the same time, these rents were balanced with strong performance requirements – e.g. export market requirements – and monitoring of firms' competitiveness.

This approach directly addresses the problem of informational externalities and problems of 'appropriability' in the innovation process which drastically affects investment in new activities. Specifically, in the so-called process of 'self discovery' (Hausmann and Rodrik 2004), firms invest heavily in the discovery of new combinations of factors and procedures. These new procedures enable firms to produce the same good already established in the international market in a more efficient way. However, if one firm cannot fully internalise the value of its discovery because of imitation by other firms, or learning by doing or informational externalities, there will be no incentive to sustain the initial investment (Rodrik 2004). In other words, 'market imperfections hinder the full private appropriability of social returns' (Rodrik, 2007:7) leading to a phenomenon of lack of investments or under investment. The 'carrot and stick approach' thus creates the incentives for innovation that are in fact missing from *laissez faire* market interactions.

Having considered the ways in which state intervention can deal with the problem of underinvestment, we will now move on to consider the set of theoretical rationales in favour of state intervention relating to coordination problems that arise in the presence of 'strategic uncertainty' (Chang 1994).

The first problem of coordination is related to the so called 'big push' argument (Roseinstein-Rodan 1955 and 1957). Many sectors and industries require a series of complementary investments in interconnected activities in the early phases of their development. If these investments are not simultaneously undertaken, or firms are not sure that they will be implemented, the profitability of their new activities will be compromised. Clearly the state can coordinate firms' investments through a series of specific subsidies and incentives in order to avoid coordination failure and achieve a higher social benefit. Thus in South Korea, for example, the state designed “ex ante subsidies that [did] not need to be paid ex post” (Rodrik, 2004:14) such as guarantee for new investments in technology.

Another, less immediate, problem of coordination occurs in the presence of ‘competing investments’ (Chang, 1994 and 2003). In modern industries, large firms sustain initial huge investments in machinery and productive capacity in order to achieve efficient scale of production. As these initial costs are generally specific and ‘sunk’, oligopolistic competition in these sectors may lead to price wars that may destroy parts of firms’ assets or may lead them to bankruptcy. Moreover, in new sectors, the impossibility for the market to coordinate ex ante investments may cause problems of under- or over-investments. The state can intervene ex ante in many ways. For example in Japan the state adopted a system of ‘entry licenses’ and in South Korea a ‘conditional entry system’ that artificially tries to ‘clear’ the market adjusting the supply to the evolution of demand (Chang, 1994).

However, collective-action problems may be related not only to investment but also to situations of temporary disinvestment or structural change in the industrial sector. Recession cartels and mechanisms of negotiated exit have been widely used to face periods of economic crisis or accompany structural transformation. In these situations industrial policies introduce “a ‘protective’ element – that is ‘helping losers’ by temporarily shielding them from the full forces of the market” (Chang, 2003:262). More generally, the state can introduce mechanisms of socialisation of risk to encourage and sustain the process of structural change and productivity growth from which economic development derives.

Finally, many studies (Wade, 1990; Chang and Rowthorn, 1995) have also demonstrated how the state can be a powerful 'visible hand'. Specifically, the state can provide the economy with an 'entrepreneurial vision' and of a series of 'focal points' which may help the main economic actors to coordinate. For example the Japanese government, through the MITI (Johnson, 1982; Okimoto 1989), indirectly led the process of mergers and creation of large domestic firms. The state encouraged the rise of powerful industrial groups (keiretsu), which were able to develop technological and business capabilities as well as international brands.

The consideration of market failures, externalities and coordination problems introduces strong rationales in support of industrial policies, that is, the idea that developing countries need effective state intervention "more than a good night watchman" (Rodrik, 2007:7). The justifications for industrial policy reviewed above generally draw from successful stories of industrialisation and from rich comparative analysis of country experiences, focusing especially on policy measures implemented by different countries' governments based on a variety of institutional forms.

While the literature is replete with excellent case studies very few contributions offer a systematic treatment of the set of *structural tensions, institutional bottlenecks and dualisms* characterising manufacturing development trajectories. Very often the analysis of countries experiences do not maintain an analytical separation between structural dynamics triggered by 'disproportional transformations' (within and across production sectors) and induced changes in the institutional matrix. Also structural dynamics tend to be addressed by adopting the same unit of analysis (typically sectors) without recognising the need for a more disaggregated and engineering-based understanding of manufacturing development trajectories[4].

Industrial sectors and production activities tend to be treated as abstract and homogenous entities, while the structural and institutional dynamics generating market failures, externalities and coordination problems are in fact profoundly different within and across sectors. Thus, although apparently more disaggregated, the NDev framework is still too aggregate and is mainly aimed at developing rationales for industrial policy in opposition to the mainstream vision[5].

As stressed by Chang (2009), during the last twenty years the industrial policy debate has been characterised by an 'unproductive confrontation' and the opportunity to advance our understanding of industrial policy to promote manufacturing development has been negatively affected. The following sections will highlight the need to refocus the industrial policy debate on a set of structural and institutional dynamics and will propose two main heuristics for addressing fundamental features of manufacturing development, that is, structural tensions, institutional bottlenecks and dualisms.

2. Disentangling structural dynamics and institutional changes: 'separation' and 'compositional' heuristics

While the mainstream industrial policy discourse (of which the NSE framework is an advanced position) is limited by a theoretical and ideological aversion to industrial policies, among old and new

[4] Charles Babbage's *On the Economy of Machinery and Manufactures* (1832 first edition) represents a pioneering attempt in this direction as stressed by Rosenberg (1994).

[5] Andreoni and Scazzieri (2013) discuss the levels of aggregation at which Keynesian and macroeconomic approaches have addressed problems of aggregation in the analysis of the structural dynamics of production. See Toner 1999 for a review of the main currents in cumulative causation theory.

developmentalists, industrial policy design is limited by the lack of effective analytical lenses for disentangling countries' manufacturing development trajectories.

The following sections of this essay will show how the design of effective industrial policies would benefit from maintaining a *separation between structural and institutional dynamics*. This separation would allow an 'economics-engineering twist' to operate, through which, given a certain economic system, structural dynamics are considered independently from institutional conditions. Such an approach allows us to look at the structural dynamics from within production structures without imposing any conditions at the institutional level. This means that institutions may take different forms in the fulfilment of certain institutional functions in the development process.

At the same time the consideration of a multiplicity of production units allows us to *recompose the structural and institutional dimensions* and to design industrial policies operating at different levels of aggregation of production activities. The consideration of a mix of separation and compositional heuristics allows to address those structural tensions, institutional bottlenecks and dualism that characterise countries' manufacturing development trajectories.

2.1 Structural tensions, institutional bottlenecks and dualisms

Structural tensions are the core of Albert Hirschman's dynamic view of economic development. He famously stated that, "if the economy is to be kept moving ahead, the task of development policy is to maintain tensions, disproportions and disequilibria. That nightmare of equilibrium economics, the endlessly spinning cobweb, is the *kind* of mechanism we must assiduously look for as an invaluable help in the development process" (Hirschman 1958:66).

Structural tensions and, thus, disproportional dynamics within and across sectors, are generated by a number of factors: rigidities and indivisibilities in production structures (Young 1928; Kaldor 1985); complementarities among production tasks but also in consumption patterns (Young 1928; Perroux 1955; Hirschman 1958; Myrdal 1958; Dahmen 1989); horizontal and vertical externalities (Scitovsky 1954; Chenery 1959); adjustment lags, shortages and surpluses, differentials in the elasticity of demand and supply (Rosenstein-Rodan 1957); disproportional variations in technological coefficients and technological (or structural) unemployment (Pasinetti 1981; Balogh 1982; see also Essay 2 and 3).

Thus structural economic dynamics underlie structural tensions, that is, the continuous unfolding of constraints in the material/technological side of production, within and across sectors. Dahmen's (1989:138) treatment of structural tensions assigns particular emphasis to *complementarities* among production activities and the fact that "economic success at certain stages [...] may lead to a depressive pressure in stages which are premature as long as the complementary ones are missing". The structural tensions triggered by the introduction of the flying shuttles in the British textile industry in 1730s and the consequent acute shortage of yarn that, in turn, introduced innovative techniques and overproduction problems solved at the end of the century with the mechanical loom are all cases in point (see section 2.2 for further details). For more recent examples of these structural tensions and resulting disproportional dynamics we can look at the productivity paradoxes (slow productivity growth despite rapid technical change) appeared with the breakthrough of electricity in industry or the application of computers and robots in the 1980s (David 1990; Schon 2000).

With few exceptions, those authors who focus their attention on the structural tensions triggering structural economic dynamics (or structural change) tend to underestimate the fact that there is an *interplay between these structural dynamics and the institutional transformations* of economic systems. This means that, in order to resolve a certain structural tension generated by the existence of a certain structural constraint (e.g. indivisibility), both a structural reconfiguration in the material/technology of production and a transformation within the institutional matrix of the economic system become necessary.

The presence of *institutional bottlenecks* may constitute an obstacle to structural dynamics. However institutional transformations may also enable the unfolding of feasible structural dynamics of manufacturing development[6]. In this second case, structural tensions become opportunities for change. As stressed by Dahmen (1989:138), "the number and importance of such opportunities and the extent to which they are seized depend on the quality of entrepreneurship as well as on 'institutional' factors such as characteristics and functioning of labour markets".

Probably the most well-known example of the interplay between structural dynamics and institutional transformations is the one provided by Alexander Gerschenkron (1962: especially chapter 5). A century ago, when Germany was attempting to catch up with Britain, production technologies available were more capital- and scale-intensive than those that had been discovered when Britain underwent its first round of industrialisation some fifty years before. Thus,

[6] The evolutionary economics literature sees institutional change as necessary for the successful exploitations of new technologies, the latter being the main driver of economic growth and structural change (e.g. Nelson 2005). However the interplay between structural tensions arising in multiple dimensions of economic systems and institutional bottlenecks is not discussed.

Germany had to develop new institutional instruments for which there was "little or no counterpart in an established industrial country" such as coordinated investments, vertically integrated production units, and a financial sector which was transformed in its institutional form and functions[7].

A similar transformation of the banking sector on the German model was also a key factor in the industrialisation of Italy between 1881 and 1913. The two main institutional innovations of German banking imported in Italy, by the *Banca Commerciale Italiana* established in 1884 under German leadership and with German capital, were (Gerschenkron 1955:375): firstly, "to maintain an intimate connection with an industrial enterprise and to nurse it for a long time before introducing it to the capital market, which as often as not meant placing its stock among the bank's own clients"; secondly "to discipline production of industrial branches, which bland phrase meant reduction or abandonment of competition in favour of various monopolistic compacts" (see also Quadrio Curzio and Fortis 2012).

The likelihood and the speed of catching up depend on a country's capacity to overcome the structural tensions as well as institutional bottlenecks. As stressed by Dahmen (1989:111), '[a] retardation in eliminating a structural tension [...] may be caused by institutional factors such as resistance of groups with vested interests, monopolies, government regulations and legal framework'[8].

This idea that manufacturing development is a conflictual process in which the distribution of power among interest groups as well as the institutional matrix may constitute bottlenecks is also articulated in Kutznets (1966 and 1973) and in Kalecki (1976). In his

[7] See Essay 2 on the different forms of production organisation and their different responses to structural constraints and opportunities.

[8] On this point see also Abramovitz's (1986) notion of technological congruence and social capability (see also Essay 1).

analysis of modern growth patterns, Kutznets notes that structural shifts require "shifts in population structure, in legal and political institutions, and in social ideology. [Not] all the … shifts in economic and social structure and ideology are requirements, [but] … some structural changes, not only in economic but also in social institutions and beliefs, are required without which modern economic growth would be impossible" (Kutznets 1971, p. 348). In Kalecki's analysis of underdeveloped economies the supply bottleneck in the agricultural sector is in fact determined by an institutional bottleneck, that is, the class structure of the rural area.

Different historical contexts involve myriad manufacturing development trajectories because of the various methods by which it is possible to deal with *structural tensions* (that is, transforming structural constraints in opportunities through institutional action). Additionally there are also multiple methods for overcoming *institutional bottlenecks*.

Such a variety of manufacturing development trajectories tend to generate various forms of *dualism* within and across countries (Lewis 1954; Spaventa 1959). While Arthur Lewis's dual model of development mainly focused on the transfer of labour surpluses to modern sectors and the connected virtuous circle of investment and profits within a given country, Luigi Spaventa (1960:1077) provided a more general conceptualisation of dualism as 'a dynamic process of cumulative differentiation' (see also Prebisch's dependency theory 1949 and Dobb's historical analysis 1951).

Spaventa's (1959; 1960:1077) two-sector model investigates those "distortions which might occur in an unplanned growth process and which result in cumulative differentiation of two parts of an economic system […] only separated by economic – not by physical – barriers". In particular the model attempts to identify those 'structural factors' that prevent: (i) the excess labour force from being absorbed by capital accumulation and (ii) a growth process from spreading across regions within the same country (Italy is presented as a representative case).

Three main factors are identified: firstly, the negative effect of inter- (or intra-) national trade on the *size of the market* for countries (regions) at early stages of manufacturing development (e.g. the South of Italy[9]).

Secondly there is the issue of the *imbalance* between demand for new commodities and production capacity in the most disadvantaged region of a dualistic economy (the new commodities being produced by the most advanced region very often with little or no flexibility of technical coefficients).

Thirdly there are problems related to *technological discontinuities*. As some countries have "been the leaders in the process of growth and, so to speak, the makers of technical progress", they "have not missed a single step in the technical evolution" (Spaventa 1959:433). In contrast, for others, "where growth has started later, often much later, there is no such gradual evolution […] Newly introduced industries adopt modern and highly capital intensive methods of production and demand 'jumps' to some of the more advanced commodities produced in more developed countries at a still very early stage of development of the system" (Spaventa 1959: 433).

Each identified factor operates through an interplay between the structural economic dynamics of supply and demand, and transformations occurring (or not) within the institutional matrix of the dual economic system. As a result, each factor may lead to the long-run coexistence (and often deepening) of different forms of dualism,

[9] See also Prebisch 1949 and Pasinetti (1981:259) who pointed out how "the primary source of international gains is international learning (not international trade)".

sometimes in terms of sophisticated production structure, sometimes in terms of demand composition, finally in terms of institutional forms or fulfilled functions.

An historical account of the various forms of dualism affecting individual backward areas of Europe after the WWII may be found in Ingvar Svennilson's *Growth and Stagnation in the European Economy* (1954). Although Svennilson is mainly concerned with the 'very large divergences in the long-term growth of various national units' (1954:41), dualisms are not addressed within a macro-aggregate framework. Instead countries divergences find explanation in structural tensions and institutional bottlenecks in specific industries and regions. For example falling-behind processes are associated with resistance to road transportation and electrification or to the retarding role of old capital in the struggle against the development of water power (Chapter 6). On the contrary catching up processes are associated to the structural opportunities offered by technological diffusion and creative imitation across a 'multi-dual Europe'.

The above selection of mainly historical contributions have explicitly highlighted the existence of an interplay between structural economic dynamics and institutional transformations. This is particularly remarkable if we notice how many paradigmatic mainstream contributions such as North's *Structure and Change in Economic History* (1981) do not do this, instead conflating structural and institutional change. This means that mainstream economic history fails to account for shifts in the production structures, structural tensions, institutional bottlenecks and pervasive forms of dualism.

From an analytical point of view, we might now ask what kind of heuristics are most suitable to disentangle such a complex set of interactions (particularly with a view to informing policy design for manufacturing development). The next subsection addresses this question and provides a set of what we have called here 'separation heuristics' and 'compositional heuristics'. The former allow policy-makers to set benchmarks for industrial policy design while the latter allow them to identify the targets for these benchmarks.

2.2 Separation and compositional heuristics for industrial policy design

To being with, the issue of setting benchmarks: from an analytical point of view, the possibility of maintaining a separation between structural economic dynamics and institutional transformations is at the very core of Luigi Pasinetti's *pure labour model* (1981 and 1993). The following passage is worth quoting at length as it presents in a compact way the three steps of his approach (structural analysis, institutional problem identification and institutional action) and, thus, the need for separation heuristics (Pasinetti 2007: 322):

> *"Here is where the separation theorem really comes to help – an analytical device to face complexity with a maximum of freedom and a minimum of self-imposed restrictions. 'Free' sectors, 'regulated' sectors, the way the 'free' sectors may need to be regulated, and 'regulated sectors' may require to be deregulated, with reference to the evolving historical events, are all subjects to be open to non pre-imposed constraints. The separation theorem suggests separating the investigation of those characteristics that lie at the foundation of the production economies…from the investigation of the institutions necessary to deal with the particularities, in time and space, of the specific problems which are constantly raised by the 'challenge of history'".*

Pasinetti's main point here is that structural economic dynamics (the ones operating at the 'foundation of the production economies') **"**set the boundaries and avenues within which institutions can operate" (Pasinetti 2007:327). Drawing from his historical reconstruction of manufacturing development trajectories, Nathan Rosenberg (1963:440) seems to have reached the same methodological conclusion when he stated that:

> *"an analytical explanation of many of the technological changes in the manufacturing sector of the economy may be fruitfully approached at the purely technological level. This is not to deny, of course, that the ultimate incentives are economic in nature; rather, the point is that complex technologies create internal compulsions and pressures which, in turn, initiate exploratory activity in particular directions".*

The possibility of conducting an analysis at the foundational level (à la Pasinetti) or at the purely technological level (à la Rosenberg) allows us to identify a set of conditions at the structural/material/technological level that regulate the structural dynamics of production independently from institutions. They are:

(i) a set of macro-economic requirements, as stated in Pasinetti's pure labour model;

(ii) physical, chemical and biological laws regulating the production process in terms of time, space and proportionality requirements;

(iii) properties of materials in use, tolerance thresholds of mechanical artifacts, bottlenecks in production structures and indivisibilities;

(iv) types of complementarities (e.g. horizontal versus vertical, static versus dynamic) and interdependencies among industries and among production tasks within industries.

Overall these macro and industry-specific conditions determine the *benchmark of structural feasibility* that policy makers have to take into account in the design of their industrial policy package. This benchmark is obtained by applying *separation heuristics*. Given a certain benchmark of structural feasibility (and, thus, the need for specific institutional functions to be fulfilled), a plurality of institutional forms will develop in different historical contexts. Institutions are the domain in which structural tensions play out since, through institutional transformation, certain structural tensions can be resolved and institutional bottlenecks removed.

Thus separation heuristics provide policy makers with a set of structural conditions that have to be satisfied given certain policy goals (e.g. the development of a certain industrial sector) and also an analytical device for disentangling the interplay between structural economic dynamics and institutional transformations. However, the benchmark conditions that separation heuristics allow us to identify are not sufficient per se as in any given historical context. We also have to identify the targets for policies based on such benchmarks.

The structural/material/technological conditions listed above do not form abstract relationship operating in a vacuum. Instead they work at specific levels of aggregation of production activities. As the historical examples presented in section 2.1 have shown, a certain structural tension or institutional bottlenecks may originate at the level of the economic system as whole, at the level of an industrial sector as well as at the level of the single establishment[10].

Compositional heuristics refer to the specific levels of aggregation of production activities (i.e. *production units*) at which the above listed structural/material/technological conditions have to be satisfied and at which certain institutional functions fulfilled. The latter will be fulfilled by the most viable institutional forms given the historical context. According to the industrial policy goal and the stages of industrial development of an economic system, different compositional heuristics (thus, different production units) acquire different relevance.

Different scholars have proposed different compositional heuristics for understanding the structural dynamics and institutional transformations of industrial economies at different levels of disaggregation. Relevant levels of disaggregation include: production establishment, constellation of establishments, production tasks (i.e. specialised production activities in increasingly vertically disintegrated sectors - VDSs), industrial districts, production systems, development

[10] Andreoni and Scazzieri (2013) identify different increasing and decreasing returns trajectories originated by the unfolding of structural opportunities within different production units.

blocks, growth poles, industries, sectors, the economic system as a whole. Most crucially, as stressed by Dahmen (1989:137), "[p]utting transformation in the centre means focusing on what is changing the content of broad aggregates. The interest is in *changes through time, within and among micro entities*. Such changes, being much of the essence of *industrial dynamics*, imply disequilibria which should not be called disturbances because they are essential in transformation processes".

The way in which economists have generally linked changes in micro entities with broader industrial dynamics at the level of the economic system has been to adopt sectors or sub-sectors (industries) as main units of analysis[11]. It is not surprising then that almost all industrial data are collected for sectors and industries as if they were the unique level of aggregation of production activities. However, as stressed by Rosenberg (1963:422), sectors (and to a less extent sub-sectors) are compositional heuristics that very often hide more than reveal structural economic dynamics and institutional transformations (as well as their interplay).

> *"it is necessary to discard the familiar Marshallian approach, involving as it does the definition of an industry as a collection of firms producing a homogenous product- or at least products involving some sufficiently high cross-elasticity of demand. For many analytical purposes it is necessary to group firms together on the basis of some features of the commodity as a final product; but we cannot properly appraise important aspects of technological developments in the nineteenth century until we give up the Marshallian concept of an industry as the focal point of our attention and analysis. These developments [rapid technical change in the American production of machine tools] may be understood more effectively in terms of certain functional processes which cut entirely across industrial lines in the Marshallian sense…" (Rosenberg 1963:422).*

[11] Pasinetti and Spaventa (1960) is a classical contributions stressing the importance of going beyond the neoclassical aggregative approach and considering different compositional heuristics, in their case a multi-sectoral modeling able to account for disproportional changes in productivity and long-run economic growth.

Structural constraints and related structural tensions, learning opportunities and institutional bottlenecks are very often not simply a sectoral (or sub-sectoral) phenomenon. The adoption of production tasks or complementary activities as compositional heuristics highlight how structural tensions caused by disproportional dynamics are pervasive not only across sectors but also *within sectors and across set of complementary production activities.* This has profound implications for industrial policy design as the target of the policy will be identified according to the compositional heuristics adopted (for further details see section 3).

Modern manufacturing systems have witnessed the emergence of two overlapping tendencies. Firstly, as stressed by Stigler (1951: 190), "[i]f one considers the full life of industries, the dominance of vertical disintegration is surely to be expected". This tendency of high-tech supply chains to experience vertical disintegration makes *production tasks* a fundamental unit of analysis for industrial policy design. At this level of disaggregation of production activities (that is, specialised production activities in VDSs), the set of structural/material/technological conditions as well as the institutional bottlenecks may be identified by adopting appropriate separation heuristics.

While vertical disintegration is dominant, a very high degree of specialisation has been achieved. This is because of a second tendency within modern manufacturing systems. Very often there is a complex bundle of interlinked firms capable of performing a set complementary production activities behind the capacity to perform certain 'difficult production tasks'. And of course production tasks in VDSs that are 'difficult to do' or 'difficult to reproduce' allow countries to capture high value.

This second tendency registered in modern manufacturing system is well described by Tassey (2010:6) when he argues that: “Most modern technologies are systems, which means interdependencies exist among a set of industries that contribute advanced materials, various components, subsystems, manufacturing systems and eventually service systems based on sets of manufactured hardware and software. The modern global economy is therefore constructed around supply chains, whose tiers (industries) interact in complex ways”. Dahmen’s concept of a *development block* is a powerful compositional heuristic for capturing various forms of complementarities linking a set of innovative production activities (or specific tasks) across and within manufacturing systems and countries.

According to Dahmen (1989:132) the development block “refers to a sequence of complementarities which by way of a series of structural tensions, i.e., disequilibria, may result in a balanced situation”. The emergence of development blocks may be either the result of ex-post ‘gap filling’, whereby a structural tension or institutional bottleneck is solved, or the result of an ex-ante ‘creation of markets’ by coordinated entrepreneurial activities or ‘economic planning’ by government institutions. As documented in the history of the steel industry (Dahmen 1989) or in empirical analysis of other Swedish industries (Enflo et al. 2007 adopt cointegration analysis), development blocks trigger cumulative dynamics of regional differentiation in technological and other factor endowments. Thus, this compositional heuristics is particularly suitable for analysing another key features of capitalist economies, that is, the pervasive presence of various forms of dualism.

The profound implications of adopting separation and compositional heuristics in industrial policy design for manufacturing development are the subject of the next section.

3. Expanding the industrial policy space: selectivity, matching and alignments over time.

The adoption of both separation and compositional heuristics allows us to expand the *industrial policy space* currently visualised by policymakers, identifying hierarchical principles through which policy measures can be sequentially coordinated. Industrial policy consists of a set of *sequentially coordinated selective measures addressing structural tensions, institutional bottlenecks and various forms of dualism* that impede the economic system from entering certain trajectories of manufacturing development. The analytical approach envisaged here suggests industrial policy thinking to be organised along three axes: selectivity, matching and alignment over time.

3.1 Selectivity: to pick or not to pick, that is not the question.

The issue of 'selectivity' has probably been the factor which has contributed most to the polarisation of the industrial policy debate. The extent to which policy measures should (or should not) favour particular sectors or even particular companies (the so called 'picking winners argument') has been extremely controversial.

Those who believe that industrial policy should be *general* (also called 'functional' or 'horizontal') argue that the state should not distort resource allocation resulting from the price system. Instead the state should facilitate the functioning of the market by enriching the environment in which it operates with investment in infrastructure, general education and basic research. This enhancement of the general endowment of the economy is not expected to have any discriminatory effect between companies or between sectors. Thus "stressing that industrial policy fosters productivity competitiveness or creates favourable general conditions for firms lays the foundation for a *horizontal approach*" (Aiginger and Sieber 2006: 582).

In contrast, those supporting *selective* (also called 'sectoral' or 'vertical') policy measures tend to stress how the very definition of industrial policy implies an element of selectivity. They argue that industrial policy always involves making choices about the specific manufacturing development trajectory that the country (or region) should follow. This can be done by selecting specific *policy targets* such as picking 'high value added' industries or channelling financial resources in specific activities, for example in basic research or specific engineering education programmes. All the following definition of industrial policy contains an element of selectivity:

> *'a policy that deliberately favours particular industries over others, against market signals, usually (but not necessarily) to enhance efficiency and promote productivity growth' (Chang, 2009; see also Chang 1994:58)*
> *'I will use the term [industrial policy] to apply to restructuring policies in favour of more dynamic activities generally, regardless of whether those are located within industry or manufacturing per se' (Rodrik 2004:3)*
> *'comprises policies affecting 'infant industry' support of various kinds, but also trade policies, science and technology policies, public procurement, policies affecting FDI, IPRs and the allocation of financial resources' (Cimoli, Dosi and Stiglitz, 2009:2)*

Those embracing a selective approach also stress how the distinction between general and selective measures is actually a fictitious one, since even supposedly 'general' measures imply some trade-offs[12]. This point has been highlighted by Landesmann (1992:245 italics added) when he argues:

> *"Industrial policies are targeted towards increasing national wealth and they thus open up positive sum options from which everybody could gain. In actual practice, however, industrial policy are designed to be specific, i.e. directed towards particular industries, firms, regions, groups in the labour market, etc., rather than general. Even in those cases in which they are general (such as general tax allowances), they have a differential impact upon different parts of, and actors in, an economy. Implicit in industrial policy formulation and execution are … trade-offs between different groups, regions, industries, etc."*

[12] Even the *matrix approach to industrial policy* (EU 2002-2006) acknowledges that "the effects of broad horizontal policies can vary significantly from industry to industry, that competitiveness needs specific policy mixes for specific sectors, and that some sectors may require complementary measures that are not necessary or relevant in other sectors" (Aiginger & Sieber, 2006:582)

Interestingly even the lack of industrial policy is an implicit form of selective intervention. A country that refuses to adopt any industrial policy is implicitly accepting the current structural configuration of its economic system, the pervasive presence of market failures, the current distributions of learning opportunities across sectors, the presence of structural tensions, institutional bottlenecks and regional dualisms[13].

Now if we accept the case for industrial policy being inherently selective, the problem is to increase its *effectiveness* by improving and refining the degree of selectivity of the implementable policy measures. The more selective policy measures are, the more they will be able to: (i) remove structural tensions by tackling structural constraints and transforming them into opportunities; (ii) trigger those institutional transformations (in forms and functions) that are necessary at a certain stage of economic development and in a given historical context; (iii) capture learning opportunities nested in specific production tasks within VDS; (iv) remove those specific forms of dualism that impede economic growth spreading across regions. Separation and compositional heuristics are aimed exactly at increasing the degree of selectivity and, thus, the effectiveness, of industrial policies.

As discussed above (section 2.2), we can improve selectivity of industrial policies that promote manufacturing development by making use of a combination of separation and compositional heuristics. Separation heuristics can be used for disentangling structural dynamics and institutional changes at different levels of aggregation of production activities, the latter identified by compositional heuristics.

The combined use of these heuristics is best understood through an example. Analyses *à la Smith-Young* have stressed how the

[13] As stressed by Chang (2002) this implies that a country which is purposefully convincing other countries that 'the best industrial policy is no industrial policy' is in fact implementing a form of industrial policy itself.

"division of labour depends upon the extent of the market, but the extent of the market depends upon the division of labour". This means that specialisation in specific production tasks and expansion of overall demand are linked by a cumulative process subject to increasing returns (Young 1928; see also Stigler 1951). However the possibility for an economic system to experience increasing specialisation and expansion of the overall demand is affected by a series of both structural tensions and institutional bottlenecks. If the size of the market is limited, firms will not find it profitable to specialise in production tasks as investment in specialised machinery and equipment introduces structural constraints (indivisibilities) and is dependent upon complementary investments by other firms. The size and composition of demand may in fact impede the development of certain production activities.

In order to be effective, industrial policies addressing such problems have to maintain a distinction between those structural tensions that are generated at the structural/material/technological level (e.g. indivisibilities or complementarities) and those that are actually the result of a certain institutional bottleneck (e.g. the composition of demand determined by income distribution; the resistance of certain interest groups in the emergence of new sectors or in complementary investments; trade openness) and be selective in an appropriate way. Moreover, policy makers have to evaluate if these structural tensions and institutional bottlenecks may be also present at different levels of aggregation of production activities. For example, indivisibilities at the plant level may not exist at the industrial district level; opposition to certain complementary investments may be solved by promoting a mix of ex-ante development blocks and negotiated exit/capacity scrapping; specialisation in certain high value production tasks for which there is high international demand and for which the need for local complementary investments is limited might also unlock the development of certain industries.

The application of a mix of separation and compositional heuristics also allows policy makers to move from 'picking sectors' to 'picking production tasks' by offering value propositions to international investors. This requires reducing particular structural tensions by the strategic promotion of complementary investments in certain production tasks within global value chains. It also requires the strategic removal of certain institutional bottlenecks such as investment in certain enabling technologies. All these measures may aim to have a direct impact on the *Schumpeterian dynamics* of supply and technological innovation, but also an indirect one by acting upon the *Keynesians dynamics* of effective demand. In this second case, instead of supporting an undifferentiated expansion of the overall demand, industrial policy might selectively stimulate sector (or production task) specific demand by public procurement, income policies and trade policies.

Further analysis is necessary to better understand how these heuristics can be used to deal with the problem of dualism which is a central issue in our analysis of the Italian dependent industrialisation experience. Here separation and compositional heuristics aim not only at disentangling structural economic dynamics and institutional change but also at identifying those structural/material/technological features that make certain manufacturing industries more developmental than others. In fact dualism is a phenomenon originating not simply from agricultural versus industrial development, but also one resulting from specialisation in certain high-potential versus certain low-potential manufacturing industries.

3.2 Matching and alignment over time

For each multi-sectoral economic system, development trajectories follow *relative invariance paths* which, in turn, are responsible for disproportional structural dynamics as well as *mismatches* within and across the structural and institutional realms. Any given economic structure is defined "in such a way that certain elements of it are considered to be fixed while other elements are allowed to change" (Landesmann and Scazzieri 1990:96). In other words, *not everything changes at the same time*. In fact it is precisely the resilience of certain structural relations or conditions (e.g. particular kinds of capital equipment), as well as of certain institutions, that make the economic system able to absorb changes and prepare the ground for subsequent transformations (Simon 1962; Hagemann and Scazzieri 2009).

Thus, at each point in time, in any given economic system, highly dynamic industries coexist with less dynamic ones, while certain traditional institutional forms and functions coexist with more innovative ones. This is why, at each point in time, we will observe structural tensions (that is, mismatches among different production activities and their mutual requirements) as well as mismatches between certain structural/material/technological features of the economic system and its institutional matrix. Moreover, mismatches among institutions assuming different forms and fulfilling different functions will also characterise the economic system at each point in time.

The principle of *relative invariance* postulates that "any given economic system subject to an impulse of force is allowed to change its original state by following an adjustment path that belongs to a limited set of feasible transformations. [The latter] is the consequence of both the characteristics of certain elements of an economic system that are taken as constant and certain patterns of interrelationships among the different components that are assumed as invariant in the structural specification of the system" (Landesmann and Scazzieri 1990:96). Thus, as soon as we introduce time, not only will we find that not everything changes at the same time but also that changes will unfold in an ordered way. Namely, the economic system will transform in a 'time-differentiated' way, that is, according to a specific *hierarchy of change* whereby structural dynamics trigger (but also are made possible by) institutional changes[14].

The fact that the economic system transforms according to a certain hierarchy of change and that structural economic dynamics and institutional changes require different time frames to work themselves out introduces the problem of *misalignments*. With the expression mismatches we focused on the interdependencies among production activities at each point in time. The expression misalignments, in contrast, refers to interdependencies (in particular complementarities) among production activities over time[15].

The problem of alignment over time of structural dynamics and institutional changes is well illustrated by the case of technological (also called structural) unemployment. Achieving full utilisation of available labour is particularly difficult as the economic system enters an accelerating process of structural change and is thus based on manufacturing industries characterised by extremely dynamic

[14] This analytical point is at the core of the *sequential analysis* initiated by Knut Wicksell study of cumulative processes and followed by other scholars. For example, Gunnar Myrdal (1939:27) stressed how cumulative processes imply "not only certain causal relations [between the different price levels] but also a *given order of sequence in their movements*". Looking at the transformation of production structures, John Hicks (1946:283) highlighted how certain "repercussions of economic change take sometimes to work themselves out" not because of "slowness of communication of or imperfect knowledge" but because of delays, time lags and technical duration in production processes. See Baranzini and Scazzieri (1990).

[15] Classical economists analysed structural dynamics mixing the two problems and, thus, by considering a combination of horizontal structures (industry interdependencies within any single time period) and vertical structures (industry interdependencies over time). See Scazzieri 2012.

technological and organisational changes. This is because a certain amount of labour (i.e. producers' capabilities) will become obsolete and, thus, redundant with economic development. The existence of mismatches and misalignments over time both 'within' and 'across' the structural and institutional domains may cause severe social and economic problems such us unemployment, underutilisation of production capacity and a lack of economic dynamism.

The existence of mismatches and misalignments over time is a strong rationale in favour of industrial policy. Their consideration leads also to the consideration of two problems that policymakers have to address:

(i) given a plurality of policy targets, picking the right *policy mix*, that is a 'package of interactive measures' (Stiglitz 1996) designed through a combination of separation and compositional heuristics (see above);

(ii) given a certain hierarchy of change, picking the right *time horizon* in policy implementation and being able to *align policies over time*.

Matching and aligning industrial policy measures over time is not trivial as policymakers have to consider a plurality of policy targets and relative trade-offs among them over time. As Landesmann's (1992:242) analysis of Scandinavia countries has shown, these countries ended adopting an 'interesting mix of both defensive and constructive policies' in order to tackle structural tensions, institutional bottlenecks and the unavoidable emergence of dualisms. Similarly Chang (2009:29) stresses how, "in East Asia, free trade, export promotion (which is, of course, not free trade), and infant industry protection were organically integrated, both in cross-section terms (so there always will be some industries subject to each category of policy, sometimes more than one at the same time) and over time (so, the same industry may be subject to more than one of the three over time)' (see also Johnson 1982; Dore 1986; Amsden 1989; Wade 1990; Chang 1994; Stiglitz 1996). The extent to which a certain policy mix is effective in addressing mismatches depends upon policymakers' capacity to design and implement measures operating at different levels of aggregation of production activities in this fashion.

Given the fact that industrial policies in most cases do not have an immediate impact, the effectiveness of policy measures will critically depend upon policy makers' capacity to identify (and eventually try to defy) the hierarchy of change imposed by existing structural and institutional conditions (see above). Also, as the policy measures will operate and benefit (or damage) different groups in a non-simultaneous fashion, new conflicts among and within classes will emerge. Interestingly, as Landesmann (1992:246 italics added) stresses in the specific case of Scandinavian countries, "[s]ocial corporatism has the problem not only of finding a *consensus (or a mode of conflict resolution) between classes*, but also of building on a consensus within classes. At least it has to show that it can successfully provide the framework to *mediate between different segments of the same class* and thus avoid open conflict" (see also Chang 1994b). Conflicts between agricultural rentiers and industrialists, industrialists and financiers, or among industrialists operating in different manufacturing industries are among the most crucial institutional bottlenecks impeding countries from entering certain manufacturing development trajectories which would be otherwise feasible from a structural point of view.

If the *conflict resolution function* of the state is related to the need to remove institutional bottlenecks or elements of inertia in production structures, its *entrepreneurial function* is associated with the need to provide “a focal point around which economic activities may be organised in times of major economic change” (Chang 1994b:299). The problem of providing focal points (i.e. providing an overall vision to orientate individual economic actors) by aligning a series of policy measures over time is not simply a problem of shifting the economic system from one configuration (or equilibrium point, in neoclassical terms) to another. Instead, if we fully embrace the idea of a continuous interplay between structural economic dynamics and institutional transformations, the economic system will be in a never-ending condition of disequilibrium. Within this framework industrial policies will be necessary for addressing at different stages of development (not just underdevelopment!) various structural tensions, institutional bottlenecks and dualisms.

4. *Cathedrals without pillars* in the Italian Mezzogiorno: a case of ‘dependent industrialisation’

In 1960 Luigi Spaventa (1960: 1077 italics added) described Italy as a country whose economic position “is *in between* that of an underdeveloped and an advanced economy […] Though the initial ‘big push’ took place later than elsewhere, the Italian economy as a whole has been growing at a good, and often rapid pace over the past eighty years or so. [However] there has been some growth in the South only in recent years and only owing to heavy public intervention…”.

During the two decades after the Second World War, the persistent dualist character of the Italian economy as well as the problems encountered by the central government in boosting the industrialisation of the South (the so called ‘Mezzogiorno’) attracted the attention of many international development economists. Many seminal articles on Italian development were written including Roseinstein-Rodan’s paper on programming (1950), Gerschenkron’s analysis of the Italian big industrial push (1955) and Chenery's (1962) evaluation of development policies for the South. Later a number of Italian economists such as Spaventa (1959), Napoleoni (1961 and 1985) and Graziani (1965) investigated various forms of dualisms in the Italian industrialisation experience.

Although the Italian debate on manufacturing development and dualism started during the Enlightenment (see note 1) and was developed to a remarkable extent in the works of Antonio Gramsci, Gaetano Salvemini and Francesco Saverio Nitti (the so called *Meridionalisti*), at the end of the WWII the idea of economic (in particular industrial) planning was seen with a certain scepticism, sometimes suspiciously or even with fear as in the case of *Confindustria* (the National Association of Industrialists). The words of Palmiro Togliatti (general secretary of the communist party in that period) capture something of this atmosphere: "the request of a national economic plan at this moment […] is utopian […] even if we were in power alone, we would rely on the private initiative for the reconstruction of the country as we know that there are certain tasks for which the Italian society is not ready" (Togliatti 1945; ref in Graziani 1972: 111-13, my translation).

Just a few years later, in 1947, the famous *Montagnana proposal* was put forward to add an article in the Italian Constitution specifically mentioning planning. The proposed draft ran: "in order to guarantee the right to labour, the state will intervene to coordinate and direct productive activities in view of maximising the returns for the collectivity" (ref in Costabile and Scazzieri 2012:750). However this idea found strong opposition among liberals and catholics[16]. In contrast, during the same years, England adopted the 'Beveridge Plan' (1944),

[16] On the contrary the Marshall Plan, in particular the Country study of ECA for Italy stated the need for a national economic plan for reconstruction.

France the 'Plan de modernisation et d'equipment' (1946) and in Netherland a central planning was created under the direction of Jan Tinbergen (Wellisz 1960; Hall 1986). Thus it is not surprising that, in Chenery's (1962:516) evaluation of development policies for Southern Italy, the 1950s were described as a decade of 'intervention without planning'. Interestingly the strong opposition towards any industrial policy package for the South were only overcome in 1957 with the Treaty of Rome which established the European Economic Community.

After having analysed the first ten years period after the WWII, the next section will apply the analytical lenses developed in the first part of this essay to interpret the subsequent phases of industrialisation of the Italian Mezzogiorno.

4.1 Intervention without planning, 1950s

In 1951 with a population of eighteen million people, Southern Italy registered a per capita income somewhat below the Latin American average. Moreover, the level of industrial development of Southern Italy (measured by its industrial output) was below even that of countries with similar income levels. The ratios of actual to the predicted levels were 1.21 for primary production and 0.84 for industry, with few exceptions (Chenery 1962:518; see Table 1).

In this context the *Cassa per il Mezzogiorno* (Cassa), a development bank set up in 1950 with the strong support of the US Government (USAID), as well as the *Schema di sviluppo della occupazione e del reddito del decennio 1955-1964*, better known as 'Schema Vanoni' created in 1954, were mainly aimed at reducing differences in consumption and income levels within the national economy.

During the 1950s, government interventions were articulated across two main axes: an agrarian reform (passed in 1950) and a sustained investment in infrastructural development aimed at increasing existing production activities. From 1950 to 1959, the agrarian reform absorbed 60% of all the resources distributed by the Cassa, while infrastructural development the remaining 40% (among which water supply and sewage disposal 13.1%, roads 12.2%, railways and shipping 7.5%, and mountain basins 4.3%)[17]. The key result achieved by these measures was the progressive dissolution of the so called 'historical block' which had exercised an hegemonic power on the Southern Italy since its unification (Gramsci 1947). They managed to prepare the subsequent stage of industrial development by transforming the South from an exporter mainly of labour to an exporter of agricultural goods (Ackely and Spaventa 1962; Del Monte e Giannola 1978).

Thus, the first result was the removal of a fundamental institutional bottleneck which had been responsible for the increasing dualism between the South and the North of the country since its unification (the dominance of the traditional class alliance). The second result was to remove a series of structural tensions, primarily in the agricultural sector, by massive investment in infrastructure and expansion of the production capacity of primary commodities (see Table 1).

If we compare industrial output in 1951 and 1959, it becomes clear that the industrial development of Southern Italy remained relatively limited. As observed by Chenery (1962:520-23) "[b]y 1959 the deviation in non-metallic mineral products was eliminated, but the pattern of specialisation in the remaining sectors showed little changes […] It has a relatively small share of national production in the sectors

[17] Bilancio 1959-60.

that have contributed the bulk of the increase in [national] exports [and] produces commodities having lower income elasticities of demand". Given the policies applied these results are not surprising.

Until 1959 the Cassa and the *Schema Vanoni* assigned little importance to the industrial development of Southern Italy. In fact the Cassa's measures to promote industrial development were limited to tax incentives and loans at lower interest rates. At the end of the decade it was estimated that only 25% of the Cassa's investments in the *Mezzogiorno* had a direct effect in commodity production (Di Simone 1960).

The Treaty of Rome in 1957 represented a first turning point in the industrial development of the South, but at the same time the beginning of a phase of what we have called here of dependent industrialisation (see below). Before describing the first decade of 'dependent industrialisation' experienced by Southern Italy, it is important to highlight three precursors of a series of problems that will characterise the phase of dependent industrialisation of the 1960s.

Table 1: Actual and Normal Value Added by Sectors in Southern Italy, 1951-1959 (in dollars per capita)

Sector	1951			1959		
	Actual Value Added [1]	Normal Value Added [2]	Actual/Normal	Actual Value Added [1]	Normal Value Added [2]	Actual/Normal
	(1)	(2)	(3)	(4)	(5)	(6)
Primary Sectors						
1. Agriculture	80.70	70.90	1.14	94.19	83.22	1.13
2. Mining	2.93	3.99	.73	6.10	5.41	1.13
Total primary	83.67	74.89	1.12	100.29	88.63	1.13
Industry						
3. Food and tobacco	17.07	11.21	1.52	22.90	16.11	1.42
4. Textiles	.93	4.33	.21	0.93	7.10	.13
5. Clothing and leather	2.10	2.55	.82	3.15	4.44	.71
6. Wood products	2.58	1.66	1.55	3.78	2.97	1.27
7. Metals	1.11	2.69	.41	2.42	5.59	.43
8. Metal products	4.48	2.72	1.65	9.12	6.37	1.44
9. Nonmetallic mineral products	1.21	1.72	.70	2.85	2.94	.97
10. Chemicals, rubber and petroleum refining	3.16	3.18	.99	6.15	5.63	1.09
11. Paper	.29	.54	.54	.56	1.33	.42
12. Other manufacturing	.60	1.82		1.19	3.17	. .
Unclassified small industry		6.13			6.36	
Total (3–12)	33.93	38.55	.88	53.06	61.96	.86
13. Construction	7.69	10.75	.72	17.65	15.64	1.12
14. Electricity, gas and water	4.48	(5.00)		7.65	(8.00)	
Total industry (3–14)	45.73	54.30	.84	78.36	85.60	.92
15. Transportation	13.70	14.00	.98	19.30	21.34	.90
16–20. Services	65.01	81.50	.80	80.29	115.10	.70
Total [3]	209.24	224.69		278.21	310.67	

Source: Chenery (1962:519)

Firstly, in 1957, by joining the European Economic Community, Italy signed a quadrennial plan of tariffs cuts (30% each time) which would have to be totally removed by 1969 (in fact Italy succeeded in this goal a few years ahead of schedule!). As it was accompanied by equivalent tariff cuts by other members, the fast industrialising regions in the North were able to boost the export of strategic products, typically machine tools and automotive. However, the few private entrepreneurs in Southern Italy found it increasingly difficult to compete with established firms within the new market boundaries. In this respect, it was noted that 'an independent government would have a much wider choice of instruments (subsidies, tariffs, wage policy, devaluation, etc.) than does the region at the present' (Chenery 1962:546).

At the same time the export-led model of industrial development in Northern Italy was increasingly in need of developing complementary industries providing intermediate goods and components, as well as raw industrial materials (Giannola and Imbriani 1990). Moreover Northern industrialists did not view the development of competitors in the South in strategic and high value manufacturing production favourably. This conflict between regions was also stressed by Chenery (1962:546) when he recognises that "[a]lthough there has been ample political support for increasing the total resource transfer to the South, there has been considerable resistance to developing the industries that would be rational for the South, which might increase competition with the established plants in the North".

The existence of this structural tension in a dualist setting was not fully captured by policy makers such as Pasquale Saraceno who designed the initial *Schema Vanoni* and participated to the CNPE (Commission for National Economic Planning) created by the Ministry Ugo La Malfa in 1962[18]. Although in 1957 the industrial development of Southern Italy was recognised as a priority and the Italian government reformed the Cassa and equipped itself with new industrial policy tools (see next section), the separation and compositional heuristics adopted

[18] See the famous *Nota Aggiuntiva* of Ugo La Malfa presented in the Easter of 1963 for denouncing the persistent dualisms and increasing structural tensions in consumption patterns and sectoral composition.

were still essentially ineffective in capturing the structural tensions and institutional bottlenecks from which various forms of dualisms were originated.

In terms of the former (structural tensions), Saraceno's analytical apparatus remained quite aggregated (mainly based on an Harrod-Domar model of economic growth) and inspired by an auto-propulsive growth model (Toner 1999; Costabile and Scazzieri 2012:753). As for the latter (institutional bottlenecks), as stressed by Chenery (1962:546 italics added),"the overhead approach either ignores the *other structural changes* that are needed in the rest of the economy or *assumes that they will take place automatically*". This means that mismatches and misalignments of policies over time inevitably emerged as a result of this insufficient industrial policy approach followed throughout the 1960s.

In sum, as Claudio Napoleoni (1962) noted in his critique of the Italian development model followed in the 1950s, economic growth in the South was mainly driven by exports and increasing consumption, while investment in fixed capital weas lacking (in particular they were noticeably below the ones that Italy would have been able to make with industrial planning). As a result productivity did not increase as it could have done and capital accumulation through savings was relatively limited given unproductive (or low-productivity) investment in real estate and agriculture.

4.2 Dependent industrialisation, 1959 - 1975

As discussed and documented in Table 1, the first two years of industrial policy from 1957 to 1959, were not able to reverse almost a decade of 'intervention without planning'. However the Law No. 634/1957 introduced a major innovation and posed the basis for a new sustained round of industrial investment in Southern Italy. According to this law, state owned enterprises had to concentrate 40% of their total investments and 60% of new investments for start-up industrial initiatives in Southern Italy. The IRI (*Istituto per la Ricostruzione Industriale*), a multi-sectoral financial holding company founded in 1933 and fully owned by the state, became a major tool for supporting massive industrial investments in Southern Italy.

IRI's strategic investment was also complemented by the intensified extraordinary investment and loans were managed by the Cassa (reformed with the Law No. 717/1965) as well as by a number of special banks supporting industrial and public investment (*Istituti di Credito Speciale per l'industria e le opera pubbliche, ICS* and others*)*. Given that during the 1960s the majority of investment was concentrated in capital intensive industrial sectors, such as steel and chemicals, or in traditional sectors such as food processing and textiles, and given that they were located in regions where the overall level of manufacturing development was quite limited (see above), few observers talked of the creation of 'cathedrals in the desert'.

The idea of building 'industrial cathedrals' was actually inspired by two main contributions: Albert Hirschman's (1958) unbalanced growth theory and Francois Perroux's (1955) theory of 'spontaneous' or 'natural' growth poles. Both of them influenced the work of the CNPE by informing Italian industrial policy design with a set of separation and compositional heuristics drastically different from those adopted in the past.

In particular Perroux's analysis started from the observation that "[g]rowth does not appear everywhere at the same time; it appears at points or poles of growth with varying intensity; it spreads along various channels and with differing overall effects on the whole economy" (1955:309; my translation). In Perroux's conceptualistion *growth poles* mainly consist of a complex of industries linked by backward and forward linkages (understood both as interfirm transactions but also technological interdependencies) and led by a primary propulsive or stimulant industry (*industrie motrice*). This propulsive industry exercises a dominant role in the growth pole both in input-output relations and in terms of originating/spreading technological innovations. Clearly the concept of growth poles introduces a compositional heuristic which resembles the one discussed by Dahmen of development block (see above).

The following tables 2 provide a summary of the main industrial sectors in which growth poles were developed by IRI between 1965 and 1975. With the centre-left government in power in 1963, which attempted an overall redesign of the national industrial plan (the so called *piano straordinario*) and the reform of the Cassa in 1965, investments in manufacturing development reached half of total IRI's investments. If we include the Cassa, investments in manufacturing development in the South over the same period were even higher, roughly two third. Four areas were mainly targeted (Pastorelli 2006):

(i) Steel industry and plant design: *Italsider* was constituted in 1961 by merging different companies and pursuing an industrial strategy of plant-specialisation (for example the ILVA in Taranto introduced innovations such as an 'integral cycle' and semi-automation processes which allowed specialisation in high-value tubes for gas pipilines); while *Italimpianti* became a general contractor for plant design.

(ii) Electronics and telecommunications: two companies *Selenia* and *Sit-Siemens* specialised in civil and military electronic systems and components;

(iii) Machine tools, Automobile and Electro-mechanics: *Finmeccanica* operated in various production lines also in parthership with *Olivetti* and *Fiat*, with a particular emphasis on automotive. The creation of an establishment for the production of Alfa Romeo sportive cars (*Alfasud*) represented an exceptional case of industrial development of high value production in Southern Italy;

(iv) Shipbuilding: in order to overcome structural constraints (indivisibilities) and the Japanese dominance in the sector, *Italcantieri* was created by merging three main producers in the shipbuilding industries, all together accounting for three quarters of the national production of medium-big size ships.

Table 2: IRI's package of industrial investments over the decade, 1965 – 1975

Manufacturing Industries	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Steel	42.2	35.8	22.7	18.6	19.7	25.6	32.0	34.5	31	24	22.2
Mechanical	3.6	4.2	5	6.6	11.2	16.1	16.1	10.9	5.7	4.7	3.3
Electronics	0	0	0	0.8	1.6	1.5	3	2.9	2.8	3.5	2.9
Construction and Ships MRO	0.8	1.4	2	2.9	1.6	0.9	0.6	0.7	0.9	1.9	2.1
Cement	1.2	0.4	0.3	0.3	0.9	1	0.7	0.7	0.5	0.7	0.6
Food	0	0	0	0	0.6	1.1	0.8	1.2	1.1	1.5	0.8
Others	1.5	2.2	1.9	3.4	2.0	1.2	1.4	1.5	1.1	1.4	0.9
Total	**49.3**	**44.1**	**31.9**	**32.6**	**37.6**	**47.4**	**55.5**	**52.4**	**43.1**	**37.7**	**32.6**
Services Companies											
Telecomunications	23.9	27.3	29.4	29.1	31	26.9	26.3	31.1	36.3	41.4	45.1
Naval transport	5.3	0.3	0.9	1.8	2.6	1	0.9	0.6	1.1	3	5.9
Air transport	3.1	6	10	13.8	12.1	6.8	4.5	2.1	3.8	3.1	2.2
Radio TV	2.2	3.1	3.5	3.2	1.6	1	0.4	0.4	0.3	0.4	0.4
Others	0.2	0.5	1.2	1.5	1.6	1.2	0.7	0.8	0.8	0.9	0.8
Total	**34.8**	**37.1**	**45**	**49.3**	**48.9**	**36.8**	**32.9**	**35**	**42.4**	**48.9**	**54.5**
Infrastructures											
High Way	15	17.7	22.1	17.2	13.1	15.5	11.2	11.4	13.6	12	11.4
Constructions	0	0	0	0	0	0.3	0.5	1.2	0.9	1.4	1.6
Total	**15**	**17.7**	**22.1**	**17.2**	**13.1**	**15.8**	**11.7**	**12.6**	**14.5**	**13.4**	**13**
Other companies	0.9	1.2	1	0.8	0.4	0	0	0	0	0	0
Total IRI (in milioni di lire 1992)	**8.259.860**	**7.267.196**	**7.097.462**	**7.953.561**	**8.553.172**	**10.622.885**	**14.395.961**	**16.488.044**	**17.240.223**	**14.676.551**	**14.834.844**

Source: *IRI Bilanci 1965-1975*

Within the growth poles framework, the IRI also pushed the technological innovation of the overall Italian industrial system by promoting, in partnership with private companies, three industry-specific competence centres: the *Centro Sperimentale Metallurgico* (CSM), dealing with metallurgic research; the *Centro Studi e Laboratori Telecomunicazioni* (CSEL), dealing with telecommunications and finally, the *Centro Studi di Tecnica Navale* (CETENA), focused on shipbuilding industry. These technological efforts were increasingly intensified since 1969 and state owned enterprises were explicitly assigned a role of industrial innovators, that is, companies focused on tackling technological and structural constraints and on importing/adapting foreign technologies and organisational solutions (Ministero delle partecipazioni statali, *Relazione Programmatica* 1969:110). In 1969 IRI's investment in R&D were equal to 7.7% of total national expenditure, while in 1975 reached almost 12%.

Despite the significant industrialisation and technological efforts of the Italian government through IRI and the Cassa, at the end of the period considered, the impact of industrial policies on dualisms within the country was not satisfactory. Although Southern Italy went through a profound process of structural and institutional transformations since the end of WWII, many of the structural tensions and institutional bottlenecks responsible for Italian dualism remained untouched. The main explanation has to be found in the fact that the industrialisation process was mainly a process of *dependent industrialisation*. To better understand this term we will now look at two totally distinct cases: one of a typically vertically integrated industry (e.g. steel production) and one more based on horizontal integration (e.g. the automotive industry).

The *IV Centro Siderurgico di Taranto* (the steel industry pole of Taranto in the southern region of Puglia) was created with the main objective of supplying the fast-growing export-led industrialisation of the northern regions with intermediate goods and components as well as raw industrial materials. Steel was among the most important of these materials as the northern regions were specialising in high-value machine tools and automotive industries. Thus the main forward linkage of the steel plant in Taranto remained in great part disconnected from local entrepreneurs, while steel production went to support the most competitive producers in the North. Given that Italy had to import the raw materials for steel production, the backward linkage with the local economy of the steel plant of Taranto was minimal.

Not only was the *IV Centro Siderurgico di Taranto* a cathedral in the desert, it was also a cathedral without pillars. Thus although the establishment of a steel plant in Taranto relaxed a structural constraint and might have induced a number of complementary investments, remained blocked by the existence of structural tensions (lack of local intersectoral linkages) and the permanence of an institutional bottlenecks represented by the conflict between the economic interests of the Northern and the Southern regions.

In contrast, Alfa Romeo established a factory plant in Pomigliano (close to Naples) called Alfasud that specialised in the production of complex products (specifically cars). The Alfasud plant was limited by a series of institutional bottlenecks. The standards of productivity of Alfasud were strongly affected by problems in labour organisation (the strong class struggle led by unions). The difficulties in overcoming such institutional bottlenecks reduced Alfasud’s impact in the area, that is, its capacity to trigger a process of horizontal integration with local companies and subcontractors.

Both cases showed how the distinction between planned and spontaneous growth poles introduced by Perroux was a crucial one. In fact, in both the cases discussed above, the development of industrial poles was not an organic process of industrial development. The economic system was not capable of automatically solving a series of structural tensions and institutional bottlenecks.

Crucially industrial policies were unable to function selectiviely, properly targeting in a medium-long term perspective the specific production tasks and levels of aggregation of production activities which would have most probably triggered the development of Southern Italy. With few exceptions entire industries were developed without tackling either internal structural constraints (such as in the case of chemicals) or structural tensions (as discussed in the case of the steel industry). Finally the incapacity of the national government to balance the interests of the fast industrialising Northern regions with the ones of the *Mezzogiorno* strongly biased the overall industrial policy design, that is, the separation and compositional heuristics adopted.

‘Dependent industrialisation’ also remained a fundamental character of the second round of industrial policy, from 1969 to 1975. Although industrial policies did focus on strategic manufacturing industries such as car-making, aeronautics, electronics and machinery during this period, the latter were mainly controlled by companies from the North. Meanwhile SMEs in the South were increasingly contracting both as a result of a lack of organic linkages and increasing competition from abroad. Although macro indicators in the South remained positive until 1976 (when industrial policies were abandoned) a second opportunity to overcome the structural and institutional dualisms of the country was missed. To conclude the kind of industrial policies implemented since 1950 triggered a process of dependent industrialisation which left Southern regions with the unexploited potentials of a number of cathedrals without pillars.

Concluding remarks

Today industrial policies which promote manufacturing development are back on the policymakers' agenda. This essay has developed new heuristics aimed at expanding the industrial policy space currently visualised by policy-makers. Within our new analytical framework, industrial policies are understood as a set of *sequentially coordinated selective measures addressing structural tensions, institutional bottlenecks and various forms of dualism* that impede the economic system from entering certain trajectories of manufacturing development.

After having critically reviewed the analytics and politics of the today's main structural economics approaches to industrial policy, the essay has investigated the very often overlooked interplay between structural economic dynamics and institutional transformations. In order to disentangle structural economic dynamics and institutional transformations, the essay develops a set of what we have called here 'separation heuristics' and 'compositional heuristics'. The former allow policy-makers to set benchmarks for industrial policy design while the latter allow them to identify the targets for these benchmarks. The essay has shown how these operate.

On the one hand separation heuristics allow an 'economics-engineering twist' to operate, through which, given a certain economic system, structural/material/technological conditions are considered independently from institutional conditions. On the other hand, compositional heuristics refer to specific levels of aggregation of production activities (i.e. *production units*) at which the above listed structural/material/technological conditions have to be satisfied and at which certain institutional functions fulfilled.

The application of a mixture of separation and compositional heuristics in addressing structural tensions, institutional bottlenecks and various forms of dualisms characterising manufacturing development trajectories has led us to rethink industrial policies along three axes: selectivity, matching and alignment. Industrial policies' effectiveness is increased by improving and refining the degree of selectivity of the implementable policy measures and by introducing new rationales for industrial policy interventions dealing with mismatches or misalignments in a fully dynamic structural framework. In this respect, the essay has shown how, according to a principle of relative invariance, structural economic dynamics and institutional transformations will follow a certain hierarchy of change, that is, will work themselves out within a limited set of possible manufacturing development trajectories.

The application of our new framework to the analysis of the industrialisation experience of Southern Italy (from 1950 to 1975) has allowed us to underline the limitations and potentialities of a mix of industrial policy measures centred around the notion of 'growth poles'. In particular, the reinterpretation of the Italian experience has led us to confirm our hypothesis of 'dependent industrialisation'. This expression has been introduced for describing an externally-led process whereby certain industrial poles are promoted but they do not organically develop and link to the overall production structures of a certain region.

Given the region's specific characteristics, such as the lack of structural linkages or the presence of institutional bottlenecks in a given historical context, state-led investment in the South only partially managed to reduce various forms of dualism present in the Italian economy. As a result, Southern regions were left with the unexploited potential of a number of cathedrals without pillars.

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