UNIVERSIDADE FEDERAL DO PARANÁ

FRANCISCO ADILSON GABARDO

THE ECONOMICS OF SUSTAINED GROWTH: THE ROLES OF STRUCTURAL CHANGE, DEMAND SATURATION AND INNOVATION

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Tese apresentada como requisito parcial à obtenção do grau de Doutor em Desenvolvimento Econômico, no Curso de Pós-Gradução em Desenvolvimento Econômico, Setor de Ciências Sociais Aplicadas, da Universidade Federal do Paraná.

Orientador: Prof. Dr. João Basílio Pereima Neto

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TERMO DE APROVAÇÃO

Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em DESENVOLVIMENTO ECONÔMICO da Universidade Federal do Paraná foram convocados para realizar a arguição da Tese de Doutorado de **FRANCISCO ADILSON GABARDO**, intitulada: "**The Economics of Sustained Growth: the Roles of Structural Change, Demand Saturation and Innovation**", após terem inquirido o aluno e realizado a avaliação do trabalho, são de parecer pela sua APROVAÇÃO.

Curitiba, 27 de Abril de 2016.

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To my mother Lourdes
and my wife Andreia, the love of my life
for their love and unconditional support.

To Dr. Daisaku Ikeda, to whom
I owe a debt of gratitude for showing me
the true value and purpose of education.

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It is through education that we are liberated from powerlessness, from the burden of mistrust directed against ourselves. To awaken the abilities that have been lying dormant within. To arouse and extend the soul's aspiration to become full and complete. Can there be any more sublime experience in life?

Daidaku Ikeda

Education makes us free. The world of knowledge and of the intellect is where all people can meet and converse. Education liberates people from prejudice. It frees the human heart from its violent passions.

Daidaku Ikeda

RESUMO

A presente tese busca analisar os papéis da mudança estrutural, da saturação da demanda e da inovação de processo e de produto no processo de crescimento econômico sustentado. Acredita-se que o crescimento econômico não é somente restringido por fatores de oferta, como acumulação de capital e progresso técnico, mas também por fatores de demanda, como a saturação da demanda para bens de consumo individuais. Se assumirmos saturação de demanda, então o progresso técnico na forma de aumento da produtividade por si só não é capaz de sustentar o crescimento com pleno emprego dos fatores no longo prazo. É fato que a introdução de novos bens de consumo criadores de demanda é condição necessária para o crescimento econômico com pleno emprego de fatores em economias de mercado. Além disso, o surgimento de novos produtos e setores gera a realocação de recursos. Embora, no plano agregado, o processo de crescimento econômico no longo prazo pareça estável, numa perspectiva histórica, o declínio do setor agrícola e a ascensão dos setores manufatureiro e de serviços levaram a uma significativa realocação de fatores produtivos. Crescimento e mudança estrutural são companheiros inseparáveis. O fato de os setores econômicos possuírem diferentes taxas de produtividade, dá a mudança estrutural um papel central, uma vez que esta pode retardar o crescimento se o seu ritmo for muito lento ou se ocorrer na direção errada, ou pode acelera-lo se promover a alocação mais eficiente dos recursos. Em ambos os casos, a mudança estrutural não deve ser pensada como um mero subproduto do processo de crescimento, mas sim como parte integral do mesmo. A interação entre saturação de demanda, introdução de novos produtos/setores, progresso técnico e mudança estrutural gera um processo de cumulação causativa que é capaz de sustentar o crescimento econômico no longo prazo. Na presente tese revisamos a literatura relacionada aos temas do crescimento, mudança estrutural e inovação e desenvolvemos um modelo econômico computacional baseado em agentes (ACE) de crescimento cumulativo para analisar as conexões entre esses temas. Simulamos as operações simultâneas e as interações de múltiplos agentes heterogêneos numa tentativa de recriar seu comportamento complexo que dá origem a padrões macroeconômicos observados na literatura. Para enriquecer a análise, incorporamos um mercado financeiro no sistema e exploramos seus efeitos sobre o crescimento, sobre o surgimeto de ciclos econômicos e sobre o progresso tecnológico. O modelo desenvolvido na presente tese somente explora aspectos da inovação de processo. Mostrasse que uma vez que assumimos a saturação da demanda, uma das consequencias do aumento continuo da productividade é o declinio no nivel de emprego. O modelo computacional desenvolvido na presente tese é limitado somente a aspectos da inovação de processo e produtividade do trabalho. Ele mostra que, uma vez assumida a existência de saturação da demanda, uma das consequências do aumento continuo da produtividade é o declínio no nível de emprego. Para absorver a mão de obra deslocada, novos produtos e/ou setores que evoquem novo crescimento na demanda devem surgir. Desta forma, apesar da ausência desse elemento em nosso modelo, a inovação de produto e a criação de novos setores são elementos essenciais para o sustento do processo de crescimento econômico com pleno emprego de fatores no longo prazo.

Palavras-chave: crescimento, mudança estrutural, saturação de demanda, inovação.

ABSTRACT

The present PhD thesis seeks to analyse the role played by structural change, demand saturation and process and product innovation in the process of sustained economic growth. We argue that economic growth is not only constrained by supply factors, such as capital accumulation and technical progress but also by demand factors, such as the saturation of demand for individual consumption goods. If one assumes that demand saturates, then technical progress in the form of increases in productivity alone cannot sustain growth with full employment of factors in the long run. It is a fact that the introduction of new consumer products that elicits new demand is a necessary condition for economic growth with full employment of resources in a market economy. Moreover, the emergence of new products and new sectors lead to resources reallocation. Although, in the aggregate, the process of long-run economic growth might seem stable, in historical perspective, the decline of the agricultural sector and the expansion of the industrial and the service sectors have led to a massive reallocation of factors. Growth and structural change are inseparable companions. The fact sectors differ in their productivities, gives structural change a central role, as it can delay growth if its pace is too slow or if it happens in the wrong direction, or it can accelerates it if it improves the allocation of resources. Either way, structural change can not be thought as a mere by-product of the growth process, but as an integral part of it. The interaction between demand saturation, introduction of new products/sectors, technical progress and structural change generates a process of cumulative causation that is able to sustain economic growth in the long-run. In the present thesis we review the literature behind the subjects of growth, structural change and innovation and develop an agent based computational economic (ACE) model of cumulative growth to analyse the connections between these elements. We simulate the simultaneous operations and interactions of multiple heterogeneous agents in an attempt to re-create their complex interactions that give rise to macroeconomic patterns found in the literature. To enrich the analysis we incorporated a financial market in the system and explored its effects on growth, business cycle and technological progress. The computational model developed in chapter 5 of the present thesis is limited to the aspects of innovation of process and increases in labour productivity. It is shown that if one assumes demand saturation, one of the consequences of continuous increase in productivity is the decline in employment. In order to absorb the displaced labour, new products and/or sectors that elicit new demand have to emerge. Therefore, despite the absence of this feature in our model, product innovation and new sector creation are essential elements in order to sustain economic growth with full employment of factors in the long run.

Keywords: growth, structural change, demand saturation, innovation.

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1. INTRODUCTION

Understanding the sources and dynamics of growth is an age-old issue in economics. From Adam Smith's 1776 seminal work *An Inquiry into the Nature and Causes of the Wealth of Nations* to the latest developments in growth theory, economists have struggled to determine the sources of sustained economic growth.

The exogenous and its successor the endogenous theory of economic growth can be understood as a long and arduous effort, which lasted for almost half a century, dedicated to identify and isolate the determinants of sustained growth. Throughout this endeavour the theory focused predominantly on some specific determinants of economic growth, such as physical capital accumulation, saving and investment decisions, human capital, 'learning by doing' and R&D in order to explain sustained long-run economic growth. Despite being an undeniable fact that an economy's growth rate depends on these factors, there are other factors, normally relegated to a secondary role by mainstream growth theory, that many economists believe to be key elements to the understanding of the process of sustained economic growth.

One of these factors is the saturation of demand. Proponents from outside and some from inside the neoclassical approach argue that the evolution of demand and more precisely the saturation of demand have a profound impact on the long-run growth rate. For instance, in the book *Escaping Satiation: The Demand Side of Economic Growth*, Ulrich Witt raises the following questions: "how is that consumption can increase to enable the expansion of demand to keep pace with the expansion of supply? If traditional consumption habits lead to satiation[1], how could the increasing industrial production ever be sold? Where does the additional demand come from?"(Witt, 2001, p. 1). These questions cannot be answered by standard neoclassical growth theory because demand satiation is not something considered by these models.

The same issue was also raised by Luigi Pasinetti (1981; 1993). He argues that there is an upper saturation level for all types of goods and services although at different levels of real income (Pasinetti, 1981, p. 77). Therefore if one assumes saturation of demand, then the rise of productivity alone could not sustain economic growth in the long

[1] For the purpose of this thesis the terms saturation and satiation will be considered synonyms when applied to demand or consumption.

run. Most neoclassical growth models do not consider the possibility of demand saturation, thus it is not a factor that can affect an economy's long-run growth rate.

If one agrees with Pasinetti and Witt's view that demand tends to saturate, then the logical question would be "How an economy can overcome demand saturation?". The answer can be found in the process of product innovation. Economic growth has been strongly influenced by the introduction of new products. It is a fact that the introduction of new consumer products is a necessary condition for economic progress in a market economy. If there were only the same unchanged final products available in the market, consumers would inevitably become satiated, leading to stagnated demand and growth. Thus, if one assumes non-linear Engel curves with income elasticities less than one for the aggregate of existing products, the consumption ratio of an economy is bound to fall continuously in the absence of new products, which means that, the rise in per-capita income due to technical progress on the production side is not accompanied by a similarly rise in demand, leading to under-consumption (Frey, 1969). One way to overcome this imbalance between productivity growth and demand growth is represented by the emergence of new sectors. Long-term economic development and growth then depends on the ability of the economic system to create the new goods and services leading to new sectors (Saviotti, 2001). Following this discussion comes the debate regarding the sources of product innovation. The investigation of the factors that influence the pace and direction of innovations is a topic that deserves some attention.

Another important issue to consider when we think about long-run growth, is the phenomenon of structural change, defined as the reallocation of resources across sectors that accompanies modern economic growth. Although the process of long-run economic growth might seem stable in the aggregate, in historical perspective, the decline of the agricultural sector and the expansion of the industrial and the service sectors have led to a massive transformation of the economic landscape. Many authors including Fischer (1939), Clark (1940), Kuznets (1957) and Chenery (1960) have documented this process. Despite being an empirical fact that structural change is an inseparable companion of the growth process, it appears as if growth theorists have relegated it to a secondary role. One of the reasons for this apparent neglect with the subject of structural change is the analytical difficulties of dealing with the issue of sectoral dynamics. Another reason is the fact that for a long time the analysis of growth, from a theoretical perspective, has focused predominantly on aspects of supply and technical change. Until the beginning of the 1990's most works on structural change were empirically-oriented contributions. Only recently that there has been a consistent effort to make structural change an integral part of modern growth theory.

Sustained economic growth is intrinsically connected to fundamental changes in the structure of production, consumption and employment. The study of demand evolution and structural change and also the emergence of new sectors which creates new demand, is essential if one wants to comprehensively understand the process of long-run economic growth. The present thesis intends to explore the issues of structural change, demand saturation, product and process innovation and how these elements interact in order to generate sustained economic growth.

This thesis is organized as follows. Chapter 2 reviews some of the most influential works in modern[2] growth theory, including the works of Roy Harrod and Robert Solow among others, and several contributions in the endogenous growth theory related to the AK, Product-variety and Schumpeterian models. It also introduces a class of models called dual economy models, which appeared in the 1950s and 1960s, and have their roots on the work of Arthur Lewis (1954).

Chapter 3 analyses the mechanisms behind the phenomenon of structural change, defines its sources and reviews some of the most recent works on the literature that integrates growth and structural change. It also includes an introduction to the theory of structural change of Luigi Pasinetti and some contributions from the evolutionary theory's perspective. The last section of chapter 2 presents some of the work done by what can be called the New Latin American Structuralist (NLAS) growth theory.

Chapter 4 explores the cumulative aspect of the growth process and the factors that influence the pace and direction of innovations. It analyses how productivity deriving from external economies of scale, demand saturation and the emergence of new products and consequently new sectors interact to give rise to a cumulative process of sustained economic growth. The chapter presents the derivation of part of the model developed in Foellmi & Zweimüeller (2008) where economic growth is sustained by the continuous introduction of new goods in the economy.

Chapter 5 develops an agent based computational economic (ACE) model of

[2] The term 'modern' growth theory is used here to distinguish post-1930 contributions to the field of economic growth from those associated with Classical economists, including Smith, Ricardo and Marx.

cumulative growth, demand saturation, sectoral dynamics, innovation and financing. The model developed portrays an economy with three sectors and heterogeneous firms that are able to finance their activities in the financial market. Firms motivated by competition based on innovation seek financing for their activities on the banking system. Financial instability can emerge as a possible outcome of the interaction between firms and the banking system, generating business cycles and recessions.

2. MODERN GROWTH THEORY

After World War II, with a number of newly independent nations, the problem of promoting economic growth became a priority and growth theory came to occupy a central position in modern economics. This chapter is devoted to review some of the most influential works in modern growth theory. Section 2.1 reviews some of the main works in the exogenous growth theory, including Roy Harrod (1939; 1948) and Robert Solow (1956)'s contribution which identified the crucial role of technical change in the determination of the long-run growth rate and influenced, in one way or another, most of the subsequent work on the field. Section 2.2, about endogenous growth models, describes how these models emerged, evolved and overcame the main limitation of its predecessor, the exogeneity of technical change. The section also presents a basic review of the main articles published at the time along with a description of the main types of endogenous models including the AK, Product-variety and Schumpeterian models. Section 2.3 introduces a class of models called dual economy models. These models appeared in the 1950s and 1960s, and have their roots on the work of Arthur Lewis (1954). We consider dual economy models to be the precursors of modern models of growth with structural change discussed in chapter 3. This chapter is concerned with the part of growth theory dedicated to identify the determinants of long-run sustained growth. Although hardly any economist would deny the existence of a relation between growth and structural change, the models and theory described in this chapter, with the exception of section 2.3, assume structural change to be a mere by-product of economic growth, with no causal relation running from the later to the former, thereby relegating it to a secondary role. However, even though these models do not deal directly with the issue of structural change, they were of paramount importance in the quest for the factors behind sustained growth. Section 2.4 closes the chapter with some final comments.

2.1 Exogenous Growth Theory

The first models that tried to tackle the issue of economic growth were highly aggregated, and thus not intended for analysing the complexities of structural change.

Among the most influential articles published at that time were the works of (1939; 1948) and Evsey Domar (1946; 1947). In his 1939 article *An Essay in Dynamic Theory*, Harrod wanted to extend the short run Keynesian static analysis into a long run dynamic one. The focus of his model was to answer the question of what must be the rate of growth of income in a growing economy that equals investment and saving and guarantees a moving equilibrium through time. His analysis aimed at determining the necessary conditions to realize full-capacity utilization and full employment.

Harrod distinguished between saving and investment behaviour and introduced three different concepts of growth rates: the actual growth rate, defined as $g_a = s/c$ where s is the savings ratio and c is the actual incremental capital-output ratio; the warranted rate of growth gw, at which saving and investment behaviour are mutually consistent; and the natural rate of growth g_n, the rate of growth of aggregate supply, i.e., the rate of growth of productive potential of an economy, or the 'social optimum' rate of growth, as Harrod called it. The warranted rate of growth need not coincide with the natural rate of growth, thus creating a dynamic counterpart to Keynes' short-run theory of income determination wherein aggregate demand was central. Assuming that the condition for a static equilibrium is one where investment equals savings, Harrod tried to identify the rate of growth of income that equal actual and warranted rates of growth. There is only one rate that equates warranted and actual growth, any departure from this rate, instead of being self-righting, would be self-aggravating. This characterized a macroeconomic instability problem, or a first 'knife-edge' condition. Moreover, even if the actual and warranted growth rates are equal, that only guaranties the full utilization of capital.

What about full utilization of labour? In Harrod's model full employment of labour depends on the natural rate of growth g_n, which is comprised of two other rates: the growth of the labour force and the growth of labour productivity, both exogenously given. The sum of the two gives the growth of the labour force in efficiency units. In order to achieve full employment of labour, the actual growth rate must match the natural rate, but in his model nothing guarantees that the two rates will be the same. If the actual growth rate falls below the natural rate then there will be growing unemployment. Hence Harrod's model has a second 'knife-edge' condition, characterizing an employment instability. In conclusion, full employment of both capital and labour will only exist if $g_a = g_w = g_n$, a very unlikely situation.

In Harrod's model nothing guaranteed that the actual and natural rates of growth would converge; there was no automatic adjustment towards full employment. Moreover, if there were an insufficient level of effective demand that left capital under-utilized, that would broaden the gap between the actual and warranted rates of growth (or between aggregate demand and supply). Since in Harrod's model aggregate demand was determined by volatile investment decisions, subject to uncertainty, economic expansion is inherently unstable.

Harrod's article inspired a wave of contributions, including one of the most influential works in growth theory, Robert Solow's 1956 article *A Contribution to the Theory of Economic Growth*. Solow's article pioneered what came to be known as the first generation of neoclassical growth theory, also called exogenous neoclassical growth theory. According to Hagemann (2009), Solow's model was a reaction to the approach followed by Harrod and the problems associated with it, in particular to the two instability problems. Solow saw that the main reason for the instability problems in Harrod's model was the absence of any adjustment mechanism. Thus, in order to fix the instability problem, Solow made two assumptions in his model: substitution between the two factors of production, capital and labour, and factor prices flexibility. By making these two assumptions Solow was able to address the employment instability. But the question of the macroeconomic instability was simply ignored by assuming that planned investment equals planned savings at all times without any explanation about the underlying macroeconomic adjustment process that makes that assumption true.

The first Solow model was comprised of three equations: an aggregate production function that exhibits constant-returns-to-scale with smooth substitution and diminishing returns to capital and labour; an equation describing capital accumulation on the assumption of a constant rate of savings as a fraction of output; and a labour-supply function in which the labour force grows at an exogenous rate. Solow argued that an economy would automatically gravitate towards equilibrium if the relative price of labour and capital are flexible enough, and a spectrum of techniques exist so that the economy can move along a continuous production function combining different amounts of capital and labour. The system generated a first-order differential equation that showed how the current level of the capital-labour ratio and two parameters (the savings rate and the rate of population growth) determine the rate of change of the capital-labour ratio. The idea is that if the labour force grows faster than capital, firms will use more labour intensive techniques, and vice versa. Thus, if g_n exceeds g_w, the capital-output ratio will fall, raising g_w to g_n, and the opposite movement will happen if g_n is less than g_w.

Solow also worked quantitative solutions for some specific constant-returns production functions (Cobb-Douglas and CES functions). He analyzed the dynamic stability of equilibrium qualitatively using a diagram to show how the economy would converge to a steady-state growth path along which output and the capital stock both grew at the exogenous rate of population growth. To account for increasing income per-capita, exogenous technical progress in the form of what later came to be known as Hicks-neutral[1] was introduced in the Cobb-Douglas case. The result was that along the balanced growth path, output and capital per worker both grow at the same rate of technological progress. Intuitively, as capital accumulates, there is a tendency for the capital-output ratio to fall due to diminishing returns to capital. Technological progress offsets the effects of diminishing returns to capital accumulation, allowing labour productivity and output per worker to rise. At the steady-state technological progress and diminishing returns to capital exactly offsets each other and the capital-output ratio is constant.

In the Solovian model, the long-run equilibrium growth rate became independent of savings and investment decisions. Any increase in an economy's saving or investment ratio is offset by an increase in the capital–output ratio, leaving the long-run growth rate unchanged, as long as diminishing returns to capital exist. With the introduction of technical progress diminishing returns to capital are offset but then output and capital per worker grow at the same rate as technical progress, which grows at an exogenously given rate. So without technical progress the effects of diminishing returns would eventually cause economic growth to cease. Moreover, despite solving part of Harrod's instability problem, Solow's model excludes aggregate demand from the determination of the long-run growth rate of output.

Throughout the 1960s the basic Solow growth model was extended into several directions. Solow himself modified his model introducing the notion of vintage capital with embodied technological progress and derived a new version without direct substitution between factors of production (Solow, 1959). One particularly important extension was

[1] Later Uzawa (1961a) established that only Harrod neutral technical progress is compatible with steady state growth. The Cobb-Douglas production function is a special case in which Hicks-neutral and Harrod-neutral technical progress are equivalent

done by Cass (1965) and Koopmans (1965). They modified and microfounded the choice of consumption in the Solovian model using the intertemporal maximisation developed by Ramsey (1928). The final model came to be known as the Cass-Koopmans-Ramsey model. The authors abandoned the assumption of fixed saving rate and incorporated the permanent income and life-cycle savings hypotheses into the Solovian model. By incorporating these hypotheses, the saving behaviour becomes the result of explicit intertemporal utility maximization, i.e. the saving rate becomes endogenously determined. Therefore, unlike in the Solow model, where the saving rate is constant, in the Cass-Koopmans-Ramsey model the saving rate may fluctuate along the transition to the long-run steady state. The model also showed that, when exogenous technical progress is introduced, capital, consumption and output all grow at the same rate as the exogenous technical progress in the steady state.

Although no economist would ever have denied the role of technological change in economic growth, the fact that this variable was assume to be exogenous was very unsettling. In the words of (Arrow, 1962b, p. 155), "a view of economic growth that depends so heavily on an exogenous variable, let alone one so difficult to measure as the quantity of knowledge, is hardly intellectually satisfactory." This limitation highlighted the need to derive a way to make technological progress endogenous and to understand the determinants and mechanisms of its accumulation.

Over the next three decades, growth theory focused predominantly on how to make technical progress endogenous. It is believed that technical progress is not an exogenous process, but actually depends on endogenous factors such as the economic decisions made by profit seeking firms, funding of science and accumulation of human capital. One of the problems with assuming that technical progress is endogenous is how to incorporate it into growth models, since endogenous technical progress normally leads to increasing returns to scale, which are not compatible with the usual theory of competitive equilibrium.

2.2 Endogenous Growth Theory

The problem faced by those who tried to endogenize technology was how to incorporate increasing returns in a dynamic general equilibrium framework. More specifically, if technical progress, normally represented by A is to be endogenized, then the decisions that make A grow must be rewarded somehow. But because the aggregate production function exhibits constant returns in capital (K) and labour (L) alone, according to Euler's theorem it will take all of the economy's output to pay capital and labour their marginal products in producing final output, leaving nothing left to pay for the resources used in improving technology. Thus a theory of endogenous technology cannot be based on the usual theory of competitive equilibrium, which requires that all factors be paid their marginal products (Aghion & Howitt, 2009, p. 47).

One example of early attempt to endogenize technical progress is Kaldor (1957). In his model Kaldor abandons the notion of an aggregate production function and the distinction between increases in productivity due to capital and those due to technological progress. Kaldor introduced the concept of a "technical progress function", which says that the growth rate of labour productivity is equal to an exogenous part (assumed to be positive) and a part that depends on the growth rate of the capital stock. In his model the steady state rate of growth was independent of savings and was determined by the exogenous properties of the technical progress function.

One very important early attempt to endogenize technical progress is Arrow (1962b)[2]. Arrow used a mechanism called "'learning by doing'". The idea is that the growth of technical progress is an unintended by-product arising from the experience of producing new capital goods. The technical knowledge acquired in the production process, immediately spill over to the entire economy. This is possible due to the non-rivalry aspect of knowledge. Each subsequent new capital good incorporates all the knowledge available, thus, becoming more productive. However, once built their productive efficiency cannot be altered by subsequent learning. In Arrow (1962b), the learning takes place only in the capital goods industry; no learning takes place in the industries using the capital goods. The 'learning by doing' was purely external to firms producing and to the firms that acquired the new capital goods. Thus, both capital and labour employed by those firms continue to receive their marginal products, since no additional compensation would be paid to A. However, the growth of A became endogenous, in the sense that an increase in the saving propensity would affect its time path (Aghion & Howitt, 1998, p. 23). The model was fully worked out only in the case of a fixed capital-labour ratio and fixed (but vintage-specific) labour requirements. This implied that in the long run

[2] Other early contributions where technological change was treated endogenously include Schmookler (1966); Haavelmo (1954); Kaldor & Mirrlees (1962); Nordhaus (1969); Shell (1973); Uzawa (1965).

the growth of output was limited by growth in labour, thus in the absence of exogenous population growth, economic growth is no longer endogenous and becomes zero. In that sense, Arrow's model was not fully endogenous.

An important empirical regularity about the mechanism of 'learning by doing' is that its external effect is bounded. So if the number of industries is fixed and their learning effects are bounded, growth cannot be sustained in the long run. A solution to this problem is to consider the possibility of new products being constantly introduced by way of learning externalities across industries and/or R&D. Such mechanism was introduced in later models based on innovations. Despite its shortcomings, Arrow's idea of 'learning by doing' formed the basis of the simplest type of endogenous growth model known as the AK model.

During the 1980's and 1990's a large number of neoclassical models were developed wherein technical change was treated endogenously. This wave of publications came to form what today is commonly called neoclassical endogenous growth theory (NEG). NEG models can be divided into three types: AK, product-Variety and Schumpeterian models. Product-Variety and Schumpeterian models are two branches of a class of models known as "innovation-based"models, which emphasize the role of technology spillovers in the determination of the long-run growth rate (Aghion & Howitt, 2009).

2.2.1 AK Growth Models

The AK models, were the simplest, and still highly aggregated types of NEG model . They were based on the idea that growth is directly linked to two processes: 'learning by doing' and capital accumulation. When firms accumulate capital, 'learning by doing' generates technological progress, which is itself a kind of capital good (disembodied capital good), that tends to raise the marginal product of capital, thus offsetting the tendency for the marginal product to diminish when technology is unchanged. The model results in a production function of the form $Y = AK$, in which the marginal product of capital is equal to the constant A (Aghion & Howitt, 2009, p. 48). The source of increasing returns in AK models at the aggregate level is not capital accumulation itself, but the learning processes. According to this type of model, high growth rates are sustained by saving a large fraction of output, needed to finance a higher rate of technological progress.

The first AK model that accounted for sustained growth in per-capita output was that of Frankel (1962). Frankel wanted to reconcile the positive long-run growth result of Harrod-Domar with the factor-substitutability and market-clearing features of the Solovian model. In order to do that he used Arrow's 'learning by doing' mechanism. He recognized that because individual firms contribute to the accumulation of technological knowledge when they accumulate capital, Harrod-Domar model did not require fixed coefficients and that aggregate productivity would depend upon the total amount of capital that has been accumulated by all firms. Therefore, as in Solow, Frankel's model displayed factor-substitutability (with Cobb-Douglas production technologies) and market-clearing, and as in Harrod, the model generated a long-run growth rate that depended on the saving rate, which was assumed to be constant.

Despite Frankel's earlier contribution, Romer (1986) and Lucas (1988) are considered the pioneering works of the neoclassical endogenous growth theory. Romer (1986) built an AK model, where productivity increased as a result of learning-by-doing externalities of the same sort as in Frankel (1962), but in which the constant saving rate was replaced by representative individual intertemporal utility maximization à la Ramsey (1928).

Lucas (1988), inspired by Becker (1964) theory of human capital, developed an AK model where the creation and transmission of knowledge occurs through human capital accumulation. He distinguishes two sources of human capital accumulation (or skill acquisition), namely education and 'learning by doing'. By assuming that human capital accumulation involves constant returns to the existing stock of human capital the model produces a positive growth rate in the steady state.

2.2.2 Horizontal Innovation: Product Variety Models

A second wave of NEG models came with the development of the so-called product-variety or expanding variety models. These are based on horizontal innovation, a type of innovation that causes productivity growth by creating new, but not necessarily improved, varieties of intermediate products. This kind of innovation can also be interpreted as a process innovation.

One of the advantages of product-variety endogenous growth models is the fact that they allow for a more explicit treatment of innovation and a better analysis of its structural effects. Most models based on horizontal innovation follow a similar structure consisting of three sequentially connected sectors: one sector that produces various ‘designs’ (‘ideas’, ‘knowledge’, etc.); a second sector that uses these ‘designs’ to produce various intermediate goods; and a third sector that uses the intermediate goods to produce the final good (and in most models, the final good is used-foregone-as an input in producing ‘designs’ and/or intermediate goods) (Park, 2010, 755).

Romer (1987) using the framework of monopolistic competition extended by Ethier (1982)[3], developed an early version of a product-variety growth model. He assumes that productivity growth comes, not from learning externalities among individual firms, but from the continuous increase in the variety of specialised intermediate products, which prevents aggregate capital from running into decreasing returns. In this second model Romer formalized an idea present in Young (1928), which is that growth can be sustained by the increased specialisation of labour across an increasing variety of activities. As the economy grows the larger market makes it worth paying the fixed costs of producing a large number of intermediate inputs, increasing the division of labour (specialisation) and raising the productivity of labour and capital, which maintains growth (Aghion & Howitt, 1998, p. 36).

Romer (1990) developed a more elaborated product-variety model. He improved his previous model by introducing a competitive research sector, which uses human capital and the existing stock of knowledge to generate new knowledge, (new designs) for new inputs (intermediate goods or machines) as a result of voluntary profit-motivated horizontal innovations. A monopolistically competitive intermediate-goods sector uses the new designs together with forgone output to produce a new variety of an intermediate good (new machines). The consumer goods sector produces final output using labour and intermediate goods, with a production function with a functional form borrowed from Ethier (1982). The final good is can be used for consumption and investment (in producing blueprints).

In Romer (1990) there are two sources of increasing returns, namely specialisation (increased labour division) and research spillovers. When a new design enables the production of a new intermediate good (new machine) there is an increase in the division (specialisation) of labour, so an increase in the variety of machines, raises the productivity

[3] The basic approach to the benefits from variety comes from Spence (1976). Dixit & Stiglitz (1977) refined Spence’s analysis and used to express consumer preferences over a variety of goods. Ethier (1982) applied this representation to inputs of production.

of labour. Additionally, a new design also increases the total stock of knowledge and thereby increases the productivity of human capital in the research sector, generating research spillovers. All researchers benefit from the accumulated knowledge A embodied in the existing designs, in other words technological knowledge is a nonrival good. But at the same time knowledge is also excludable in the sense that intermediate firms must pay for the exclusive use of new designs which are monopolized by the firms which created them. A characteristic of the model is that even though the aggregate production function exhibits constant returns to scale from the viewpoint of final good firms, which take the variety of machines as given, there are increasing returns to scale for the economy as a whole.

The product-variety framework has been extended in several directions[4]. Grossman & Helpman (1991, chapter 4) model utility as a function of an expanding variety of consumer goods due to a sort of product innovation but where innovative products are in no way superior to older varieties, what eliminates the possibility of product obsolescence. In their framework real income increase because of the consumer shows love-for-variety, meaning that the greater is the number of differentiated varieties that the individual consumes, the higher is his utility.

2.2.3 Vertical Innovation: Schumpeterian Models

The product-variety type of growth model, like all the other type of models, has some problems. One of them is the fact that it assumes that the cost of inventing a new product declines as society accumulates more ideas, and this implies a positive relation between the rate of technological change and the absolute quantity of labour engaged in R&D. Such empirical regularity has not been observed in most advanced countries[5]. Another limitation of the product-variety type of growth model is that it assumes away obsolescence of old intermediate inputs. So when a new variety of a machine is invented it is used alongside all of the previous vintages of that type of machine. If old intermediate inputs were to become obsolete over time, the division of labour summarized in the aggregate factor A would cease to increase systematically over time, and hence would cease to ward off the growth-destroying forces of diminishing returns (Aghion & Howitt,

[4] We refer the reader to Gancia & Zilibotti (2005) for a more thorough review.
[5] This implication has been criticized empirically by Jones (1995, 1999).

1998, p. 39). This type of model do not capture the competitive aspect of innovations, since most of the time when a new machine comes to the market, it does not complement previous models but replaces them.

In order to overcome the no-obsolescence limitation of the product-variety models one needs to move away from horizontal innovation models and into vertical innovation models of quality improvement. Models based on vertical innovation grew out of modern industrial organization theory, and came to be known as Schumpeterian models of endogenous growth. This type of models embody the force that Schumpeter (1942) called "creative destruction", and draw on the idea that growth is generated by a random sequence of quality-improving or also called vertical innovations that make existing products obsolete. In Schumpeterian models of endogenous growth a new variety of intermediate good replaces the old one, and its use raises the technology parameter, A, by the constant factor.

Despite some earlier works[6], the benchmark model of Schumpeterian endogenous growth was developed by Aghion & Howitt (1992). In their model the research sector is portrayed as in the patent-race literature surveyed in Tirole (1988) and Reinganum (1989). Growth results exclusively from technological progress generated by competition among research firms that create innovations. Each innovation consists of the invention of a new intermediate good, whose use as input allows more efficient methods to be used in producing the consumption good. Research firms are motivated by the prospect of monopoly rents that can be captured when a successful innovation is patented. The monopoly rents, however, will only last until the next innovation, which will render obsolete the existing intermediate good (Aghion & Howitt, 1992).

While these two last types of NEG models complement each other, neither of them analyse the role of demand on the innovation process, nor the evolution of consumer's preferences as income per-capita increases. Moreover, in these models, the old products disappear only through the introduction of new products, which means that the number of final products remain constant.

Much of the work developed by the exogenous and the early NEG theory adopted an aggregated strategy. Despite being insightful on the conditions required for a steady

[6] One of the earliest versions of a Schumpeterian endogenous growth model is Segerstrom et al. (1990). In their model, sustained growth arises from a succession of product improvements in a fixed number of sectors.

state growth path, the structure and diversification of economic system was neglected in favour of deepening the understanding of the determinants of growth and its effects. The later endogenous growth models, such as the product-variety and the Schumpeterian models have showed that an important mechanism of sustained growth is the rise of variety based on new and improved capital. The evolution of economic system through diversification implies a change in productive structure. However, these models have difficulties in explaining major processes of structural changes, sector interdependence and transfer of resources across different industries. Aghion and Howitt (1998, 65) recognise that these models

> [...] miss the stages of development in which resources are gradually reallocated from agriculture to manufacturing and then to services, all with different factor requirements and different technological dynamics. The economy is always a scaled up version of what it was years ago, and no matter how far it has developed already prospects for future development are always a scaled up version of what they were years ago.

When we compare the two generations of neoclassical growth models, the exogenous and endogenous, we can observe that they are similar in a number of aspects. First, they both treat growth as being essentially a supply-driven process. Second, in both approaches, diminishing returns in technology is the factor which brings about a slow down of economic growth. Third, they both assume that aggregate demand passively adjusts to accommodate output growth. Finally, both approaches take as given consumers' tastes and preferences, and assume that they remain fixed as income grows. At the micro-level their main focus is to determine the set of relative prices that reconciles these given tastes and preferences with the limited resources and technological capacity available to satisfy them (Argyrous, 2002, p. 237). At the macro-level, the sum of these preferences forms the aggregate consumer demand, which adjusts passively to changes in prices at the micro-level so that aggregate demand always equals aggregate supply.

2.3 Dual Economy Model: The Precursor of Growth with Structural Change Models

One-sector growth models have been extensively used by economists of all schools of thought. The main advantage of this type of model is their minimalist structure, what makes them easily tractable. One-sector models focus essentially on the growth process within a modern sector. However, they abstract from several features of the process of economic growth, making it not suitable for analysing the first stages of economic development and inter-sectoral phenomena such as industrialization or structural change.

By the beginning of the 1950s, some economists dissatisfied with the approach followed by aggregated growth theory, started to developed alternative frameworks better suited to describe the process of structural change that occurs in the first stages of economic development. One of these alternative approaches came to be known as dual economy model, and include the works of Lewis (1954), Ranis & Fei (1961) and Jorgenson (1961) among others.

Dual economy models are commonly used to represent the first stages of an economy's development. A period in which, emphasis is laid on the balance between capital accumulation and the growth of population, each adjusting to the other. These models are based on the concept of structural heterogeneity, wherein the economy is composed of two asymmetric sectors, a relatively advanced and a relatively backward sector. These asymmetries are not merely technological but also include institutional, behavioural, and informational aspects. These two sectors follow completely different economic logics, so they cannot be lumped together as the neoclassical theory does with the capital and the final goods sectors. The two sectors differ in terms of the goods produced, the nature of the growth process, wages and employment mechanisms. The traditional sector is characterized by subsistence wages, abundance of labour, low productivity, labour-intensive production process, no capital accumulation and no technical progress. In contrast, the modern sector is defined by higher wages as compared to the traditional sector, higher marginal productivity, capital-intensive production process, technical progress. Dual economy models focus on inter-sectoral relationships and flows. Growth in these models depend in large part on the rate at which resources, especially labour, can be transferred from the traditional to the modern sector. The sectors have received other denominations in the literature such as capitalist and subsistence, modern and traditional, industry and agriculture, urban and rural and primary and secondary.

The first dual economy model was formalized by Lewis (1954). The Lewis model, as it came to be known, is a classical model consisted of an underdeveloped economy with two sectors: a traditional, overpopulated subsistence sector characterized by zero marginal labour productivity and a high-productivity modern sector. There is an unlimited supply of labour available at subsistence wage, so labour is able to move to the modern sector without lowering output. Moreover, capitalists save everything, but workers (and landlords) save nothing. The unlimited supply of labour from the traditional sector keeps wages from increasing in the modern sector and ensures that capital accumulation in that sector is sustained over time. Both labour transfer and the modern sector employment growth are brought about by output expansion in the modern sector. The speed with which this expansion occurs is determined by the rate of investment and capital accumulation in the modern sector. Thus, the source of structural transformation can be found in the unlimited supply of labour from the traditional sector. The Lewis model underlines the importance of transfers of resources from low-productivity to high-productivity activities in the process of economic development.

Jorgenson (1961) is another seminal example of a dual economy model. He develops a neoclassical version of Lewis dual economy model. Jorgenson's model assumes two sectors: agriculture and industry. Agricultural output depends on labour and on a fixed amount of land. Industrial output depends on labour and on capital. The production functions have the Cobb-Douglas form, with constant returns to scale and neutral technological change. Only labourers in the advanced sector can be assumed to respond to wage differentials between employment opportunities in agriculture and industry. Industrial wage-rate is equal to the marginal product of labour. In Jorgenson's model, the division of labour between the two sectors is straightforward: if there is no agricultural surplus, all labour remains in the agricultural sector; if an agricultural surplus is generated, labour is released from the land and transferred to the manufacturing sector at a rate that is equal to the rate of growth of the agricultural surplus. Manufacturing production is only possible if some initial capital stock exist, however small it may be, the model shows that there is no critical level of initial capital endowment below which no sustained growth is possible. Even the smallest initial stock can give rise to sustained growth. Once the initial injection of capital is made, capital accumulation in the manufacturing sector continues at a pace determined by the growth of the labour force in that sector and by the terms of trade between the two sectors. The modern sector is also subject to technical progress, so the more rapid the rate of technical change, the higher the saving ratio, and the more rapid the rate of growth of population, the more rapid is the pace of growth in the advanced sector. Eventually, the economy is dominated by the development of the advanced sector and becomes more and more like the advanced economic systems described neoclassical model and less like a dual economy.

In dual economy models, the assumption of unlimited supply of labour is crucial, because it allows the possibility of having increasing saving and in turn capital accumulation and faster growth without increasing wages. However, this process does not continue forever. Eventually, the withdrawal of labour from the traditional sector reaches the point at which the marginal product of the remaining labour rises to equality with the subsistence wage. From this point on wages rise in both sectors as growth continues and workers can choose and offer their labour to the highest bidder (the traditional or the modern sector). A labour market, in a neoclassical way, is formed. The dualistic structure is over and the economy enters a new stage of development characterized by scarcity of labour.

There is another class of models with two-sectors that divide the economy into capital and consumption goods sector. Those models are very different from the dual economy ones described in this section, and despite having two sectors, are not intended at analysing structural transformation. In that class of model all the final good sectors (agriculture, manufacturing, service) have the same structure, thus they can be aggregated into one unified "consumption"goods sector. Examples of this type of models are Meade (1961), Uzawa (1961b), Kurz (1963), Takayama (1963, 1965).

2.4 Final Comments

The exogenous and its successor the endogenous theory of economic growth can be understood as a long and arduous effort, which last for almost half a century, dedicated to identify and isolate the determinants of sustained growth. Throughout this endeavour the theory and its models focused on some specific determinants of economic growth such as saving and investment decision, human capital, 'learning by doing' and R&D in an increasing returns to scale environment in order to explain sustained long-run economic growth. However, the phenomenon of structural change has been absent in mainstream growth theory. Until the beginning of the 1990's most works on structural change were empirically-oriented contributions. Only recently that there has been a consistent effort to make structural change an integral part of modern growth theory. It is interesting to note that structural change has been present in the business cycle theory but not in growth theory. Despite the absence of the expression "structural change", there were some early attempts to explain macroeconomic fluctuations on the basis of industrial structural change made by Robertson (1915), Aftalion (1927), Frisch (1933)[7] and Schumpeter (1939). Even Schumpeter referred to "industrial structure" rather than "structural change" and used the term in the same meaning as Alfred Marshall, namely industrial diversification, despite of the known criticism from the first to the second. Modern growth theory chose to follow the aggregated approach, inspired by the nascent Keynesian and neoclassical macroeconomic theory.

Dual economy models can be seen as one of the first attempts to model economic growth with structural change. They provided important insights on the determinants and on the outcomes of sectoral structural dynamics. However, dual economy models models were limited in scope and not fully equipped to incorporate all the driving mechanisms of structural change. More comprehensive models were required in order to fully analyse the complexities involved in the process of structural transformation. These models are reviewed in the next chapter, which explores the modern literature on structural change, including recent empirical and theoretical developments.

[7] Ragnar Frisch was who invented the term "econometrics" and was the first to use the words "microeconomics" to refer to the study of single firms and industries, and "macroeconomics" to refer to the study of the aggregate economy.

3. THE ECONOMICS OF STRUCTURAL CHANGE

Although, in the aggregate, the process of long-run economic growth might seem stable, in historical perspective, the decline of the agricultural sector and the expansion of the industrial and the service sectors have led to a massive transformation of the economic landscape. One possible way to define structural change is: the process of reallocation of resources across these three broad sectors (agriculture, manufacturing, and services) that accompanies modern economic growth. Many authors including Fischer (1939), Clark (1940), Kuznets (1957) and Chenery (1960) have documented this process. Despite most of these works being predominantly empirical, some authors started to lay down the basic theoretical relations that later would become the base of the theory of structural change. One example is Colin Clark. He related the observed shifts to differential productivity growth and Engel effects, the two principal elements in subsequent attempts to account for the transformation in the structure of production (Syrquin, 1988, 213).

Some authors, such as Simon Kuznets and Luigi Pasinetti, despite following very different approaches[1], are praised for having emphasized the important aspects of structural change. Kuznets[2] in particular documented and analysed the process of structural transformation and showed it to be an integral part of modern economic growth. His analysis gave rise to a broader search for uniform features or "stylized facts"of development and growth.

This chapter is devoted to analyse the mechanisms behind the phenomenon of structural change, defined here as the process of reallocation of resources across the three broad sectors of agriculture, manufacturing, and services. Section 3.1 presents a brief introduction to the issue. Section 3.2 reviews some of the most recent works on the literature that integrates growth and structural change, dividing them according to the driving force behind the structural change; demand or supply. Section 3.3, presents the theory of structural change of Luigi Pasinetti, which does not focus on the trichotomy of agriculture, manufacturing, and services, but is one of the greatest contributions to the analysis of structural dynamics. Section 3.4, summarizes three models that analyse the relation of growth and structural change from the evolutionary theory's perspective.

[1] For more on the distinction of the two approaches refer to Syrquin (2012).

[2] Kuznets (1966) documented structural change for 13 OECD countries and the USSR between 1800 and 1960.

Section 3.5 presents some of the work done by what can be called the New Latin American Structuralist (NLAS) growth theory. By combining three important branches of the literature, the NLAS has tried to develop an integrated theory that includes increasing per capita income, sectoral dynamics, productive diversification and international specialisation across countries. Section 3.6 closes the chapter with some final comments.

3.1 Some Facts About Structural Change

In his 1971 Nobel lecture, Simon Kuznets summarized six characteristics of modern economic growth that emerged in his analysis based on conventional measures of national product. The third of his six characteristics states that "the rate of structural transformation of the economy is high. Major aspects of structural change include the shift away from agriculture to nonagricultural pursuits and, recently, away from industry to services."(Kuznets, 1973, 248). Kongsamut et al. (2001) termed these empirical regularities the 'Kuznets facts' in analogy to the stylized facts established by Kaldor (1961).

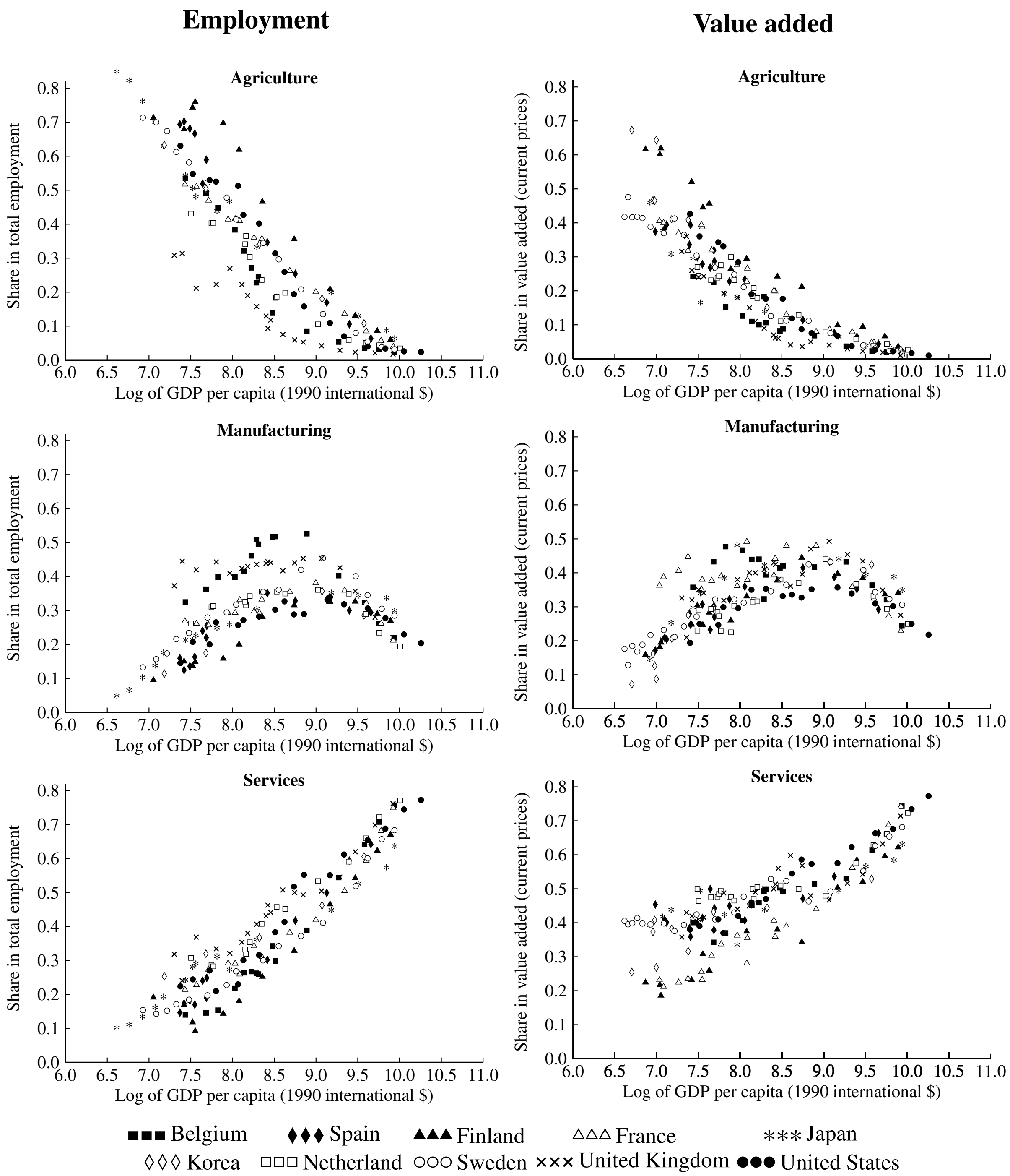
In a more recent contribution, Maddison (1987) documented the same sort of regularity on the reallocation of labour in six major industrialized countries (France, Germany, Japan, Netherlands, U.K. and U.S.). His data shows that the average employment share in agriculture was 46.0% in 1870 and fell to 5.5% by 1984. During the same period, the average employment share in the service sector increased from 26.4% to 62.2%. The most commonly observed pattern of structural change is characterized by a systematic fall in the share of labour allocated to agriculture over time, by a steady increase in the share of labour in services, and by a hump-shaped pattern for the share of labour in manufacturing. Herrendorf et al. (2014) reported evidence of this pattern for currently rich countries[3].

In addition to the regularities regarding the reallocation of the labour force among the three sectors, an interesting pattern in the manufacturing sector has been documented. Figure 3.1 from Herrendorf et al. (2014) plots the historical time series of sectoral employment shares and value added shares over the 19th and 20th century for the following ten countries: Belgium, Finland, France, Japan, Korea, Netherlands, Spain, Sweden, United Kingdom and United States. The vertical axis is either the share

[3] Belgium, Finland, France, Japan, Korea, Netherlands, Spain, Sweden, United Kingdom and United States.

of employment or the share of value added in current prices in agriculture, manufacturing and services. The horizontal axis is the log of GDP per-capita in 1990 international dollars as reported by Maddison (2010). The figures show the stylized facts, or Kuznets facts, of structural transformation.

Figura 3.1: Sectoral Shares of Employment and Value Added - Selected Developed Countries 1800-2000.



Source: Herrendorf et al. (2014).

Looking at figure 3.1 we can observe that over the last two centuries, increases in GDP per capita have been associated with decreases in both the employment share and the nominal value added share in agriculture, and increases in both the employment share and the nominal value added share in services. Interestingly, the manufacturing sector has behaved differently from the other two sectors: its employment and nominal value added shares follow a hump shape, that is, they are increasing for lower levels of development and decreasing for higher levels of development (Herrendorf et al., 2014).

Despite being an empirical fact that structural change is an inseparable companion of the growth process, structural change has not been fully integrated into growth theory yet. One of the reasons for this is the fact that many of the early models of growth were based on aggregate variables. While this approach highlights important aspects of the growth process, it is unable to analyse the driving forces of structural change. In order to incorporate structural dynamics into growth models, multi-consumption sectors/goods models had to be developed. Luigi Pasinetti recurrently pointed out the limitations of aggregate models. He has argued that,

> Technical progress, productivity, consumption, investment, are no longer sufficient to define the economic system in a dynamic research. We must go beyond this, and find out what lies behind the façade of these aggregate expressions. In short, the research must be formulated in disaggregate terms. (Pasinetti & Spaventa, 1960, 1770)

A second reason is the fact that for a long time the analysis of growth has focused predominantly on aspects of supply and technical change. This particular focus has led to the development of models ill-equipped to replicate the empirical features of structural change. Let us briefly elaborate on that. Structural change is thought to originate from two sources. It is the result of sectoral differences in income elasticities of demand (demand side explanation), or of sectoral differences in productivity growth (supply side explanation). On the demand side, standard neoclassical growth models normally assume homothetic preferences, which imply that all the goods have the same unitary income elasticities and that rich and poor individuals consume all the goods in the same proportion. On the supply side, they usually assume identical productivity growth across all sectors. Although not very realistic, these assumptions simplify the analysis and make models more tractable and suitable for analysing other aspects of growth than structural change. According to Moshe Syrquin:

> For Kuznets, and more generally in economic history and development, growth and structural change are strongly interrelated. Once we abandon the fictional world of homothetic preferences, neutral productivity growth with no systematic sectoral effects, perfect mobility, and markets that adjust instantaneously, structural change emerges as a central feature of the process of development and an essential element in accounting for the rate and pattern of growth. It can retard growth if its pace is too slow or its direction inefficient, but it can contribute to growth if it improves the allocation of resources by, for example, reducing the disparity in factor returns across sectors or facilitating the exploitation of economies of scale (Syrquin, 2012, 72).

In order to allow the emergence of structural change and replicate more realistic sectoral dynamics, theorists had to depart from the traditional assumptions and introduce new mechanisms in their models. In the next section we review some of the articles that model economic growth with structural changes. The articles are divided according to the channel that drives structural change: demand or supply.

3.2 Models of Growth and Structural Change

Recently, a new wave of growth models have developed more comprehensive ways of analysing the process of structural change. Theorists have identified several channels to explain the process of structural change, ranging from demand-driven factors to purely technological determinants. The mechanism used to integrate structural change into growth models depends in part on the assumptions made about the origin of the structural change and in part on the characteristics of the model, if it is balanced or non-balanced. Although balanced aggregate growth is not an inevitable property of growth models, most of them strive to be consistent with the Kaldor facts[4]. Since, one of the properties of balanced aggregate growth models is that the fraction of capital and labour allocated to different industries remain constant over time, *prima facie*, combining structural change at the sectoral level with the Kaldor facts at the aggregate level seems to be non-trivial. However, some authors were able to explain a transition along which, aggregate variables exhibit an almost balanced growth path, while there is sectoral change.

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[4] These facts propose that the growth rate, the interest rate, the capital output ratio, and the labour share are roughly constant over time while capital per worker and real wage grows over time (Kaldor, 1961). This set of stylised facts are probably the most influential contribution of Kaldor to the analysis of economic growth. They provide a good characterization of the long run behaviour of the U.S. economy and are believed by many to be a reasonable approximation of the long-run growth experience of a modern economy.

3.2.1 Utility-Based Explanation: The Demand Side

One strand of the literature have proposed that differences in income elasticities of demand across sectors are at the root of the process of structural change. This explanation has been dubbed 'utility-based' and suggests that if one assumes non-unitary expenditure elasticities of demand, then increases in real per-capita income levels affect the sectoral expenditure shares leading to the reallocation of expenditure across sectors. This income effect may decrease the expenditure shares of necessities and increase the expenditure shares of luxuries even at constant relative prices, leading to the reallocation of resources, including labour across sectors. In order to capture these differences in income elasticity of demand across sectors, non-homothetic preferences have to be assumed. Authors that locate the origin of structural change in long-run changes in consumer tastes incorporate structural dynamics into their models through the use of non-homothetic utility functions. These are multi-sector models consistent with Engel's law[5] wherein structural change is driven by differences in the income elasticity of demand across goods. In the next pages we briefly review a series of articles and models that use different specifications of non-homothetic preferences to derive structural change from differences in income elasticities of demand across sectors.

Matsuyama (1992) assessed the role of agriculture productivity in the process of industrialization. He builds a two-sector model of endogenous growth, where he is able to combine Engel's Law with learning-by-doing externalities in the industrial sector. The labour market is competitive and the wage rate is equalized across the two sectors. He makes two key assumptions in his article: (a) preferences are non-homothetic and the income elasticity of demand for the agricultural good is less than unitary, and (b) manufacturing productivity rises over time because of learning-by-doing. Agricultural productivity is determined purely exogenously. The model also analyses the relationship between industrialization and the assumptions concerning the openness of the economy. For the closed economy case, the model finds that an exogenous increase in agricultural productivity shifts labour from agriculture to manufacturing and thereby accelerates

[5] Engel's law states that as a household's income increases, the fraction that it spends on food (agricultural products) declines. Several authors have found that Engel's law holds not only for food, but it is a more general law of consumption. According to Houthakker (1987) Engel's law is one of the most robust empirical findings in economics. Deaton & Muellbauer (1980) concluded that the vast majority of studies obtains the result that the expenditure share of a product changes systematically with income.

economic growth. However, for the open economy case, there exists a negative link between agricultural productivity and economic growth. An economy with less productive agricultural sector allocates more labour to manufacturing and will grow faster, in contrast, an economy with a more productive agricultural sector squeezes out the manufacturing sector de-industrializing over time and growing slower. Some limitations of the model are the fact that agricultural productivity is determined purely exogenously, there is no learning-by-doing in agriculture and technological advances in manufacturing do not improve agricultural productivity.

Echevarria (1997) introduced structural change on a dynamic general equilibrium model. Her paper explains the relation between income levels and rates of growth as an effect of changes in sectoral composition driven by different income elasticities for primaries, manufacturing and services. She assumed three different consumption goods (primary, manufacturing and services) demanded by agents displaying non-homothetic preferences. There are two factors of production: labour and capital, and each consumption good is produced using different factor intensities. Capital is produced in the second sector (manufacturing) and distributed among all the sectors. Since the productivity rate in each sectors is different and exogenously determined, the growth rate of the economy is affected by changes in sectoral composition, which is in turn driven by non-homothetic preferences (Echevarria, 1997, 431). The assumption of nonhomotheticity of preferences is crucial and drives the results in the model. Echevarria explains that a poor country, which consumes mainly necessities (primary), cannot save (invest) much. As it gets richer, it will invest or save more, thereby encouraging growth. At the same time production will shift to the second sector (manufacturing), which has a higher rate of technical change; thus, the first effect is reinforced. Both effects, increase in investment and increase in average total factor productivity, imply an acceleration in the growth rate. Yet, the savings rate (net savings or investment as percentage of GDP) does not increase monotonically over time, eventually the savings rate falls, thus driving the growth rate down. If, at the same time, production shifts to the third sector (service) with its lower rate of technical change, that will reinforce the reduction in the growth rate Echevarria (1997, 445).

Echevarria's model is able to predict a series of regularities observed in the real world. These regularities include: (1) a hump-shaped correlation between growth rates and income levels, with poor countries having the lowest rate of growth and middle-income countries having the highest growth rate; (2) the higher proportion of agriculture on GDP in poor countries, and the higher proportion of services on GDP in rich countries; (3) the comparatively more expensive services in rich countries; (4) the larger share of the labour force employed in agriculture in less-developed countries, and the larger share employed in services in developed countries; and (5) the higher share of output paid to labour in rich countries. Echevarria concludes that sectoral composition explains an important part of the variation in growth rates observed across countries.

Park (1998) analyses the transformation of an economy based on agriculture to one based on manufacturing. In order to do that he developed a three-factor, three-good endogenous growth model with a non-homothetic utility function of the Stone-Geary type in order to analyse the transitional dynamics of structural change. The three factors are land, unskilled labour and the capital stock, which includes physical and human capital. The three goods are agricultural goods, manufacturing goods and new capital goods. In Park's model the long-run growth rate of the economy is determined by the size of the capital-producing sector, but the growth rate of each good is different on the balanced growth path as well as during the transitional period and although the capital-producing sector is assumed to be the engine of economic growth, the sectoral growth rate of this sector is not necessarily highest. Stone-Geary utility is useful and convenient, since it allows the presence of subsistence level and the possibility of income elasticity of demand for goods be less than unitary. This kind of utility function implies that there is a minimum, or subsistence level of food consumption that the household must consume. After this level has been achieved, the household starts to demand other items, in this case manufactured goods. Therefore, Stone-Geary utility has the ability to yield different growth rates during the transitional period. Park shows that sectoral contributions of respective industries to economic growth are variable and different and that structural change in production and factor use favours the manufacturing industry as opposed to the agricultural industry during the transitional period.

Laitner (2000) shows that structural change can affect the economy's saving rate through the operation of Engel's law taking account the composition of assets in household portfolios. Assuming the existence of non-homothetic preferences, Laitner builds a model with two sectors: agriculture and manufacturing. The model is based on the following structure: household saving follows the stages of life-cycle behaviour with overlapping generations, where each household lives for two periods, and is identical to all others born at the same time. There are no inheritances or bequests and the household takes prices as given. Young households will save all labour earnings and retired households will spend all their wealth. This pattern do not change over time even if incomes change, but the composition of consumption depends on changes in income. On the production side, aggregate effective labour supply depends on the number of young households and current technology. Exogenous technological progress raises per-capita income over time. In Laitner's model, a household whose standard of living is low cares only about agricultural consumption, but a household with a high standard of living, on the other hand, becomes satiated with agricultural products and devotes its remaining expenditures exclusively to manufactured goods. Hence, Engel's law implies a demand shift from agriculture to manufacturing goods as income rises. Consequently, the economy goes from an initial position where it specialises in agriculture to devoting more and more labour to manufacturing production. In the limit, the share of agriculture in total GDP tends to zero and the share of manufacturing converges to unity.

Kongsamut et al. (2001) build a three-sector model displaying what they define as a generalized balanced growth path, which is a trajectory consistent with the dynamics of structural change and along which the real interest rate is constant. Structural change is driven by income effects. The authors use a Stone-Geary utility to represent the consumer preferences. They directly manipulate the function in order to generate different income elasticities of the goods and sectors. Income elasticity of demand is assumed to be less than one for agricultural goods, equal to one for manufacturing goods, and greater than one for services. Although being perhaps the most popular in the literature, specially in models with two goods, this Stone-Geary-type specification has some disadvantages. It is only applicable when working with a small number of goods and in order to obtain consistency with the Kaldor facts the model had to rely on a widely criticized knife-edge condition, which ties together preference and technology parameters and implies constant relative prices.

Caselli & Coleman (2001) present a joint study of the U.S. structural change (the decline of agriculture as the dominating sector) and regional average wage convergence. The authors attempt to explain the decline of agriculture as the dominating sector in the United States (US) and the convergence of income per-capita across the various states that constitute the United States. The authors use human capital accumulation to explain discrepancies in labour and output trends in the decline of agriculture. The model features a closed economy with two locations, North (N) and South (S); two goods, farm (F) and manufacturing (M); and three factors of production, land (T), labour (L), and capital (K). They assume that North and South are equally good at producing manufactures but the South enjoys a comparative advantage in the production of farm goods. Structural change is explained by non-homothetic preferences of Stone-Geary type, represented by a less than unit income elasticity of demand for farm good.

They find empirical evidence that most of the regional convergence is attributable to the structural transformation: the nationwide convergence of agricultural wages to non-agricultural wages and the faster rate of transition of the southern labour force from agricultural to non-agricultural jobs (Caselli & Coleman, 2001). However, in order for the model to be consistent with balanced growth, a restriction had to be imposed. Despite being initially higher than in manufacturing for a period of time, TFP growth in agriculture must fall linearly and converge to the same value in the long run.

Although these two mechanisms of structural change are able to explain the decrease of farm share in GDP and agriculture share of employment, the authors argue that they cannot explain the rise in farm relative wages. In order to explain the rise in farm wages Caselli & Coleman (2001) include a downward shift in the farm-labour supply curve, so that the decline in farm employment is consistent with the increase in farm wages. They model the relative supply of farm-workers as the result of farm-born workers' optimal decision whether to remain in agriculture or join the urban sector. They assume that sectoral migration involves a cost, such as investment in the differential skills required by urban, non-agricultural employment. They introduce a new mechanism that give rise to the required shifts in the relative supply of farm-workers, namely a long-run decline in the relative cost of acquiring non-agricultural skills across subsequent cohorts of farm-born individuals. Caselli and Coleman argue that the effective cost of education decreased in the first half of the 20th century, thereby increasing the relative supply of skilled workers, decreasing the relative price of non-agricultural goods and moving resources out of agriculture (Herrendorf et al., 2014).

Gollin et al. (2002) built a model of structural change to explain why the process of industrialization occurs at different dates and why it proceeds slowly. The authors, like others, also make use of a non-homothetic utility function of the Stone-Geary variety in order to generate structural transformation. The model uses a basic neoclassical framework modified to include both an agricultural and a non-agricultural sector. Countries begin the process of industrialization only after they satisfy their basic agricultural needs. Hence, low agricultural productivity can substantially delay industrialization. Asymptotically, agriculture's employment share shrinks to zero, and the model becomes identical to the standard one-sector neoclassical growth model. One important conclusion is that improvements in agricultural productivity can accelerate the start of industrialization and so, have large effects on a country's relative income.

Foellmi & Zweimüeller (2008) construct a model consistent with the Kaldor and Kuznets facts based on the assumption of hierarchical preferences. Their model shows that reallocation of labour is driven by differences in income elasticities across sectors. The basic idea of their analysis is that household expand consumption along a hierarchy of needs, where goods are weighted according to their essentiality. In order to depict the equilibrium process of growth and structural change consistent with the Kaldor facts, the 'hierarchy function' which characterizes the willingness of consumers to move from goods with high priority to goods with lower priority must take a particular form with some specific characteristics. In their model the authors adopt a particular form of power function. Foellmi's model is capable of generating realistic movements not only of labour out of agriculture and into services, but also a hump shape in the evolution of the manufacturing share, with a period of increasing manufacturing employment followed by a period of de-industrialization just as depicted in figure 3.1.

Differently from other models that also adopt the utility-based explanation for structural change with non-homothetic preferences, their model introduces a situation where new goods are continuously introduced. Each new good starts out as a luxury with a high income elasticity and ends up as a necessity with a low income elasticity. According to the authors these non-linearities in Engel curves generate consumption cycles that account for structural change. For the sake of simplicity and to highlight the demand channel the authors abstract from technological differences across sectors and assume that the relative price structure remains constant over time. The authors assume exogenous and identical sectoral productivity growth across all sector. In order to generate constant growth rates consistent with the Kaldor facts, technological differences had to be assumed uncorrelated with the hierarchical position of a good.

3.2.2 Technological Explanation: The Supply Side

Another strand of the literature adopts the alternative thesis that views structural change as a supply side phenomenon brought about by changes in relative prices. These changes affect the expenditure structure whenever the elasticity of substitution across sectors is different from one. The supply side explanation for structural change is known in the literature as the 'technological' explanation.

Two mechanisms have been proposed to explain this process. The first mechanism explains that relative price changes result from differential productivity growth across sectors. One of the first articles to analyse this mechanism was Baumol (1967). The second mechanism is based on changes in the relative prices of inputs if sectors vary in the intensity with which they use inputs and there are changes in the relative supply of factors (Herrendorf et al., 2014). Despite their differences, these two mechanisms can account for structural change from a supply side perspective.

Baumol (1967) was one of the first articles to model structural change based on the technological explanation in which unbalanced growth is a general feature of the growth process. Baumol built a model consisted of two sectors, a 'progressive' and a 'non-progressive' one and of a single factor, labour. In the progressive sector, as a result of continuing technological progress, labour productivity grows cumulatively at a constant compounded rate r, and in the non-progressive sector labour productivity is constant. Baumol's models makes four propositions: (1) through time the non-progressive sector unitary cost of output, relative to that of the progressive sector, will rise without limit; (2) unless demand for it is highly inelastic, output in the non-progressive sector will decline and perhaps approach zero; (3) in order to maintain balanced growth, represented by a constant ratio between the outputs of the two sectors, the share of the labour force allocated to the non-progressive sector must approach unity; (4) an attempt to maintain balanced growth, in a world of unbalanced productivity, will lead to a zero rate of growth of real output-per-capita.

More recently, Ngai & Pissarides (2007) formalized the first mechanism, that derives structural change purely from different sectoral total factor productivity (TFP) growth rates. They show that, given a low (below one) elasticity of substitution between the final goods produced by each sector, and assuming that all goods have unit income elasticity, different TFP growth rates predict sectoral employment changes. Ngai & Pissarides' model contains many consumption goods and a single capital good, supplied by a manufacturing sector. They assume identical Cobb-Douglas production functions in all sectors except for their rates of total factor productivity growth. Each sector produces a differentiated good that enters a constant elasticity of substitution (CES) utility function. The model is able to predict a shift of employment away from sectors with high rate of technological progress toward sectors with low growth, and eventually, in the limit, all employment converges to only two sectors, the sector producing capital goods and the sector with the lowest rate of productivity growth (Ngai & Pissarides, 2007, 438). In order to satisfy Kaldor's stylized facts of aggregate growth a logarithmic intertemporal utility function is required. Ngai & Pissarides (2007)'s results are consistent with the evidence concerning the decline of agriculture's employment share, the rise and then fall of the manufacturing share, and the rise in the service share. The key requirement for their results is a low substitutability between final goods. Ngai & Pissarides's model confirms Baumol (1967)'s claim that the production costs and prices of the stagnant sector should rise indefinitely and labour should move in the direction of the stagnant sector. However, it contradicts Baumol's conclusion that as more weight is shifted to the stagnant sector, the economy's growth rate will be on a declining trend and eventually converge to zero. The reason for the contrasting result is that Ngai & Pissarides included capital in their analysis, which was left out in Baumol (1967).

Acemoglu & Guerrieri (2008) construct a model that not only allows for different rates of technical progress but also for differences in capital intensities across sectors. In their model capital deepening and sectoral factor intensity differences are the determinants of the relative price dynamic. The authors build a two-sector general equilibrium model with constant elasticity of substitution preferences and Cobb-Douglas production technologies, where they show that, capital deepening increases the relative output of the more capital-intensive sector while simultaneously induces a reallocation of capital and labour away from that sector (Acemoglu & Guerrieri, 2008). The authors also show that provided the elasticity of substitution is less than one, one of the sectors (typically the more capital-intensive one) grows faster than the rest of the economy, but because the relative prices move against this sector, its (price-weighted) value grows at a slower rate than the rest of the economy. Moreover, they show that capital and labour are continuously reallocated away from the more rapidly growing sector, thus generating sectoral structural change. Their model shows that convergence to equilibrium is slow with the capital share in national income and the interest rate varying only by relatively small amounts.

Despite reconciling structural change with balanced growth, in Acemoglu and Guerrieri's model the Kaldor facts hold only asymptotically. Moreover, regarding the demand side, the authors do recognize the importance of income effects but abstract from non-homotheticity of preferences, placing the source of structural change on the supply side of the economy.

It is possible to believe that the two explanations for structural change described above, the utility-based and the technological explanation are not mutually excludable, but actually complementary. Boppart (2014) builds a model where he integrates the two explanations for structural change, the utility-based and the technological explanation. He combines non-homothetic preferences and differential TFP growth reconciling the Kaldor facts with structural change simultaneously determined by relative price and income effects. Boppart relies on non-Gorman preferences where the marginal propensity to consume goods and services differs between rich and poor households and inequality affects the aggregate demand structure. Moreover, the author conducts a structural estimation that allows for the decomposition of the structural change into an income and a substitution effect showing that both channels of structural change are of roughly equal importance. The empirical analysis shows that the model's functional form fits the data and the framework can replicate the observed structural change quantitatively Boppart (2014, 2192). To our knowledge Boppart's model is the only one that integrates both sources of structural change described in the literature.

Consistency with the Kaldor facts is not a feature present in all the models that combine growth with structural change. The reason for this might be found in the interpretation of the Kaldor facts. According to Pasinetti, Kaldor never interpreted his 'facts' as an empirical justification for the construction of a theory of balanced growth. Nicholas Kaldor himself did not claim that any of the regularities he had uncovered would be constant at all times. Jones & Romer (2010) points out that the Kaldor facts might be outdated since they revolved around a single state variable, namely physical capital. They argue that the facts should be updated and include variables such as ideas, institutions, population, and human capital. Another article that questions the validity of the Kaldor facts is Jorgenson & Timmer (2011). The authors examine whether Kaldor's stylized facts provide an accurate description of more recent structural changes. The authors especially question Kaldor's stability of the share of labour in GDP over time, they find that the labour share in value-added is declining and that the decline is pervasive in all sectors and regions, except in US finance and business services.

How well the original Kaldor facts really represent long-run economic growth nowadays is an open question. Especially regarding developing and less developed countries. Some authors believe that general equilibrium and aggregate balanced models may not be the best way to represent long-run economic growth. In the next sections we briefly summarize two different approaches to analyse the issue of structural change, the Passinetian model of structural change and the evolutionary growth theory. These approaches do not see the economy as a balanced system or as an unbalanced one heading towards equilibrium. Instead, they see the economic system as being in constant change, in constant evolution.

3.3 Pasinetti's Structural Change Theory

An important contribution to the development of the theoretical foundations of structural change was given by Luigi Pasinetti. One of the merits of his contribution was to make the issue of structural change the centre of his analysis of growth. Pasinetti shifted the focus of the analysis from the determinants of growth to the structural dynamics of the economic system. His theory of structural dynamics was laid out in two books published in 1981 and 1993. The name of his books are illustrative of his interest in explaining de origin and effects of structural change on growth, and especially, on the development of societies: *Structural Change and Economic Growth* (1981) and *Structural Economic Dynamics* (1993).

Pasinetti follows a completely different approach from the authors surveyed in the previous sections. His theory is based on post-Keynesian and classical elements and stresses the inevitability of structural change. While for some authors structural change is a transitional step towards balanced growth, in Pasinetti's approach disequilibrium and instability are the normal state of affairs. Economic growth is seen as a process of continuous change. Pasinetti's view of structural change is based on what he calls a pure production model. This model abstracts from institutions of the economic system and the behavioural modes of economic agents and concentrates on the natural or primary characteristics that enable a system to grow.

The prime mover of structural change in Pasinetti's analysis is technical progress as a result of exogenous learning activity. Technical progress in a sector has two effects. The first effect is the reduction of the labour coefficient in that sector and consequently an increase in productivity. Increases in productivity lead to increases in per-capita income. These two things are inseparable as Pasinetti puts it: "Increases in productivity and increases in income are two facets of the same phenomenon. Since the first implies the second, and the composition of the second determines the relevance of the first, the one cannot be considered if the other is ignored." (Pasinetti, 1981, 69). Increases in per-capita income "endows single individuals with the possibility of obtaining larger amounts, or a larger number, of goods and services, or entirely new goods and services altogether." (Pasinetti, 1993, 37). However, consumers do not expand their demand for all goods proportionally, consumption expansion follows Engel's law, when consumption of a good has become satiated, only then attention turns to the next higher good in the hierarchical ordering. The second effect of technical progress is the emergence of new products. Thus, over time, the sector's labour and demand coefficients are modified by technical progress and by changes in consumer's tastes. If the rate of variation of these two coefficients are equal, the economy expands the various sectors proportionately, and its structure remains unchanged over time. This is what happens in the traditional models of exogenous growth. However, nothing guarantees that these rates will be the same. If the rates are different, as normally happens, the economy experiences structural dynamics of employment. Hence, in Pasinetti's analysis, structural dynamics of technology and demand generates structural dynamics of employment.

One of the weakness of Pasinetti's model was the assumption that the labour and demand coefficients were exogenously determined. Recently, Andersen (2001) overcame this weakness and developed an evolutionary micro founded model based on a set of rules that made endogenous the demand coefficients, the labour coefficients, and the number of available sectors.

3.4 Evolutionary Theory and Structural Change

With its roots on the works of Nelson & Winter (1982) and Dosi (1982) among others, evolutionary theory places itself in the direct line of Joseph Schumpeter writings regarding long-run economic growth and development. Evolutionary theory's early works on growth focused predominantly on the issues of changes in technology and innovation, concentrating less on full analytic solutions and more on illustrative simulations including agent-based modelling. Evolutionary models relating growth with structural change are fairly recent. In this section we review some of these works.

One example of this literature is Montobbio (2002). In his article, Montobbio analyses the determinants of structural change and aggregate productivity growth based on the aggregation of the behaviours of heterogeneous firms in different economic sectors. Using an evolutionary approach, Montobbio's model sheds new light on the determinants of sectoral shifts and non-uniform growth. The main purpose of his analysis is to show that productivity growth, at sectoral and aggregate levels, is the result of a general evolutionary process. In order to do that the model explores the properties that connect the distribution of heterogeneous firms to the growth of industries, and the mechanisms that account for changes in the relative weight of different sectors (i.e. structural change) within an economy. Aggregate productivity growth is analysed as the result of the aggregation and interdependence of heterogeneous firms and sectors and is guided by the selection mechanisms within and between industries. Moreover, he analyses the impact of sector-specific income elasticities of demand. One of Montobbio's findings is that the aggregate growth rate of labour productivity depends negatively upon the covariance between the sectoral elasticities of demand and the sectoral average unit costs, positively on the exogenous rate of demand growth and is proportional to the variance between sectoral unit costs and to the average of firms' unit cost variances within sectors.

Following a different approach from Montobbio, Saviotti & Pyka (2004) construct an evolutionary model where growth and structural change are driven by the creation of new sectors. The authors develop a dynamic model of growth involving qualitative change where economic development is driven by the creation of new industrial sectors. In their model, they put forward two hypotheses that link variety to economic development: (1) the growth in variety is a necessary requirement for long-term economic development, and

(2) variety growth, leading to the development of new sectors, and productivity growth in pre-existing sectors, are complementary and not independent aspects of economic development. The authors justify these two hypotheses based on the imbalance between productivity growth and demand growth raised in Pasinetti (1981, 1993). According to Saviotti & Pyka, if the economy were constituted by a constant set of activities, in presence of growing productivity it would become possible to produce all demanded goods and services with a decreasing proportion of the resources used as inputs, including labour. This imbalance would then constitute a bottleneck for economic development and could lead to technological unemployment. The introduction of new goods and services can be a way of compensating for the potential displacement of labour and of other resources.

Another article that tackles the issue of structural change from an evolutionary perspective is Ciarli et al. (2010). The authors offer a theoretical analysis of long-run economic growth as an outcome of structural changes. In an agent-based micro-founded framework they investigate the properties of a growth model that embeds the relation between technological and organizational change, income distribution and the dynamics of consumption affecting macroeconomic growth. Microeconomic behaviours are modelled in line with the large and consolidated evolutionary theory of technical change and economic growth, while the macro-framework borrows from the structuralist literature including the presence of a capital sector and endogenous consumption classes. They observe and explain the interactions between technological change, firm organization, income distribution, consumption behaviour and growth. Ciarli et al. (2010) confirm the relevance and interdependence of these structural changes and underline their microeconomic sources.

Agent-based evolutionary models are able to integrate elements that were disconnected and isolated in the literature within a coherent theoretical framework. They also have the ability to generate non-linear dynamical systems that exhibit non-ergodic properties, something that is not possible in standard neoclassical models (Gräbner, 2016). Therefore, agent-based evolutionary models seem to be perfectly suitable for working with cumulative causation processes.

3.5 Structural Change and International Trade

In recent years, there has been an effort to develop an integrated theory that includes increasing per capita income, sectoral dynamics, productive diversification and international specialisation across countries. Structural change theory has focused in explaining the growth process of a country as a closed economic system. It has been paying scarce attention to the effects of structural change on world inequality, which trap some nations under poverty and ties them in a perpetual lagged position. A more complete explanation of this process has been made available by what can be called the New Latin American Structuralist (NLAS) growth theory. This approach combines three important branches: the contribution of Latin American Structuralism (LAS), originally due to Prebisch (1950), ECLAC (1954), Cimoli (1988) and more recently to Cimoli & Porcile (2010, 2014); the growth theory led by demand under balance of payment restriction Thirlwall (1979) and technological change and its effects on international trade Dosi et al. (1990). An empirical study in which the NLAS approach is grounded is Hausmann et al. (2006), where the authors show that countries that export goods associated with higher productivity levels grow more rapidly, even after controlling for initial income per head, human capital levels, and time-invariant country characteristics.

According to the NLAS approach, the level of diversification and technological development of a country's productive structure conditions its insertion in the international trade which, in turn, determines its balance of payment (BoP) equilibrium and its national gross product consistent with its BoP equilibrium. A country with low productive diversification, due to low technological capabilities, tend to specialise in the production of few commodities in order to explore the relative, but restrict advantages. Since this economy does not produce many of the final and intermediate goods that it requires, its dependency on imports is high. However, as the income elasticity of its imports tend to be high, the income elasticity of its exports tend to be low. This combination produces a permanent restriction on growth. If the rate of growth remains high for consecutive periods, a crisis emerges to correct the BoP deficit, reducing the growth rate. The crisis can be postponed by attracting capital inflow through high interest rates. However, high interest rates discourage investment leading to a situation of insufficient demand. Growth in this economy cannot be sustained, after some periods accumulating external deficits the system exhibit its internal contradiction and growth without fail stops. The NLAS approach falls in line with the Schumpeterian and endogenous theory of growth when it locates the source of long-run sustained growth in the innovation and diversification processes. Yet, the NLAS approach differs from the tradition, in two important aspects. The first is the recognition of the important role played by aggregated demand, which became the main channel through which the restrictions operate. The second is the integration of structural change and growth into the international trade literature.

A recent example of this literature is Cimoli et al. (2010). The authors depart from the Schumpeterian assumption that countries that increase the share of technology-intensive sectors in their economic structures benefit more from technological learning and innovation. These countries are more able to respond to changes in the international markets and to compete in sectors whose demand grows at higher rates. The authors find evidence that certain kinds of structural change (namely those in which technologically intensive sectors increase their participation in the economy) favour growth. The process of structural change was measured by the Krugman Index and by the participation of high-tech and medium-tech exports in total exports. Both variables show a positive association with relative rates of growth in the international economy.

In the NLAS approach, structural change is embedded in the idea of productive diversification, which is captured by an aggregate index that represents the number of different goods the economy is able to produce and export. Structural change is analysed from a macroeconomic standpoint and, therefore, different from the evolutionary micro-approach where structural change emerges from the decision of individual firms. Despite being a macroeconomic approach, the NLAS has the advantage of allowing for the analysis of the insertion of a country or region into the international economy.

3.6 Final Comments

The models reviewed in this section have contributed to the understanding of the mechanisms behind the relationship between growth and structural change and have pushed further the frontier of the field of growth theory. However, as Acemoglu points out "[...] we are still far from a satisfactory framework for understanding the process of sectoral reallocation of factors [...]" (Acemoglu, 2009, 720). Moreover, the majority of these models focus on the reallocation of productive factors from some sectors of the economy to others, normally from agriculture to manufacturing and then to services. However, Jorgenson & Timmer (2011) argues that the classical trichotomy among agriculture, manufacturing, and services may have lost most of its relevance. They have discovered enormous heterogeneity among different services subsectors, largely ignored in the previous literature, something that calls for greater attention to individual service sectors to understand the process of economic growth and structural change. Models of structural change have to derive better ways to account for sector heterogeneity. We argue that the use of more flexible theoretical approaches that allow greater sectoral heterogeneity is a necessary condition for a better understanding of the interrelations between economic growth and structural change.

Moreover, the majority of growth models that deal with structural change assume the number of sectors and/or products in the economy to be constant. From the analytical standpoint, this simplification makes models more tractable. However, if one wants to understand the interactions between sectoral dynamics and growth, models should account for the increase/decrease in the number of sector/products in the economy. Lastly, the analysis of the impacts of structural change on international trade and its feedback effects on growth must also be considered if a comprehensive theory of growth and structural change is to be developed.

4. GROWTH, CONSUMPTION EVOLUTION AND INNOVATION

Increases in productivity, demand saturation and the emergence of new products and new sectors are all integral parts of the growth process. This chapter analyses how these factors are connected, and how they interact giving rise to a cumulative process of sustained economic growth. Section 4.1 analyses the cumulative aspect of the growth process. We introduce the concept of cumulative causation and discuss how it is related to the theory of sustained long-run growth. Section 4.2 introduces the debate about the driving forces the process of product innovation. Section 4.3 explores the Engel's law and the tendency of Engel curves to flatten out at high income levels. This tendency creates bottlenecks that can bring growth to a halt. These bottlenecks can be overcome through the emergence of new goods that elicit new demand. Section 4.4 presents the derivation of part of the model developed in Foellmi & Zweimüeller (2008) which introduces a situation where new goods are continuously introduced in the economy. In the model household expand consumption along a hierarchy of needs, where goods are weighted according to their essentiality. Each new good starts out as a luxury with a high income elasticity and ends up as a necessity with a low income elasticity. These non-linearities in Engel curves generate consumption cycles. As consumption and output of the newly introduced product increase, capital is accumulated, process innovation and economic growth initially accelerate, and later decelerate as consumption reaches the saturation point. In order to sustain the economic growth a new product has to be introduced and a new cycle started. Section 4.5 closes the chapter with some final comments.

4.1 The Cumulative Aspect of Growth

Growth is inherently a cumulative process, and under the right conditions it can be self-re-enforcing. One way to analyse the process of sustained economic growth is through a concept called cumulative causation. In abstract terms, cumulative causation describes a relationship between an initial change in an independent variable and a dependent variable, whereby the dependent variable in turn causes a change in the formerly independent variable in the same direction as the initial movement. Circularity is at the heart of cumulativeness, for if A caused B, but B had no feedback to A, then, moving it again in the initial direction, there would be an equilibrium after the initial effect if A is exhausted. With feedback, however, the system evolves. The effect is cumulative if the feedback reinforces and amplifies the original change (Schmid, 1999).

Despite being often associated with Nicholas Kaldor, the concept of cumulative causation has a long tradition in the social sciences. The notion was already present in Quesnay's *Tableaux*, and in the works of Thorstein Veblen (1898). However, it was Gunnar Myrdal (1957) who first described it in detail and named it. Although Myrdal started out applying the concept of circular cumulative causation to money and macroeconomics (Myrdal, 1939), his most famous application was to the underprivileged situation of African Americans in the US (Myrdal, 1944). Myrdal also employed the principle to explain persistent underdevelopment. In *Economic Theory and Under-Developed Regions* (1957), Myrdal argues that the differences in economic development within and between countries are the result of cumulative processes, whereby regions or nations that have an initial advantage maintain and expand it as they attract more resources than others.

It is difficult to trace back the exactly origin of theory of cumulative causation. According to (Fujita, 2007) the theory has basically three different origins and currents. One deriving from the works of Allyn Young and Nicholas Kaldor on macroeconomic growth, another deriving from the works of Veblen on institutional change and a third one deriving from the work of Wicksell (1936) on monetary theory. Young and Kaldor's current explains macroeconomic growth from both demand and supply sides based on the concept of increasing returns. We will concentrate our analysis on this current[1].

Despite being fond of the Walrasian approach in his early works, Kaldor came to reject that approach in place of one based on cumulative causation and increasing returns. The basic hypothesis of Kaldor's cumulative causation theory first appeared in Young (1928). At the heart of his theory was Young's concept of increasing returns; that an increase in the degree of specialisation among firms and industries raises the overall productivity of the economy. One of Young's arguments was that a growing market allows for a wider range of specialised firms and industries, which leads to comprehensive cost reductions and hence to further increase in the size of the market. His argument was an extension of Adam Smith's dictum 'the division of labour is limited by the extent of the

[1] For more on the theory of cumulative causation and other applications refer to Berger (2009).

market' (Smith, 1776). For Smith, the greater the extent of the market, the greater the amount of sales and the greater the growth in productivity through the division of labour. In Smith's theory of division of labour, the causality runs from the increase in demand for goods to the increase of supply of goods. The possibility of the opposite causality was not clear in Smith's work nor was the determinants of the scale of the market. It was Young who filled in the gap arguing that the size of the market is determined by the volume of production using the Marshallian concept of reciprocal demand also known as 'offer curves'. This resulted in a new vision of economic growth based on cumulative causation theory (Fujita, 2007). Young did not use the term cumulative causation, however, he argued that economic growth, under the condition of increasing returns, is "progressive and propagates itself in a cumulative way"(Young, 1928, 533). In the following passage, he explains how growth propagates itself in a cumulative way:

> [W]hen the commodities exchanged are produced competitively under conditions of increasing returns and when the demand for each commodity is elastic, in the special sense that a small increase in its supply will be attended by an increase in the amounts of other commodities which can be had in exchange for it. Under such conditions an increase in the supply of one commodity is an increase in the demand for other commodities, and it must be supposed that every increase in demand will evoke an increase in supply. (Young, 1928, 534)

Chandra & Sandilands (2005) point out that Young's increasing returns do not derive from large-scale production nor from production by large firms, but from external economies that are passed on to other firms in the form of reduced prices. Moreover, they are external rather than internal, macroeconomic rather than microeconomic. Thus their presence does not necessarily lead to the emergence of monopoly or to the breakdown of competition (Chandra & Sandilands, 2005, p. 468). As a matter of fact, Young advocated that increasing returns are achieved through more rather than less competition, and thus are most fully realised in a well-functioning competitive market system. What Young had in mind was 'large production' rather than 'large-scale production' in response to expansion of the market as a whole (Young, 1928, p. 531). In his view, increasing returns result from economies of specialisation rather than economies of scale, and specialisation does not arise due to fixed costs or monopoly power but due to the expansion of the size of the market.

According to Chandra & Sandilands (2005), Young had a demand-based view of growth, inputs of labour, capital and technology were seen more as the outcome of the growth process than its cause[2], and although he knew that different industries grow at different rates depending on their elasticities of demand and supply, in his mind the growth process is such that "even with a stationary population and in the absence of new discoveries in pure and applied science there are no limits to the process of expansion except the limits beyond which demand is not elastic and returns do not increase" (Young, 1928, p. 534).

Kaldor's theory of cumulative causation incorporated Young's idea of increasing returns. Kaldor was convinced that technical change was at the heart of the growth process, and it was directly linked to the existence of increasing returns. However, for him this was not sufficient to explain the growth process. Thus, Kaldor went a step further and argued that demand functions as a link between increases of production capacities due to increasing returns and the generation of income growth[3]. Demand induces a 'chain reaction' along the economy. Thus, "the increase in demand for any commodities [...] reflects the increasing in supply of other commodities, and vice versa" ((Kaldor, 1966, 19)). For Kaldor, cumulative causation was an integral part of the growth process. In his model, increases in demand for goods lead to the expansion of the market, which creates opportunities for increasing specialisation giving rise to increasing returns. Increasing returns raise the productivity of inputs, generating growing incomes, which feeds back into increases in demand. Under conditions of increasing returns, capital and labour become complementary, therefore sectors expands simultaneously as the expansion of one sector generates demand for the goods of other sectors. In the real world forces for change are endogenous, and there is a cumulative process of change (Thirlwall, 1987, 322).

Additionally, Kaldor recognized that sectors differ in their productivities. Therefore, if demand shifts to goods produced by more productive sectors, average productivity levels will increase. Kaldor (1966, 1967) emphasize that the composition of demand is a crucial factor affecting productivity growth and consequently economic growth. He was convinced that manufacturing is different from agriculture and most service activities in its ability to generate increasing return in Young's sense. Thus, he suggested that aggregate growth would depend upon manufacturing growth, and not the other way around. According to him increasing returns occur in manufacturing with agriculture and services

[2] To support this view, (Chandra & Sandilands, 2005, p. 466-467) refer to some empirical works, affirming that there are considerable evidence to suggest that growth is indeed not caused by inputs of labour or capital.

[3] See Kaldor (1966, 1972)

subject to diminishing and constant returns respectively. Hence, economies that developed their manufacturing sector would be able to embark on a virtuous cycle of productivity and income growth; in contrast, economies specializing in agriculture or services would experience stagnating productivity and incomes.

One of the main aspects of models were growth results from cumulative causation, such as Kaldor (1972, 1981); Dixon & Thirlwall (1975); Verspagen (2002), is the existence of dynamic increasing returns through the Verdoorn law and the mechanisms underlying it. This law was coined by Kaldor after the Dutch economist Petrus Johannes Verdoorn, who found in 1949 a positive correlation between labour productivity and output growth in manufacturing from an analysis of sectoral and international industry data. He observed that there was a relative constancy of the average value of the elasticity of labour productivity with respect to output of about 0.45, a result that may indicate the presence of increasing returns to scale in industry.

Verdoorn was among the first[4] to find such empirical regularity in cross section of industries. His work went unnoticed until Kaldor drew attention to it in his famous inaugural lecture in 1966, in which he used Verdoorn Law to examine the slow growth rate of the post-war UK economy. Although the Verdoorn Law might reflect the existence of both static and dynamic increasing returns in manufacturing, Kaldor emphasized the later. Static increasing returns to scale relate to the size and scale of production units and are a characteristic largely of manufacturing where in the process of doubling the linear dimensions of equipment, the surface increases by the square and the volume by the cube. Dynamic increasing returns to scale refer to increasing productivity derived from 'induced' technical progress that arise from 'learning by doing' as analysed by Arrow (1962b), and from economies of specialisation resulting from the overall expansion of an interrelated set of industries (or Allyn Young's (1928) idea of 'macro-increasing returns'). While the former returns to scale are reversible, i.e. they can be lost if the level of production of the firm declines, the later are not, because they arise from 'learning by doing', thereby does not vanish, even if the level of production falls. McCombie (2002) argues that the Verdoorn Law may result from a combination of 'learning by doing' and increasing returns at the firm level (in Arrow's sense), together with an increasing degree of specialisation

[4] A regularity similar to Verdoorn Law was described earlier by Solomon Fabricant in 1942. Fabricant using cross-industry data for the US found that productivity growth is negatively correlated with the growth of wage costs per unit of output and with the rate of growth of prices. These regularities are called Fabricant's laws.

(in Young's sense) at the inter-firm or inter-industry level.

After Kaldor's seminal work, the Verdoorn Law has been the object of many studies and debates. The specification of the law and the has been associated with a large number of possible econometric problems including an errors-in-variables problem, omitted-variable bias, and simultaneous-equation bias. Nevertheless, the law has proved remarkably robust across different data sets[5].

Both Young and Kaldor's analysis of growth were based on dynamic increasing returns to scale, which raises firms productivity. Moreover, they both had a demand-based view of growth. However, if one agrees with Pasinetti and Witt's view that demand tends to saturate, then the logical question would be "How an economy can overcome demand saturation?". The answer can be found in the process of product innovation. Foellmi & Zweimüeller (2008) argues that "When consumption evolves along a hierarchy of wants and consumers get increasingly satiated with existing products, new goods have to be continuously introduced to ensure that demand keeps pace with technical progress." Economic growth has been strongly influenced by the introduction of new products. It is a fact that the introduction of new consumers' products is a necessary condition for economic progress in a market economy. If there were only the same unchanged final products available in the market, consumers would inevitably reduce their purchases as they become satiated. In the next section, we introduces the debate about the driving forces the process of product innovation.

4.2 The Driving Forces of Innovation

The role of demand and supply factors in the process of innovation has been the focus of intense debated for many decades (Mowery & Rosenberg, 1979). In the 1950's and 1960's two competing group of theories emerged to explain the sources of innovation: the "demand-pull"theories and the "technology-push"theories. According to the former perspective, what drives innovation is need pull forces (opportunities pulling from peoples' needs and the market), firms innovate when they anticipate strong demand. The later assumes supply push forces (technological opportunities pushing forward from scientific discoveries, and internal capabilities of firms) as the main sources of innovation,

[5] For a more comprehensive review on the empiric and theoretical foundations of the Verdoorn Law refer to McCombie et al. (2002).

thus following a supply-side view where innovation is a linear process from research to development and ultimately to commercialization.

Demand-pull theory of innovation started with the works of Griliches (1957) and Schmookler (1962, 1966). Schmookler emphasized the importance of demand-induced inventions[6] pointing out the fact that an innovation requires not only pre-existing knowledge but also a sufficiently urgent want that consumers seek to satisfy. He wanted to link up inventive activity with the structure of human wants and therefore with changes in the composition of demand.

In his book *'Invention and Economic Growth'* Schmookler (1966) presented a study of U.S. patent statistics on inventions in four industries (rail-roads, agricultural equipment, paper, and petroleum) and concluded that demand was more important in stimulating inventive activity than advances in the state of knowledge. He argued that innovation would be driven by expected profitability. That means, if an improvement in production technique or product quality results in a higher mark-up per unit, then the higher the number of units sold, the greater would be the value of the future stream of profits. If the size of the market is taken as proxy for expected demand, then incentives to innovate should be positively correlated with the size of the market. In 1982 Scherer re-ran Schmookler's analysis including all manufacturing industry rather than a small subset, and although weaker than those obtained by Schmookler, found significant correlations between capital goods patenting and using industry investment (Scherer, 1982).

In addition to Schmookler (1962)'s positive correlation between a reduction in unit cost, due to process innovation, with the level of output, more convincing analytical account of this effect was found by Cohen & Klepper (1996a,b). Assuming a mechanism where firms spread the cost of R&D among their current output (cost spreading), they showed that firms incentive to engage in innovation are correlated with their current output, represented by firm size. They found this correlation to be stronger for process innovation than for product innovation. Cohen & Klepper (1996a) successfully tested their theory in a sample of 587 firms from various sectors.

On the other hand, contrary to the arguments of demand-pull theories, the theories of technology-push have emphasized the supply of scientific and technical knowledge as a crucial factor in developing opportunities of major innovations. Among the fiercest critics

[6] While Schmookler uses the term invention, we will use the terms 'invention' and 'innovation' as synonyms.

of pure demand-pull theories are Mowery & Rosenberg (1979). Dosi (1981) argues that the innovation process is very complex and advances in scientific knowledge play a very strong part in major innovations, especially at an early stages of the development of a new technological paradigm.

An interesting and rather alternative approach to this dichotomized debate is of Nelson & Winter (1977). Using the terminology R&D strategy for a particular set of heuristics regarding R&D project selection, they propose that a strategy that looks at the demand side and puts marketability ahead of technical feasibility when selecting a R&D project be defined as demand-pull strategy while a strategy that selects projects based first on technical feasibility be defined as technology-push (they call capabilities-push) strategy. They argue that demand-pull and technology-push strategies will have different consequences in terms of payoffs achieved (Nelson & Winter, 1977). According to them a demand-pull strategy normally results in modest cost and high confidence, whilst technology-push strategies will have a high payoff, if R&D projects are successful. However, they emphasize that a good R&D strategy must attend to factors on the demand side and factors on the supply side simultaneously. There is no point in undertaking projects that are technologically exciting and doable, but which have no demand, or to undertake projects which if successful would have a high payoff, but where there is no chance of success.

Nelson & Winter (1977) point out that several different studies have concluded that, if strategies can be dichotomized, then demand-pull strategy is by far the more common of the two, and when applied, is more likely to result in a commercially successful project than a strategy of capabilities-push. However, they stress that either a pure demand-pull or a pure technology-push strategy would appear to be naive.

While the relative importance of demand and supply factors has been hotly debated, it has never been questioned that demand factors play an important role in shaping the rate and direction of technological change. Clearly, if a firm intends to introduce a new product, it makes sense to produce one that meets consumer's needs, otherwise it probably will not be sold. This would seem to be a fundamental principle of business, and firms spend large sums on market research trying to understand people's need and preferences. Regarding the interplay between demand and supply, or as one may prefer the interplay between firms and consumers in the process of innovation, Freeman writes:

> [T]he crucial contribution of the entrepreneur is to link the novel ideas and the market. At one extreme there may be cases where the only novelty lies in the idea for a new market for an existing product. At the other extreme, there may be cases where a new scientific discovery automatically commands a market without any further adaptation or development. The majority of innovations lie somewhere in between these two extremes, and involves some imaginative combination of new technical possibilities and market possibilities. Necessity may be the mother of invention, but procreation still requires a partner. (Freeman & Soete, 1997, p. 201)

Nowadays, there is a consensus that knowledge and market demand, instead of being conflicting, are complementary factors in the development of new processes and products. Yet, given the heterogeneity of different sector the degree of the intensity of their influence on the process of innovation may vary depending on the phase of the innovation process and on the technological characteristics of the industries.

However when firms look at consumers' needs for selecting which R&D project to pursue they want to identify needs not yet satisfied. It is important to note that consciously or unconsciously, consumers have a hierarchy of needs and wants and that this hierarchy is shaped by the consumer's income. The consumer' willingness to pay for a product changes as his income increases and as his basic needs and wants are satisfied. Wants are ranked according to their priorities on what is called hierarchic preferences. In this hierarchy the most basic needs are ranked first and the more luxurious needs last. The number of needs currently satisfiable is limited by the number of existing goods, so innovations are needed to satisfy additional needs. If a firm decides to innovate based on marketability of its innovation, the scope for innovations consists of the list of those currently unsatisfiable needs which are technically feasible. Within this list the direction of actual innovation is determined by the relative urgency of these needs.

Once a successful product innovation is introduced its consumption expansion, like all the other goods, tends to follow an Engel's consumption cycle. In this cycle, as described by Kindleberger (1989, p. 9), demand starts off with high income elasticity, and then declines as income rises, a good starts as a luxury, with high income elasticity, and ends up as a necessity with low income elasticity. As consumption and output of the newly introduced product increase, capital is accumulated, process innovation and economic growth initially accelerate, and later decelerate as consumption reaches the satiation point. In order to sustain the economic growth a new product has to be introduced and a new cycle started.

4.3 Engel's Law and the Role of Demand-Creating Innovation

For more than a century scholars have observed that as economies grow and income rises household consumption of particular goods changes in a systematic way. The first scholar that investigated this relationship systematically was a German statistician named Ernest Engel. In his famous 1857 article Engel produced empirical evidence showing that the poorer a family is, the larger the budget share it spends on nourishment. This empirical regularity is known as Engel's law. Engel's analysis initially suggested that as income rises, the proportion of income spent on food falls, even if actual expenditure on food rises. Moreover, he argued that such a change in the composition of demand implies that, as the economy grows and per capita income increases, new resources can be dedicated to the production of other goods unrelated to food (Engel, 1857, p. 50). The relation that describe how household expenditure on particular goods or services depends on household income is called Engel curve[7].

Several authors have found that Engel's law holds not only for food, but it is a more general law of consumption[8]. This regularity is one of the most robust empirical findings in economics according to Houthakker (1987). Kindleberger states that,

> Engel's law applies to more than food, it is a general law of consumption. With growth, demand for some one or more products - but only a few at a time - starts off with high income elasticity, and then declines as income rises. (...) A given item may go through the Engel's consumption cycle of a luxury, with high income elasticity, to a necessity with low income elasticity. (Kindleberger, 1989, p. 9).

Moreover, Pasinetti argues that regardless of the level of income per-capita or the price structure, the proportion of income spent by each consumer on any specific commodity varies from one commodity to another, and as income increases, the tendency is not to increase proportionately the consumption of already bought goods and services, but rather to buy new goods and services (Pasinetti, 1981, p. 77). Due to these characteristics the literature on Engel curves often assume that they follow a logistic path.

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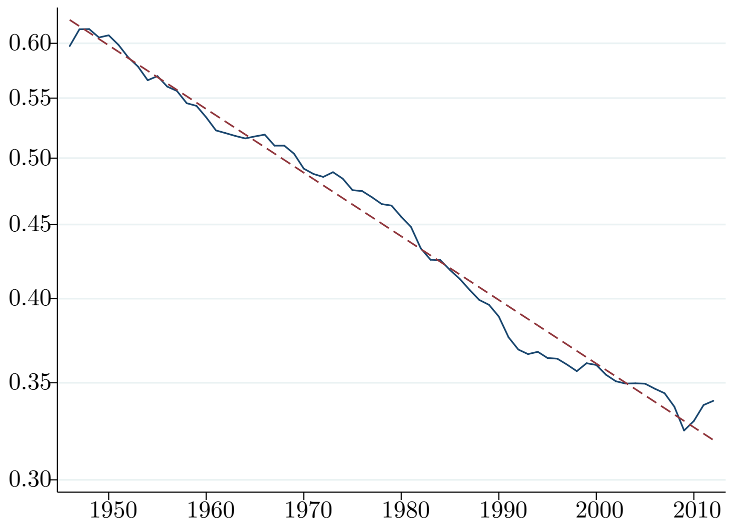
[7] For a more detailed account on Engel's law and Engel curves see Moneta & Chai (2010)

[8] Deaton & Muellbauer (1980) concluded that the vast majority of studies obtains the result that the expenditure share of a product changes systematically with income.

The empirical evidence indicates that the structure of consumption changes in a systematic way, not only across individuals, as we compare a rich and a poor individual, but also over time, as income per-capita increases (Foellmi, 2005, p. 3). In a recent study, Boppart (2014) using data from the Consumer Expenditure Survey (CEX) of the years 1986-2011 find that the share of goods in total personal consumption expenditure on goods and service sector in post-war U.S declines at a constant rate over time. Figure 4.1 from Boppart (2014) plots the share of personal consumption expenditures devoted to goods in the U.S. on a logarithmic scale. This regularity can only be explained by assuming non-homothetic preferences.

Figura 4.1: Expenditure share of goods



Notes: The figure plots the share of personal consumption expenditures devoted to goods in the U.S. on a logarithmic scale. The main (sub)categories the BEA classifies as 'goods' are: "motor vehicles and parts", "furnishings and durable household equipment", "recreational goods and vehicles", "food and beverages purchased for off-premises consumption", "clothing and footwear", "gasoline and other energy goods"and "other durable/nondurable goods". The dashed line represents the predicted values obtained by regressing the logarithmized expenditure share on time and a constant. The estimated slope coefficient and its standard error are -0.0101 and 0.00015, respectively. The regression attains an R^2 of 0.9848.

Source: Boppart (2014).

However, the change in the share of goods in total household consumption expenditure is not the only regularity regarding Engel curves. There is also a tendency for expenditure Engel curves to flatten out at high income levels. This tendency is frequently seen as evidence that major shifts in household expenditure take place as household income rises. Moneta & Chai (2014) using data from the UK Family Expenditure Survey and non-parametric techniques, find evidence of the tendency for Engel curves to saturate, is indeed widespread across a wide range of goods and services. This tendency was also described by Pasinetti (Pasinetti, 1981, p. 77). He argues that the expenditure on any particular good cannot increase forever, there is always an upper limit on the amount of expenditure that is allocated by households to any one particular good or service, regardless of how much household income grows. Although expenditure on different commodities display this limit at different levels of real income, its attainment is inevitable. Once the household reaches this upper limit its expenditure ceases to increase in response to increasing income.

If Engel curves saturate that means that the growth of production of a commodity or in an individual industry is bound to slow down, because demand grows fast initially but eventually slows down. As demand falls, production, capital accumulation and technical progress slow down. If there is no introduction of new products/sectors to elicit new growth in demand the economy's growth rate slows down. According to Aoki & Yoshikawa (2002), this is an indication that products and consequently sectors face different income elasticities of demand. Moreover, the existence of a saturation level implies that the demand growth for a particular sector will eventually slows down as more households reach the saturation level of income. As a result of the slowdown in demand growth, resources will be shifted away from industries where demand has saturated towards newly emerged industries producing goods for which demand has not yet saturated (Moneta & Chai, 2014).

Aoki & Yoshikawa (2002) build a growth model based on logistic Engel curves, where the factor restraining growth is saturation of demand. In contrast to the so called 'creative destruction', 'quality ladder' or 'product variety' models (Grossman & Helpman, 1991; Caballero & Jaffe, 1993), their model assume no TFP growth, thus for the economy to grow, capital must accumulate. However, saturation of demand constrains capital accumulation and leads the economy to deceleration of growth. Innovation or technical progress in their model creates a major new product or industry which commands high growth of demand and thereby elicits new capital accumulation and so sustains economic growth. Aoki and Yoshikawa's model is consistent with a common observation that for individual products, there is a logistic evolution in consumption and production which inevitably reaches a saturation point. Other important conclusions of their model are that the creation of new products/industries depend not only on profit motivated R&D,

but also heavily on basic scientific research and growth and saturation of demand often parallel diffusion among different households, thus appropriate income distribution policy which triggers diffusion of major product can be taken as a demand-creating innovation. Models like Aoki & Yoshikawa (2002) demonstrate that growth can not only be restricted by supply factors but also by demand factors.

Foellmi & Zweimüeller (2008) developed a model that introduces a situation where new goods are continuously introduced in the economy. Household expand consumption along a hierarchy of needs, where goods are weighted according to their essentiality. Each new good starts out as a luxury with a high income elasticity and ends up as a necessity with a low income elasticity. According to the authors these non-linearities in Engel curves generate consumption cycles. To demonstrate how these factors can be integrated into a standard neoclassical growth framework, in the next section we derive sections 2 and 3 of Foellmi & Zweimüeller (2008)'s model as an analytical exercise. Foellmi & Zweimüeller use the growth model developed by Ramsey (1928) and subsequently adapted by Cass (1965) and Koopmans (1965) (hereinafter RCK model) as a benchmark. However, as preferences are assumed to follow a hierarchy of needs, some interesting new dynamics emerge when compared to the standard RCK model. By solving the model on a step-by-step manner and making minor modifications, we intend to make the derivation more explicit than the one in their original article. Some changes were made in the optimal savings and capital accumulation section, so the derivation becomes analogous to the one in chapter 2, Part A of Romer (2011).

4.4 An Analytical Model of Growth and Engel's Consumption Cycle

In this section, we present the work on hierarchic preferences developed in Foellmi (2005); Bertola et al. (2006); Foellmi & Zweimüeller (2008). Although our focus is on the model presented in Foellmi & Zweimüeller (2008), the other two works provide valuable insights on the derivation of the model. In sub-section 4.4.1 we determine the equilibrium composition of demand across the different sectors. In this set-up instead of entering the utility function in a symmetric way, the different goods have different priorities. In sub-section 4.4.2 we incorporate the equilibrium composition of demand into the RCK model and finally in sub-section 4.4.3 we derive the optimal expenditure and capital accumulation paths. We conclude with some closing comments on sustained growth.

4.4.1 Hierarchic Preferences and Hierarchy Utility Function

Assuming a representative consumer economy with infinitely many potentially producible goods ranked by an index $i \in (0, \infty)$. There is a correspondence between consumption of good i and satisfaction of a certain need i. According to Foellmi (2005, p.10) a meaningful specification of hierarchic preferences has to consider three facts:

1. Needs are ordered.
2. Some goods may not be consumed because the consumers cannot afford them. Technically speaking, marginal utility at zero must be finite, at least for goods of lower priority.
3. If a consumer has additional income, he or she should spend it primarily on goods that have lower priority because the needs of higher priority are already saturated (at least in relative terms).

The consumers' preferences follow a hierarchic in the sense that the goods are ranked according to their priority in consumption. Hence, low-i goods are high-priority goods (necessities) and high-i goods are low priority goods (luxuries). Preferences are given by

$$u\left[c(i)\right] = \int_0^\infty \xi(i)v(c(i))di \tag{4.1}$$

where $\xi(i)$ is the hierarchy function, which is basically a weighting function and $v(c(i))$ is the baseline utility or subutility function that gives the utility derived from consuming good i in quantity c. The utility function $v(c(i))$ satisfies the usual assumptions $v' > 0$ and $v'' < 0$ and the hierarchy function $\xi(i)$ is monotonically decreasing in i, $\xi'(i) \leq 0$, which means that low-i goods receive a greater weight than high-i goods (Foellmi & Zweimüeller, 2008, p. 1319).

According to Foellmi & Zweimüeller (2008), differently from the standard monopolistic competition model (Dixit & Stiglitz, 1977) where all available goods are consumed in positive amounts, the specification of hierarchic preferences has to take into account the fact that some goods may not be consumed because the consumer cannot afford them. This requires the marginal utility of consuming good i in quantity zero, $\xi(i)v'(0)$ to be finite for all $i > 0$. By contrast, in the standard monopolistic competition model the marginal utility at quantity zero is infinitely large, so in that model it is always optimal to consume a (small) positive amount even when prices are very high or income is very low. Moreover, the marginal utility of good i only depends on $c(i)$ and does not depend on the consumption level of other goods. Thus, utility is assumed to be additively separable. It is also important to note that the non-homothenticity of the utility function $u[c(i)]$ do not depend on the presence of the hierarchy function $\xi(i)$, but on the form of the subutility function $v(\cdot)$ (Foellmi, 2005, p. 11).

An important feature of this formulation where the utility of consumption of different goods differs in the factor $\xi(i)$, is that it captures the idea of the generalized version of Engel's law, that additional income is spent primarily on goods with high income elasticity i.e. low-priority goods. Since the hierarchy function $\xi(i)$ is decreasing in i, the marginal utility of a high priority good (low i) falls quickly, so the optimal consumer behaviour implies that additional income is spent primarily on the low-priority (high i) goods with slowly falling marginal utilities.

Following Foellmi & Zweimüeller (2008)'s specification we assume the weighting function to be a power function, $\xi(i) = i^{-\gamma}$ with $\gamma \in (0, 1)$ and the subutility function to be quadratic, $v(c(i)) = (1/2)[s^2 - (s - c(i))^2]$, where s is a positive parameter, $s > 0$, that denotes the saturation level. This functional form makes the utility non-homothetic, which implies that the expenditure shares of the different goods i differ or, equivalently, that the income elasticities of the different goods differ from one. This functional form for the subutility function, not only allows for explicit solutions but also for binding non-negativity constraints, as marginal utility at quantity zero is finite, $\xi(i)v'(0) = i^{-\gamma} < \infty$, for all goods $i > 0$. Assuming that all goods i are available on the market, the representative consumer objective utility function is

$$u\left[c(i)\right] = \int_0^\infty i^{-\gamma}\frac{1}{2}[s^2 - (s - c(i))^2]di \tag{4.2}$$

The consumer's objective function (4.2) will be maximized subjected to the budget constraint $\int_0^\infty p(i)c(i)di = E$, where E is the consumer's total expenditure, and the non-negativity constraints $c(i) \geq 0$, for all i. The Lagrangian becomes

$$\mathcal{L} = \int_0^\infty i^{-\gamma}\frac{1}{2}[s^2 - (s - c(i))^2]di + \lambda\left[E - \int_0^\infty p(i)c(i)di\right], \tag{4.3}$$

and the first order conditions are[9]

$$\begin{aligned} i^{-\gamma}(s - c(i)) - \lambda p(i) = 0 \qquad if \qquad c(i) > 0, \\ i^{-\gamma}(s - c(i)) - \lambda p(i) \leq 0 \qquad if \qquad c(i) = 0 \end{aligned} \tag{4.4}$$

the optimality conditions require that the above constraints be satisfied, where the Lagrangian multiplier λ is the marginal utility of income. In sections 2 and 3 of their model Foellmi & Zweimüeller assume that all goods i are supplied on competitive markets. Goods price are chosen as numéraire, as the technology is symmetric and prices are the same for all products. Thus, $p(i) = 1$ for all i. Therefore from (4.4) we have that the optimal level of consumption of good i becomes

$$c(i) = s - i^\gamma \lambda \tag{4.5}$$

From equation (4.5) we can see that $c(i)$ is decreasing in i which means that low-priority goods (high-i) are consumed in smaller quantity. Since the consumer chooses not to consume all goods, let us call N the last good consumed. Assuming that all goods $i < N$ are consumed, the last good N is determined by the following condition

$$N^{-\gamma}v'(0) = \lambda p(N) \tag{4.6}$$

which also illustrates that as the consumer gets richer he will not only consume more of the previous goods but also more goods. Since the consumer's marginal utility of income λ decreases as income rises, the condition (4.6) requires a larger N in order to be maintained. The consumption of the last good N equals zero, $c(N) = 0$, as long as $\xi(i)/p(i)$ is continuous at $i = N$ (otherwise the consumption of good N is strictly positive). So, from equation (4.4) we can express λ in terms of the quantity of the last good consumed, $\lambda = s/N^\gamma$. Substituting this expression for λ into (4.5) the equilibrium composition of demand becomes

[9] This step is slightly informal; we simply cancelled the di's in (4.3). However, methods used to derive the calculus of variations provide a formal justification for cancelling the di's in (4.3). For a more detailed explanation on this technique refer to (Romer, 2011, p. 55) footnote 7.

$$c(i) = s\left[1 - \left(\frac{i}{N}\right)^{\gamma}\right], \qquad i \in (0, N) \tag{4.7}$$

Equation (4.7) shows that the quantity consumed $c(i)$ of a particular good i depends on the relative position of the good in the hierarchy of needs, i/N. Since $c(i)$ decreases in i, goods with relatively higher priority (low-i) are at a lower position in the hierarchy, and so *ceteris paribus* are consumed in higher quantities. Moreover, the steeper the hierarchy (the higher is γ) the stronger the effect of the relative position on equilibrium quantities. As we can observe the consumption profile follows a hierarchy of needs. This is the key difference between homothetic and hierarchic non-homothetic preferences. With homothetic preferences, the consumption profile expands vertically as income rises, which means that if the consumer's income doubles he will consume double the amount of every good. Instead, in the case of hierarchy non-homothetic preferences, if we assume a hierarchy function $\xi(i) = i^{-\gamma}$ and that prices are equal, the consumption profile expands horizontally, that is N expands as income increases, so expenditure E and the range of consumed goods N are proportional.

From (4.7) assuming that prices are equal, we can derive an expression for the income elasticity of demand $\epsilon_d(i)$ for a particular good i. By definition the income elasticity of demand for a good is $\epsilon_d(i) = \partial c(i)/\partial E \cdot E/c(i)$. Since E and N are proportional we have that $\partial E/E = \partial N/N$. From this relation we can see that $\epsilon_d(i) = \partial c(i)/\partial N \cdot N/c(i)$. Differentiating (4.7) with respect to N gives us the following expression

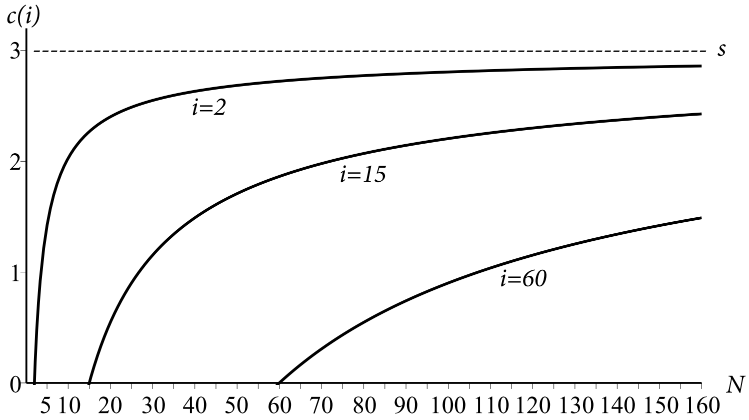
$$\frac{\partial c(i)}{\partial N} = \gamma\left(\frac{i}{N}\right)^{\gamma} s\frac{1}{N} \tag{4.8}$$

substituting the equation above and equation (4.7) into $\epsilon_d(i) = \partial c(i)/\partial N \cdot N/c(i)$ gives us the following expression for the income elasticity of demand for some good i

$$\epsilon_d(i) = \frac{\gamma\left(\frac{i}{N}\right)^{\gamma}}{1 - \left(\frac{i}{N}\right)^{\gamma}} \tag{4.9}$$

Equation (4.9) above shows that when a new good is just introduced, i.e. when $i = N$, its income elasticity of demand is infinity but as the economy develops and the number of goods increase, i/N becomes small, and so its income elasticity approaches zero. Each good follows what Kindleberger calls a Engel's consumption cycle (Kindleberger, 1989, p. 9), where it stars out as a luxury with high income elasticity and low consumption when is first introduced and finishes as a necessity with low income elasticity and consumption approaching the saturation level s. Figure 4.2 depicts how the consumption quantities of some goods evolve as the number of goods consumed N increases.

Figura 4.2: The consumption quantity of good i as a function of the total number of goods consumed N.



Source: Author's own elaboration (2016) based on Foellmi & Zweimüeller (2008).

We can also calculate the aggregate consumption given by $C = \int_0^N c(i)di$. Integrating (4.7) from 0 to N yields

$$C = \frac{Ns\gamma}{(1+\gamma)} \tag{4.10}$$

It is important to note that since we are assuming that new goods are continuously introduced, we can see from (4.9) that the income elasticity of demand of each existing product i is monotonically decreasing over time as N increases, but the income elasticity of aggregate consumption C is constant and equal to one, $\partial C/\partial N \cdot N/C = 1$.

4.4.2 Incorporating Hierarchy Utility into the Ramsey-Cass-Koopmans Model

The model developed in Foellmi & Zweimüeller (2008), uses the RCK model as a benchmark. It assumes the existence of a large number of identical firms. At each point in time firms employ labour and capital, pay them their marginal products, and sell the resulting output. Capital and consumption goods are produced with the same technology given by the following production function

$$Y(i,t) = F(K(i,t), A(t)L(i,t)), \tag{4.11}$$

where $Y(i,t)$, $K(i,t)$ and $L(i,t)$ denote, respectively, output of sector i at date t, physical capital employed in sector i at date t and labour employed in sector i at date t. $A(t)$ is effectiveness of labour or in other words the stock of (labour-augmenting) technical knowledge, which firms take as given. We assume that A grows at an exogenous rate g.

The production function (4.11) is assumed to have constant returns to scale in its two arguments, capital and effective labour. This assumption not only guarantees that firms earn zero profits but also allows us to work with the production function in its intensive form. Multiplying both sides of equation (4.11) by $1/A(t)L(i,t)$ gives us

$$\frac{Y(i,t)}{A(t)L(i,t)} = F\left(\frac{K(i,t)}{A(t)L(i,t)}, 1\right) \tag{4.12}$$

By defining capital per unit of effective labour as $k(i,t) = K(i,t)/A(t)L(i,t)$, output per unit of effective labour as $y(i,t) = Y(i,t)/A(t)L(i,t)$ and $f(k(i,t)) = F(k(i,t), 1)$, we can rewrite equation (4.12) as $y(i,t) = f(k(i,t))$ which is output per unit of effective labour as a function of capital per unit of effective labour. The intensive-form production function, $f(k(i,t))$, is assumed to satisfy $f(0) = 0$, $f'(k) > 0$, $f''(k) < 0$.

The marginal product of labour is given by $\partial F(K, AL)/\partial L$, which is equal to $A\partial F(K, AL)/\partial AL$. With the production function in its intensive form the labour marginal product can be written as $A[f(k) - kf'(k)]$. Thus real wage at time t is given by

$$W(t) = A(t)[f(k(t)) - k(t)f'(k(t))] \tag{4.13}$$

If we consider the wage per unit of effective labour, then we have

$$w(t) = f(k(t)) - k(t)f'(k(t)) \tag{4.14}$$

Since $F(K, AL)$ equals $ALf(K/AL)$, it follows that the marginal product of capital, $\partial F(K, AL)/\partial K$, equals $ALf'(K/AL)(1/AL)$, which is just $f'(k)$. For simplicity, we assume there is no depreciation of capital, so the real rate of return on capital equals its earnings per unit time. Thus the real interest rate at time t is $r(t) = f'(k(t))$. Finally, in equilibrium each firm produces with the same capital-labour ratio, hence marginal costs are equalized across firms and sectors. Given our previous choice of the goods price as numéraire, and the fact that in equilibrium marginal costs equal prices, marginal costs are normalized to unity.

4.4.3 Optimal Savings and Capital Accumulation

Let us consider the question of optimal intertemporal allocation of consumption expenditures of the representative consumer. The consumer divides its income at each point in time between consumption and saving so as to maximize its lifetime utility. Assuming that time is continuous and that the representative consumer maximizes an additively separable lifetime utility $U(t)$ over an infinite horizon, the objective function is given by

$$U(t) = \int_t^{\infty} \frac{u(\tau)^{1-\theta}}{1-\theta} e^{-\rho(\tau-t)} d\tau, \qquad \theta > 0, \qquad \rho > 0 \tag{4.15}$$

where $u(\tau) \equiv \int_0^{\infty} i^{-\gamma} \frac{1}{2}[s^2 - (s - c(i,\tau))^2] di$ is the instantaneous consumption aggregator for the various goods. We assume that the instantaneous utility function, which gives the consumer's utility at a given date, takes the constant-relative-risk-aversion (or CRRA) functional form. This form is needed for the economy to converge to a balanced growth path. The coefficient of relative risk aversion for this utility function is θ. Since there is no uncertainty, the household's attitude toward risk is not directly relevant. But θ determines the consumer's willingness to shift the composite $u(\tau)$ across time[10]. When θ is smaller, marginal utility falls more slowly as consumption rises, and so the consumer is more willing to allow its consumption to vary over time. The parameter ρ is the subjective rate of time preference, which is the discount rate; the greater is ρ, the less the consumer values future consumption relative to current consumption, in other words it expresses the trade off between consumption today and consumption in the future.

The representative consumer's budget constraint is such that the present value of its lifetime consumption cannot exceed its initial wealth $V(t)$ plus the present value of its lifetime income. To write the budget constraint formally, we need to account for the fact that r may vary over time. In order to cope with this we define the the cumulative interest rate $R(\tau, t)$ as $\int_t^{\tau} r(s)ds$, so for instance $e^{R(\tau,t)}$ shows the effects of continuously compounding interesting over the period $[t, \tau]$. Therefore the consumer's intertemporal budget constraint becomes

[10] It can be show that $1/\theta$ is the elasticity of intertemporal substitution (or intertemporal elasticity of substitution), which reflects the households' willingness to substitute consumption between time periods in response to changes in the expected real interest rate.

$$\int_t^{\infty} E(\tau)e^{-R(\tau,t)}d\tau \leq \int_t^{\infty} w(\tau)e^{-R(\tau,t)}d\tau + V(t) \tag{4.16}$$

where $E(\tau) \equiv \int_0^{N(\tau)} p(i,\tau)c(i,\tau)di$ is the level of consumption expenditure at time τ. We can now use the objective function (4.15), and the budget constraint (4.16) to set up the Lagrangian where μ is the Lagrangian multiplier:

$$\begin{aligned}\mathcal{L} = \int_t^{\infty} \frac{u(\tau)^{1-\theta}}{1-\theta} e^{-\rho(\tau-t)}d\tau \\ + \mu\left[\int_t^{\infty} w(\tau)e^{-R(\tau,t)}d\tau - \int_t^{\infty} E(\tau)e^{-R(\tau,t)}d\tau + V(t)\right]\end{aligned} \tag{4.17}$$

taking the derivatives with respect to $c(i,\tau)$ yields the first order condition

$$u(\tau)^{-\theta} i^{-\gamma}(s - c(i,\tau))e^{-\rho(\tau-t)} = \mu e^{-R(\tau,t)} p(i,\tau) \tag{4.18}$$

This first order condition and the intertemporal budget constraint determines the optimal consumption level for each good i at each date. Equation (4.18) must hold for all i at all τ. To see what (4.18) implies for the behaviour of consumption, first we set $i = N(\tau)$ in (4.18) and take logs of both sides, thus the equation becomes,

$$\begin{aligned}-\theta \ln u(\tau) - \gamma \ln N(\tau) - \ln(s - c(i,\tau)) - \rho(\tau - t) &= \ln \mu - R(\tau,t) + \ln p(N(\tau),\tau) \\ &= \ln \mu - \int_t^{\tau} r(s)ds + \ln p(N(\tau),\tau)\end{aligned} \tag{4.19}$$

in the second line of (4.19) we use the definition of $R(\tau,t) = \int_t^{\tau} r(s)ds$. Taking the derivative of (4.19) with respect to τ gives us,

$$-\theta\frac{\dot{u}(\tau)}{u(\tau)} - \gamma\frac{\dot{N}(\tau)}{N(\tau)} - \frac{\partial c(N(\tau),\tau)}{\partial \tau}\frac{1}{s - c(N(\tau),\tau)} - \rho = -r(\tau) + \frac{\partial p(N(\tau),\tau)}{\partial \tau}\frac{1}{p(N(\tau),\tau)} \tag{4.20}$$

note that $p(i,t) = 1$ for all t due to our choice of the numéraire, thus $p(N(\tau),\tau)$ is constant. Equation (4.20) simplifies to,

$$-\theta\frac{\dot{u}(\tau)}{u(\tau)} - \gamma\frac{\dot{N}(\tau)}{N(\tau)} - \rho = -r(\tau) \tag{4.21}$$

Now, from equation (4.21) we derive the relation of $\dot{e}/e$. But first we need to find three other relations. The first one is the relation between the growth rates of $N(\tau)$ and $E(\tau)$. The price of goods was normalized to unity $p(i) = 1$, and we know that the equilibrium composition of demand is $c(i) = s[1-(i/N)^{\gamma}]$ (equation 4.7), thus we calculate $E(\tau)$ as,

$$E(\tau) = \int_0^{N(\tau)} p(i,\tau)c(i,\tau)di = \int_0^{N(\tau)} 1 \cdot s\left[1 - \left(\frac{i}{N(\tau)}\right)^{\gamma}\right] di = \frac{N(\tau)s\gamma}{(1+\gamma)} \tag{4.22}$$

taking logs of both sides of (4.22) and then taking the derivative with respect to τ yields

$$\begin{aligned} \ln E(\tau) &= \ln N(\tau) + \ln s + \ln \gamma - \ln(1+\gamma) \\ \frac{\dot{E}(\tau)}{E(\tau)} &= \frac{\dot{N}(\tau)}{N(\tau)} \end{aligned} \tag{4.23}$$

This is the first relation we need. It shows that $N(\tau)$ and $E(\tau)$ grow at the same rate. The second relation is obtained from the maximized instantaneous utility $\hat{u}(\tau)$ at time τ. This can be done by substituting the equilibrium quantities (4.7) into the utility function (4.2) assuming time τ, which after some manipulations yields

$$\hat{u}(\tau) = \frac{N(\tau)^{1-\gamma}}{1-\gamma}s^2\frac{\gamma}{1+\gamma} \tag{4.24}$$

solving (4.22) for $N(\tau)$ and substituting into the above (4.24) expression gives us

$$\hat{u}(\tau) = \frac{E(\tau)^{1-\gamma}}{1-\gamma}s^{1+\gamma}\left(\frac{\gamma}{1+\gamma}\right)^{\gamma} \tag{4.25}$$

taking logs of both sides of the above equation and then taking the derivative with respect to time τ yields

$$\begin{aligned} \ln u(\tau) &= (1-\gamma)E(\tau) - \ln(1-\gamma) + (1+\gamma)\ln s + \gamma \ln \gamma - \ln(1+\gamma) \\ \frac{\dot{u}(\tau)}{u(\tau)} &= (1-\gamma)\frac{\dot{E}(\tau)}{E(\tau)} \end{aligned} \tag{4.26}$$

Equation (4.26) is the second relation we needed. The third and last relation comes from the definition of expenditures in efficiency units as $e(\tau) \equiv E(\tau)/A(\tau)L(\tau)$.

Taking logs and then the derivative with respect to time τ gives us

$$\frac{\dot{e}(\tau)}{e(\tau)} = \frac{\dot{E}(\tau)}{E(\tau)} - \frac{\dot{A}(\tau)}{A(\tau)} - \frac{\dot{L}(\tau)}{L(\tau)} \tag{4.27}$$

Define $\dot{A}(\tau)/A(\tau) = g$. Since, in our case, $\dot{L}(\tau)/L(\tau)$ is equal to zero, the above relation can be rearranged so $\dot{E}(\tau)/E(\tau) = \dot{e}(\tau)/e(\tau) + g$, where g is the rate of increase of the stock of labour-augmenting technical knowledge, which is assumed to be exogenous. Now we have all the components needed to write the Euler equation from equation (4.21). The three relations we have derived are:

$$\text{(A)}\ \frac{\dot{E}(\tau)}{E(\tau)} = \frac{\dot{N}(\tau)}{N(\tau)} \qquad \text{(B)}\ \frac{\dot{u}(\tau)}{u(\tau)} = (1-\gamma)\frac{\dot{E}(\tau)}{E(\tau)} \qquad \text{(C)}\ \frac{\dot{E}(\tau)}{E(\tau)} = \frac{\dot{e}(\tau)}{e(\tau)} + g$$

substituting these three relations into (4.21) yields

$$-\theta\left[(1-\gamma)\left(\frac{\dot{e}(\tau)}{e(\tau)} + g\right)\right] - \gamma\left(\frac{\dot{e}(\tau)}{e(\tau)} + g\right) - \rho = -r(\tau). \tag{4.28}$$

since we assume no depreciation of capital, the real rate of return on capital equals its earnings per unit time $r(\tau) = f'(k(\tau))$, thus the above equation can be simplified and rewritten as

$$\frac{\dot{e}(\tau)}{e(\tau)} = \frac{f'(k(\tau)) - \rho}{\theta(1-\gamma) + \gamma} - g \tag{4.29}$$

Equation (4.29) is the Euler equation for this maximization problem. This equation is very similar to the standard Ramsey-Cass-Koopmans model's result. If $\gamma \to 0$ we have $\dot{e}/e = ((r-\rho)/\theta) - g$, the same equation derived from the standard model (equation 2.24 in Romer (2011, p. 58)). In the standard Ramsey-Cass-Koopmans model goods enter the utility function in a symmetric way so $\gamma = 0$. In Foellmi & Zweimüeller (2008)'s model, goods enter in a hierarchic fashion, with the parameter γ changing the relevant intertemporal elasticity of substitution in (4.29).

The dynamics of capital accumulation is straightforward. Because the economy may be growing over time, it turns out to be much easier to focus on the capital stock per unit of effective labour, k, than on the unadjusted capital stock, K. Since $k = K/AL$, we can use the chain rule to find

$$\begin{aligned}\dot{k}(t) &= \frac{\dot{K}(t)}{A(t)L(t)} - \frac{K(t)}{[A(t)L(t)]^2}[A(t)\dot{L}(t) + L(t)\dot{A}(t)] \\ &= \frac{\dot{K}(t)}{A(t)L(t)} - \frac{K(t)}{A(t)L(t)}\frac{\dot{L}(t)}{L(t)} - \frac{K(t)}{A(t)L(t)}\frac{\dot{A}(t)}{A(t)}\end{aligned} \tag{4.30}$$

in our case $\dot{L}(t)/L(t)$ is zero, $\dot{A}(t)/A(t)$ is g, $K(t)/A(t)L(t) = k(t)$, and since we assumed for simplification that there is no depreciation, capital is accumulated according to $\dot{K}(t) = Y(t) - E(t)$. Substituting these facts into (4.30) yields

$$\dot{k}(t) = \frac{Y(t) - E(t)}{A(t)L(t)} - gk(t) \tag{4.31}$$

Finally, since $f(k(t)) = Y(t)/A(t)L(t)$, and the expenditure in efficiency units is $e(t) = E(t)/A(t)L(t)$, the capital accumulation equation in efficiency units is given by

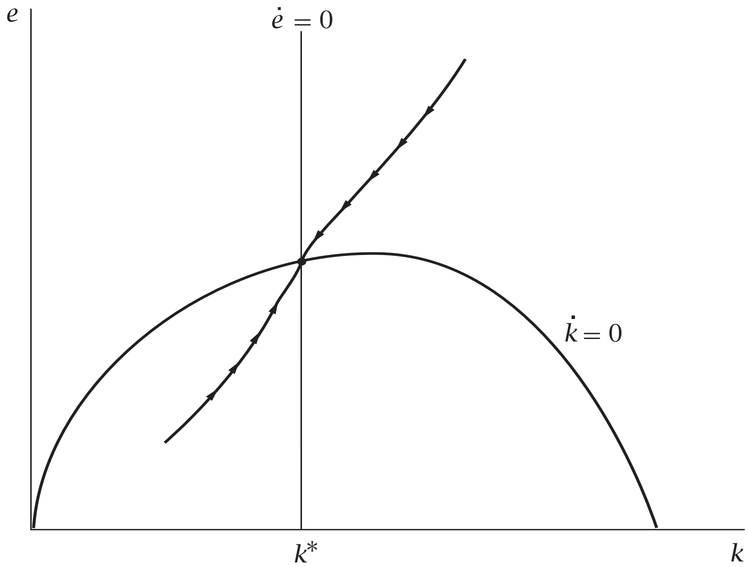
$$\dot{k}(t) = f(k(t)) - e(t) - gk(t) \tag{4.32}$$

Equation (4.32) is the resource constraint. The differential equations (4.29) and (4.32) are isomorphic to those of the standard Ramsey-Cass-Koopmans growth model. Therefore, it is straightforward to see that a unique expenditure level $e(0)$ exists, given an initial level of capital $k(0)$ (Foellmi & Zweimüeller, 2008, p. 1322). This can be shown in figure 4.3. As in the standard RCK growth model, it can also be shown that for any positive initial level of k, there is a unique initial level of e that is consistent with households' intertemporal optimization, the dynamics of the capital stock, households' budget constraint, and the requirement that k not be negative. The function giving this initial e as a function of k is known as the saddle path.

This model[11] can be extended in several directions, Foellmi & Zweimüeller (2008) suggest a few possibilities at the end of their article. In addition to those, the analysis could incorporate a mechanism of product destruction, so that the number of products in the economy would not increase indefinitely.

[11] The part of Foellmi & Zweimüeller (2008)'s model derived in this section focused on the case where the introduction of new products was costless. To see how they endogenized the process of R&D and product innovation refer to section 4 of their article.

Figura 4.3: The saddle path.



Source: Author's own elaboration (2016).

4.5 Final Comments

In this chapter we discussed the processes of product and process innovation. The two are obviously connected and are endogenous to the economic system. The combination dynamic increasing returns to scale, which raises firms productivity and the continuous introduction of new products, which elicits new demand allowing the economy to escape satiation, creates the necessary conditions for economic growth to be cumulative and self-re-enforcing. The fact that industries differ in their productivities, makes structural change a catalytic force, as it is able to reduce the disparity in factor returns across sectors and facilitates the exploitation of external economies of scale. On the other hand, as emphasized by Syrquin (2012, 72), structural change can retard growth if its pace is too slow or its direction inefficient.

5. AN AGENT BASED COMPUTATIONAL MODEL OF CUMULATIVE GROWTH AND STRUCTURAL CHANGE

Agent based computational economic (ACE) models are used to simulate the simultaneous operations and interactions of multiple agents (e.g. firms, consumers, etc.) in an attempt to re-create and predict the appearance of complex phenomena (e.g. economic growth). ACE models have the ability to generate non-linear dynamical systems that exhibit non-ergodic properties (Gräbner, 2016). They allow a realistic representation of an evolutionary system in the lines of Veblen (1898).

In ACE models, one needs to specify the fundamental entities (e.g. firms, consumers and their relations) in an adequate manner in order to study their interactions. Because the resulting system is usually very complicated, computational simulation is used to solve it. Differently from Computable and Dynamic Stochastic General Equilibrium modelling, in ACE models one starts from the assumptions about the system to the conclusions regarding the overall dynamics, while in the formers, which are said to be micro-founded, one has to specify the assumptions on the micro level not solely based on their adequateness, but in a way such that they stay mathematically tractable and are suitable to yield a stable equilibrium for the overall dynamic (Gräbner, 2016).

Another particularly useful aspect of ACE simulations is their modular nature. This produces results that can be explored at different levels of aggregation (e.g. firm, sector, economy), while always retaining the micro-foundations. Given all their characteristics, agent-based models are perfectly suitable for working with cumulative growth and the path dependence of real world dynamics[1].

In this chapter we develop an ACE model of cumulative growth, demand saturation and structural change. The objective of our analysis is twofold. First, to explore the macroeconomic properties of growth and structural change that emerge from the interactions of heterogeneous firms' innovation and financing strategies. Second to show that when one assumes that demand saturates, then the introduction of new products and/or sectors that creates new demand, is a necessary condition to sustain the growth process with full employment of factors in the long run.

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[1] For a more detailed account on the strengths and weaknesses of agent-based computational models refer to Richiardi (2004).

The present model portrays an economy with three sectors. Sector 1, can be thought as agriculture, sector 2 as manufacturing and sector 3 as services. We note that sector 3, encompass services with high technological content and thus displays high productivity. Each sector is populated by heterogeneous firms able to finance their activities in the financial market, which's performance is not predetermined, but depends endogenously on the firm's financing and pricing strategy, on the technological progress rate and on banks' spreads strategy.

Firms motivated by competition based on innovation seek financing for their activities on the banking system. Depending on their innovation success rate, firms' financial situation can evolve from a healthy one to a fragile situation. Firms may need to finance their operational expenses, investments and R&D activities. However, there is no assurance, a priori, that a firm's pricing and innovation strategies will generate enough profit to sustain its cash flow in the long run, if it does not then the firm disappears. Financial instability can emerge as a possible outcome of the interaction between firms and the banking system, generating business cycles and recessions. Firms on one side, adopt an evolutionary behaviour, on the sense that, before they choose their pricing and innovating strategy they observe their competitors' behaviour. On the other side, banks choose their spread based on their perception of firms' credit risk. The banking system has a pro-cyclical behaviour that may give rise to expansion or crisis.

The model replicates the dynamics of structural change where production factors (labour) is reallocated among the three sectors. The process of structural change, as in Boppart (2014), is driven by demand and supply factors simultaneously, as sectors differ in their income elasticities of demand and in their productivity rates. The model is able to approximate, for a selected period of the simulation, the pattern of structural change of the share of employment described in figure 3.1 of chapter 3 and found by Foellmi & Zweimüeller (2008). It also shows that, in the event of a financial crisis, sectors are affected at the same time but in different intensities by it.

Our analysis contributes to the literature as it demonstrates the possibility of building a framework that integrates business cycle, growth, structural change, innovation and the financial development through a heterogeneous agent approach. The model shows that business cycles are neither exclusive attributes of firms behaviour, nor a restriction of pre-existing properties at the macroeconomic level, but an emergent phenomenon of the interaction between all parts of the system. Moreover, it shows that structural change can be driven simultaneously by supply and demand factors as in Boppart (2014), and that the introduction of new products and/or sectors is a necessary condition to sustain growth with full employment of factors in the long run.

5.1 Economic Growth and Financial Development

The interaction between economic growth, technological progress and firm financing has been largely studied on the field of economics, from both the theoretical and the empirical perspective. Even though a growing number of researchers refer to contemporary relation between growth and financial market development, there is no agreement over the causality between the two. The issue becomes even more complicate when a third variable, innovation, is introduced into the analysis.

A vast literature suggests the existence of a strong relation between the financial sector and economic growth (Levine, 2005). However, the establishment of a specific causality is controversial, since the interaction between the two tend to be bi-causal. Despite being dismissed or underrated by some (Lucas, 1988) [2], and relegated to a secondary role by others (Robinson, 1952), there are authors such as Goldsmith (1969), McKinnon (1973) and Shaw (1973), who claim the existence of a strong link between the financial superstructure of a country and its real infrastructure. This relation, says Goldsmith (1969, p. 400) "accelerates the economic growth and enrich the economic performance on an extension that facilitates the movements of funds for its best application, that is, to places on the economy where the funds will produce higher social return rates". Goldsmith (1969) presents data for the period of 1860-1963 that shows a secular tendency of increase in the proportion of financial institutions' assets relative to national gross product, for both developed and less developed countries. However, as the author points out it is difficult to trust the causal direction mechanism, that is, to decide if the financial factors were responsible for economic growth or if the financial development reflects the growth of the economy, in which case its causes must be searched somewhere else.

Another positive econometric evidence is provided by Jung (1986). Who analysed

[2] Lucas (1988, p. 6) argues that "In general, I believe that the importance of financial matters is very badly over-stressed in popular and even much professional discussion and so am not inclined to be apologetic for going to the other extreme".

a group of 56 countries and found that the causality (on the Granger sense) runs both ways. Finally, studies of historical cases, as the one made by Cameron (1967), highlighted the importance of financial factors for the economic development of many European countries.

In general, the macroeconomic literature argues that the existence of financial instruments and market institutions improve the risk management and contributes to shorten the effects of asymmetric information and transaction costs by changing the incentives and restrictions, with which economic agents are faced (Merton, 1995; Merton & Bodie, 1995). More than that, the financial intermediaries may produce a better information set, share risks, improve asset allocation and, through that, stimulate growth (Greenwood & Jovanovic, 1990).

In addition to the relation between finance and growth, there is a specific and complementary literature that has analysed the interaction between finance and innovation. According to Arrow (1962a) and De la Fuente & Marin (1996), in an uncertain environment, as the one where innovation takes place, firms can benefit from a well developed financial market if they are able to obtain financing for their R&D activities. As the financial system becomes more and more efficient in allocating assets to research projects, by selecting the most profitable ones and by monitoring and sharing the risks, economic growth tend to rise. That is, the financial system has a positive impact on the growth rate by allocating credit among firms with the best profit prospects. According to the literature, financial mediation may provide a solution to the problem of adverse selection on the credit market[3].

An additional explanation about the relation between financing and innovation was proposed by (King & Levine, 1993). The authors discuss financing and innovation on an endogenous growth model, in which the financial system grades potential entrepreneurs and mobilize savings to finance the projects with the greatest chances of success, in terms of productivity improvement. The banking system select the innovation projects with the highest expected profit, instead of selecting those with the lowest cost which rely on existing production methods and therefore are less risky.

Galetovic (1996) argues that when increased specialisation is a necessary condition for growth, as in knowledge-driven economies, sustained growth may not start if financial intermediaries do not emerge. These intermediaries not only provide financing to entrepreneurs but also act by reducing the costs of monitoring. Without them monitoring costs

[3] Other works on this literature include Bencivenga & Smith (1991), Levine (1991), Boyd & Smith (1992) e Saint-Paul (1992).

may swallow the efficiency gains brought about by specialisation, making it unprofitable. In this sense, a financial market is a necessary condition for growth to start and persist.

Following a similar approach, Morales (2003) builds an endogenous growth model in which the research activity is financed by intermediaries that are able to reduce the incidence of researcher's moral hazard. The author shows that financial activity promotes growth because it increases research productivity. His argument is based on the existence of moral hazard on research. In the absence of monitoring, researchers choose the amount of effort that maximizes their expected utility, which is smaller than the one that would maximize the expected value of the project. The no-monitoring level of effort is smaller because the researcher receives only a part of the value of the innovation while the rest goes to the intermediary. The intermediary is not only able to monitor the researchers, but also to control the monitoring intensity, which will determine the amount of effort affordable and the probability of success of the research project. The author shows that a policy that incentives monitoring is able to improve the growth performance of the economy due to its positive effect on R&D productivity. Furthermore, he also shows that a direct subsidy to research may reduce the growth rate of the economy due to increasing incidence of moral hazard. Thus, he proposes subsidies to capital accumulation and to financial activity as alternative growth promoting policies.

The financial system, as perceived by the growth and business cycle literature, exerts a positive effect on economic growth. A precondition for this to happen is that the financial institutions be capable of correctly manage the credit risk and direct the investment to the most profitable opportunities. However, economic history is full of episodes where financial crises produce negative impacts on economic growth. As observed by Brown et al. (2009), if firms need financing for R&D and there is some constrains on the supply of financing, this could lead to significant negative macroeconomic consequences. An expansion in the supply of financing may lead to an increase in R&D and a contraction to a reduction in R&D[4].

[4] Brown et al. (2009, p. 152) presents some data showing that "the U.S. has recently experienced a finance-driven cycle in R&D. From 1994 to 2004, there was a dramatic boom, and subsequent decline, in R&D: the ratio of privately financed industrial R&D to GDP rose from 1.40% in 1994 to an all-time high of 1.89% in 2000 before declining to an average of 1.70% from 2002 to 2004, according to a survey from the National Science Foundation. (...) From 1994 to 2004, there was also a dramatic boom and bust in both cash flow and external equity finance in these industries. Internal finance (cash flow) for publicly traded firms increased from $89 billion in 1993 to $231 billion in 2000, and then collapsed in 2001 and 2002. External public equity finance rose from $24 billion in 1998 to $86 billion in 2000, but then plummeted 62% in 2001."

The emergence of financial instability in economies, where firms are able to finance their R&D expenses, was formally treated by Gallegati et al. (2003) and de Freitas & Lima (2007). The model presented in section 5.2 differs from the one developed by Gallegati et al. in many aspects, specially regarding firms interaction and the banking system behaviour. In our case, firms set their prices by applying a mark-up rate over their costs, which also include financial expenses. The productivity growth rate is determined by a complex technological competition, based on a higher level of interaction (complexity) between the firms. In Gallegati et al. prices are set based on expectations about relative prices ($E[P_i/P]$) and productivity growth rate is exogenous and constant. Another important difference is that, in our analysis the banking system reacts to the crisis by changing the interest rate (price), while in Gallegati et al. it does by restricting the supply of financing (quantity). In both cases, financial crises emerge as a macroeconomic phenomenon. However, in our case they emerge as the result of the interaction between heterogeneous firms with different financing needs.

The model present in this chapter has properties also present in de Freitas & Lima (2007), but expands the analysis into different directions. First, the technical progress rate (labour productivity) is made endogenous. This extension shows promising results in terms of understanding the interactions and feedback effects of financing to growth. Second, the model adds a sectoral component, by analysing how demand and productivity evolves sectorally, as sectors differ in their income elasticities of demand. Finally, the model shows that financial crises affect sectors with different intensities.

5.2 Model Structure

The following model is comprised of an economy divided in sectors inhabited by heterogeneous firms and of an adaptive banking system. Firms are different in terms of pricing strategy, resources allocated to R&D, sales expectation formation and financing demand. An adaptive banking system creates the possibility of credit restriction through increases in interest rate. This happens when banks realize that the sum of all the firms' accumulated debt in proportion to their accumulated profits has risen. As firms incur in losses and need to increase their financing two simultaneous effects happen: As firms are able to finance their losses, and thus stay in business longer than otherwise, they are able to continue producing and innovating, what increases the innovation rate. The second effect is an increase in the firms accumulated debt, which might lead to financial fragility, forcing banks to restrict credit by raising interest rates. Therefore, this financing regime may result on either positive or negative macroeconomic effects depending on the firms' financing strategy and on their own and on the economy's technological vocation and intensity.

5.2.1 Production, and Inventory at Level Firm

On the production side it is assumed a pure labour economy, wherein output is determined by the quantity of labour employed at each period. It is assumed the following production function from Leontief & Strout (1963), $Y = min\{BK; AL\}$. A firm's production depends on the amount of labour employed and on the labour productivity $A_{z,i,t}$, which varies over time among the sectors z and firms i depending on the R&D developed by the firm. Therefore, a firm i will produce $X_{z,i,t}$ unities at time t by hiring $L_{z,i,t}$ unities of labour with productivity $A_{z,i,t}$, which increases according to a process described ahead in sub-section 5.2.3. The production function can be represented as follows,

$$X_{z,i,t} = A_{z,i,t}L_{z,i,t} \tag{5.1}$$

The economy is divided into sectors $z \in \{1, 2, ..., Z\}$, where each sector produces one final good which satisfy one consumer need. The economy has a constant labour supply. In the simulation ahead the number of sectors is constant and set to three as a reference to the common trichotomy of agriculture, manufacturing, and services, however, the analysis can be expanded to include any number of sectors. Each sector is populated by $i \in \{1, 2, ..., n\}$ firms which choose their pricing and innovation strategies by interacting with each other within their respective sectors. The economy's aggregate production is given by:

$$X_t = \sum_z \sum_i X_{z,i,t} \tag{5.2}$$

In order to carry out their production plans, firms hire a given quantity of labour at time t, based on their labour demand in the previous period, on their expected demand, on their productivity, and on the unemployment rate according to the following equation:

$$L_{z,i,t} = \xi L_{z,i,t-1} + (1-\xi)\frac{C^{Exp}_{z,i,t}}{A^{\iota(1-\mu_{t-1})}_{z,i,t-1}} \tag{5.3}$$

where ξ is a fixed parameter equal to all firms in all sectors that shows how much of their labour demand firms adjust from one period to the next based on variations in their expected demand, labour productivity and the unemployment rate. The parameter ι is also fixed and equal to all firms in all sectors. Firms calculate their expected demand according to the following adjusting mechanism:

$$C^{Exp}_{z,i,t} = \eta C^{Exp}_{z,i,t-1} + (1-\eta)C^{Eff}_{z,i,t-1} \tag{5.4}$$

where η is a fixed parameter common to all firms in all sectors. This mechanism ensures that differences between firms expected and effective demand are corrected as time passes. For instance, if effective demand is higher than expected, firms do not increase production immediately, but adjust their production in the next periods, according to the interaction between equations (5.4), (5.3) and (5.1). Thus, if the effective demand grows at time t, production increases at time $t+1$. This mechanism allows for a non-instantaneous adjustment of the goods market, or between supply and demand. It is possible that some firms might accumulate unplanned inventory, while others might face excess demand. However, firms are able to correct their balances from one period to another.

The demand for goods or consumption is given by $C_{z,t}$ and is initially determined at the aggregate sectoral level. Once the aggregate sectoral consumption is computed according to sub-section 5.2.4 ahead, it is divided among the firms within their respective sectors according to their market shares ($ms_{z,i,t}$). A firm's market share may vary from one period to the next, depending on its competitiveness and its price.

Since firms calculate how much to produce based on sales expectation ($C^{Exp}_{z,i,t}$), given by equation (5.4), their production and effective demand might not be equal, what results on the formation of unplanned inventory or excess of demand. This difference will affect the firm's profit in that period and might even have further negative consequences. This scenario would force the firm to resort to the banking system to finance its own cash flow, in case it does not have enough accumulated profit in equity. The sectoral aggregate consumption $C_{z,t}$ (see sub-section 5.2.4 ahead) is distributed among firms and determines their effective demand ($C^{Eff}_{z,i,t}$):

$$C^{Eff}_{z,i,t} = ms_{z,i,t} C_{z,t} \tag{5.5}$$

The demand distribution is based on a previously computed market share, which depends on the firms' own competitiveness $E_{z,i,t}$ and on the average competitiveness $\bar{E}_{z,t}$ of all the firms in the sector, according to equation (5.11). A firm's own competitiveness is equal to the inverse of its price $E_{z,i,t} = 1/P_{z,i,t}$, whereas the average competitiveness $\bar{E}_{z,t}$ is equal to the weighted average of the individual competitiveness within the sector, with the individual market share as the weighting factor (Dosi et al., 1994).

Firms, based on their own sales expectations $C^{Exp}_{z,i,t}$, produce a quantity $X_{z,i,t}$. If production is higher than their individual effective demand $C^{Eff}_{z,i,t}$, those unsold units will be accumulated in form of inventories $X^S_{z,i,t}$. If effective demand is higher than their production plus previous periods inventories, firms do not accumulate units, resulting in a zero inventory balance.

$$X^S_{z,i,t} = \begin{cases} X_{z,i,t} + X^S_{z,i,t-1} - C^{Eff}_{z,i,t} & \text{if } C^{Eff}_{z,i,t} < X_{z,i,t} + X^S_{z,i,t-1} \ , \\ 0 & \text{otherwise.} \end{cases} \tag{5.6}$$

5.2.2 Price, Mark-up, Income and Firms profit

Firms' effective demand depend on their market share and, therefore, on their prices and on their mark-ups. The firms' mark-up must be sufficiently high to cover their operational costs (basically wages), R&D and financial expenses. If a firm has a loss in a certain period, it has to finance it in the financial market by taking out a loan. Accumulated debt generates financial expenses that make its product more expensive. If an individual firm does not have any accumulated debt and does not take any financing in the current period, then it will set its price equal to its previous period's. Firms price formation is described by the following equation

$$P_{z,i,t} = (1 + mk_{z,i,t}) \frac{W_{z,i,t}}{C^{Exp}_{z,i,t}} \tag{5.7}$$

where $mk_{z,i,t} > 0$ is the firms mark-up rate. It is important to note that the pricing mechanism as specified in (5.7), does not mean that the only source of price change is the ratio between the firm's total labour cost ($W_{z,i,t}$) and its expected demand ($C^{Exp}_{z,i,t}$). When a firm successfully innovates, it reduces its labour demand, reducing its labour costs, which increases its profits and reduces its accumulated debt ($D^{S}_{z,i,t}$). A reduction in the firm's debt might affect its price by reducing its mark-up ($mk_{z,i,t}$) (see equations 5.8 and 5.9). This logical path, by which the technological progress may affect the firm's price, is not very obvious at first sight. Increases in productivity have positive effects on wages, firm's profits and on the firm's debt management.

The mark-up rate is fixed by firms through an adaptive and interactive behaviour. First, firms calculate how much they want to increase or decrease their mark-up rate by calculating a desirable mark-up adjusting rate ($mk^{des}_{z,i,t}$) based on two factors, or motives. The first factor is related to the firms' demand. If a firm's effective demand is recurrently higher (lower) than its production, the firm will want to increase (reduce) its mark-up rate. Second, if the firm has accumulated debt, it will want to increase its mark-up rate to raise more revenue to pay for the financial expenses ($DF_{z,i,t-1} = i_{t-1}D^{S}_{z,i,t-2}$). The desirable mark-up adjusting rate is calculated by the following equation:

$$mk^{des}_{z,i,t} = \frac{\check{mk}_1}{\left[1 + \lambda_1 e^{\left(\lambda_2\left(\frac{C^{eff}_{z,i,t-1}}{X_{z,i,t-1}}\right)\right)}\right]^{\lambda_3}} + \frac{\check{mk}_2}{\left[1 + \lambda_4 e^{\left(\lambda_5 (DF_{z,i,t-1} - f)\right)}\right]^{\lambda_6}} \tag{5.8}$$

where $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \check{mk}_1, \check{mk}_2$ and f are parameters constant over time and equal to all firms in all sectors. The parameters $\check{mk}_1, \check{mk}_2$ represent the maximum increase in mark-up that each firm is able to apply. This values are exogenous and constant and are listed on table 5.1. After having determined its desirable mark-up adjusting rate, each firm evaluates the feasibility of effectively implementing this adjustment onto its mark-up rate. In order to do that a firm compares its price with the average price of *four*[5] randomly selected firms. If its price is higher than the average price ($\bar{P}_{z,t}$), the firm reduces its mark-up rate by a factor ($1 - \rho + mk^{des}_{z,i,t}$). If its price is lower than the average, the firm raises its mark-up rate by a factor ($1 + \rho + mk^{des}_{z,i,t}$), where $0 < \rho$. One of the main advantages of this approach is that it allows for the adjustment of firms mark-up to the market conditions as a whole. This mechanism also ensures that, although firms compete

[5] The exact number of firms is not crucial, one can assume any number or even that firms compare their prices with the market's average price. It is a matter of firms' market monitoring capacity.

in prices, since they are always monitoring their competition, increases in productivity do not change prices too drastically. Formally the firms' mark-up is determined by the following equation:

$$mk_{z,i,t} = \begin{cases} (1-\rho+mk^{des}_{z,i,t})mk_{z,i,t-1} & \text{if} \quad P_{z,i,t-1} > \bar{P}_{z,t-1}, \\ (1+\rho+mk^{des}_{z,i,t})mk_{z,i,t-1} & \text{if} \quad P_{z,i,t-1} < \bar{P}_{z,t-1} \end{cases} \tag{5.9}$$

Once the firm has determined its mark-up rate and consequently its price, this variables will determine the firms market share ($ms_{z,i,t}$) in each period, and its respective share of the sectoral aggregate demand ($C_{z,t}$). A firm's market share depends on its competitiveness, which is related to its price. We define competitiveness as being the inverse of the firm's price, as follows:

$$E_{z,i,t} = \frac{1}{P_{z,i,t}} \tag{5.10}$$

thus, the market share can be calculated by assuming that a firm owns a larger portion of the market, if its price is below the average market price, and a smaller portion if it is above the average price, as defined by the equation (5.11):

$$ms_{z,i,t} = \left[1+\beta\left(\frac{E_{z,i,t-1}}{\bar{E}_{z,t-1}}-1\right)\right]ms_{z,i,t-1}, \qquad 0<\beta<1 \tag{5.11}$$

where β is a common parameter to all firms and measures the market share sensibility in relation to the competitiveness (price) degree. A larger β, means that a firm gains more market share if its price is below the market's average and vice-versa.

After defining its price and its market share, the firm is able to calculate its revenue, operational costs and its profit. The firm's total revenue is composed of operational revenue and financial revenue, which is interest income received on its accumulated profits remunerated at a percentage κ of the interest rate (i). Total costs are composed of the operational costs (wages), R&D expenses calculated as a percentage ($\varphi_{z,i}$) of accumulated profits at the beginning of period t and financial expenses on the accumulated debt. Hence, the firm's total profit at the end of period t is given by:

$$\Pi_{z,i,t} = (R^O_{z,i,t} + R^F_{z,i,t} - W_{z,i,t} - DF_{z,i,t} - RD_{z,i,t}) \tag{5.12}$$

In equation (5.12), $RD_{z,i,t} = \varphi_{z,i}\Pi^S_{z,i,t-1}$ is the share of accumulated profits that the firm allocates to R&D in each period. $R^O_{z,i,t}$ is the firm's operational revenue, $R^F_{z,i,t}$ is the financial revenue from accumulated profits at the beginning of period t, remunerated at a percentage κ of the interest rate (i), $W_{z,i,t}$ is the firm's total labour cost, which in this case is the firm's total variable cost, and $DF_{z,i,t} = i_t D^S_{z,i,t-1}$ is the firm's financial expenses, calculated by applying the interest rate i_t to the firm's accumulated debt $D^S_{z,i,t-1}$. We assume that the parameter $\varphi_{z,i}$ is constant over time, this means that firms always allocate the same percentage of their profits to R&D, independently of the macroeconomic situation. A firm's total labour cost $(W_{z,i,t})$ depends on the nominal wage (V_t) and its labour demand $(L_{z,i,t})$:

$$W_{z,i,t} = V_{t-1} L_{z,i,t} \tag{5.13}$$

The Nominal wage (V_t) is calculated at the economy level by the following equation:

$$V_t = \begin{cases} \left[1 + \left(\frac{A_t}{A_{t-1}} - 1\right)\left(1 - \mu_{t-1}\right)^{\zeta}\right] V_{t-1} & if \quad \frac{A_t}{A_{t-1}} - 1 > 0, \\ V_{t-1} & otherwise \end{cases} \tag{5.14}$$

where A_t is the economy's average productivity rate at time t, ζ is a fixed parameter and μ_{t-1} is the economy's unemployment rate at time $t-1$.

5.2.3 Technological Progress and Productivity

Once technical change is taken into account, technological improvements that raise labour productivity will affect firms' profitability and financial fragility, as they affect unit labour costs and, therefore, the firms' competitiveness. This interaction becomes more intense and complex when technological progress is endogenous. Technological progress, in this model, results from three different sources: from dynamic increasing returns to scale deriving from a 'learning by doing' cumulative process, from imitation and from innovation based on the firm's own R&D.

The first source, follows the concept of dynamic increasing returns to scale arising from 'learning by doing' as analysed by Arrow (1962b) and embedded in the Kaldor-Verdoorn Law[6]. According to this concept, productivity grows as a function of the firm's own production expansion. This is represented in equation (5.15), where the technological

[6] The Kaldor-Verdoorn Law was discussed in section 4.1 of chapter 4.

learning rate depends linearly on the production growth rate:

$$\hat{A}^{LD}_{z,i,t} = \delta_1 \hat{X}_{z,i,t} \quad \text{if} \quad \hat{X}_{z,i,t} > 0 \tag{5.15}$$

and

$$A^{LD}_{z,i,t} = (1 + \hat{A}^{LD}_{z,i,t}) A_{z,i,t-1} \tag{5.16}$$

where δ_1 is the Kaldor-Verdoorn coefficient, which represents the sensibility of labour's productivity growth relative the growth of production. This parameter is is exogenous and constant to all firms[7]. $\hat{A}^{LD}_{z,i,t}$ is the rate of technological learning from production and $\hat{X}_{z,i,t}$ is the production growth between periods $t-1$ and t. Additionally, $A_{z,i,t-1}$ is the firm's productivity at time $t-1$. The restriction $\hat{X}_{z,i,t} > 0$ implies that negative growth of production do not cause technological unlearning.

The second source of increase in labour productivity is imitation. This source of technological progress is stochastic, local and is available to all firms. The technology subjected to imitation has some tacit components, what means that the imitating firm is only capable of absorbing part of the productivity from its imitated counterpart. First, the imitating firm randomly selects three firms and compare their productivities before deciding which one it is going to imitate. The imitating firm chooses the technology of the firm with the highest productivity within the selected ones, formally we have:

$$A^{IM,max}_{z,i,t} = \max(A^{IM}_{z,1,t-1}, A^{IM}_{z,2,t-1}, A^{IM}_{z,3,t-1}) \tag{5.17}$$

Once the imitated firm is chosen, the next step is to define how much of that firm's productivity can be imitated. This depends on the technological distance between the imitating and the imitated firm, as shown by the following equation:

$$A^{IM}_{z,i,t} = A_{z,i,t-1} + e^{\left[-\ln\left(\frac{A^{IM,max}_{z,i,t-1}}{A_{z,i,t-1}}\right)\right]} \delta_2 (A^{IM,max}_{z,i,t-1} - A_{z,i,t-1}) \tag{5.18}$$

The functional form of equation (5.18) captures the technological gap effect. The wider the gap between the two firms the less the imitating firm is able to absorb from the imitated one's technology. Since the wider the gap the harder it is to make the technological

[7] A Kaldor-Verdoorn coefficient equal to zero would imply that no 'learning by doing' takes place. Although equation (5.15) applies the Kaldor-Verdoorn Law correlation at the microeconomic level, the aggregate relation is preserved.

transition or "jump". The exponent of the neperian term captures the technological gap, which follows an inverse exponential process. The parameter δ_2 determines how much of the productivity difference between the imitating and the imitated firm will be absorbed by the former.

The third source of technological change is the innovation based on the firms' own research. At the beginning of each period firms allocate a fraction $\varphi_{z,i}$ of their accumulated profits $\Pi^S_{z,i,t}$ to R&D. Even though innovation depends on R&D expenses, it is a highly uncertain process. Therefore, in the present model this process is set as a two stages stochastic event. In the first stage, there is the event "success or failure"in the discovery of a new technology, while in the second stage there is the event of increasing labour productivity, which follows an inverse exponential function as in Nelson & Winter (1982) and Valente & Andersen (2002).

In equation (5.19), the probability of innovation follows an exponential inverse process that depends on the relation of R&D expenses to total revenue, where $RDR_{z,i,t-1} = RD_{z,i,t-1}/RT_{z,i,t-1} = \varphi_{z,i}\Pi^S_{z,i,t-2}/(R^O_{z,i,t-1} + R^F_{z,i,t-1})$ and on cumulative effects of productivity $A^{IN}_{z,i,t-\tau}$. Therefore, to capture the non-linearity of the labour productivity growth, in equation (5.20) we assume that the event "success"in innovate results from an inverse exponential distribution with mean $\ln(A_{z,i,t-\tau})$ and variance σ^2_2. This result is only implemented if the probability of innovation ($P^{IN}_{z,i,t}$) given by (5.19) is greater than or equal to a pseudo-random number generated by a uniform probability distribution function varying between 0 and 1:

$$P^{IN}_{z,i,t} = \frac{\gamma_0}{(1+\gamma_1 e^{-\gamma_2 RDR_{z,i,t-1}})^{\Omega_1}} + \frac{\gamma_0}{(1+\gamma_3 e^{-\gamma_4 A^{IN}_{z,i,t-\tau}})^{\Omega_2}} \tag{5.19}$$

where γ_0, γ_1, γ_2, γ_3, γ_4, Ω_1 and Ω_2 are parameters that adjust the sensibility of the probability of innovating to accumulated profits ($\Pi^S_{z,i,t}$) and to cumulative effects of productivity ($A^{IN}_{z,i,t-\tau}$). The value of the probability is $P^{IN}_{z,i,t} \in [0,1]$. The innovation's productivity is, therefore, calculated as:

$$A^{IN}_{z,i,t} = \begin{cases} e^{Norm(\ln A_{z,i,t-1},\sigma^2_2)} & \text{if} \quad P^{IN}_{z,i,t} \geq \text{RND(0,1)} \\ A_{z,i,t-1} & \text{if} \quad P^{IN}_{z,i,t} < \text{RND(0,1)} \end{cases} \tag{5.20}$$

The innovation process has a cumulative technological learning component, therefore its productivity depends on cumulative effects of past productivity. The firm may discover a technology that results in higher or lower labour productivity than the old one. If the newly discovered technology delivers a lower productivity than it will not be implemented and the firm will continue to use the old technology.

We have described three sources of technical progress that firms can resort to in order to increase their labour productivities. It can be thought that each source correspond to a different technology that delivers a different level of productivity. The firm will compare these three technologies: the one deriving from 'learning by doing', the one deriving from imitation and the one deriving from innovation based on the firm's own research. Then, the firm will choose to implement the technology that delivers the highest labour productivity. This is formalised by equation (5.21) below:

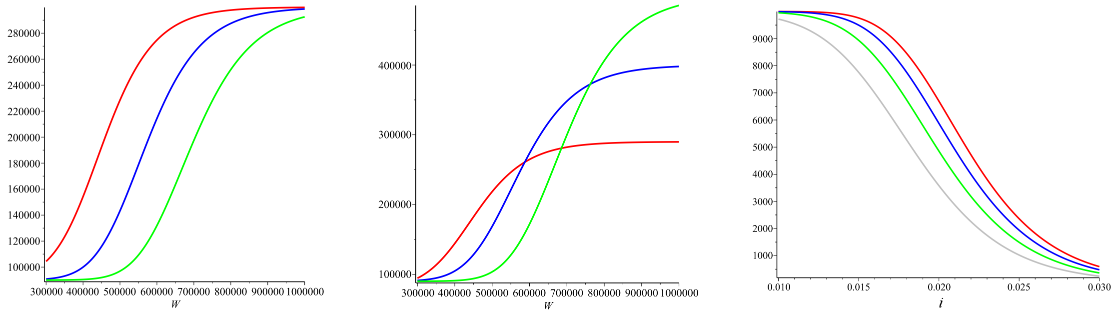
$$A_{z,i,t} = \max(A^{LD}_{z,i,t-1}, A^{IM}_{z,i,t-1}, A^{IN}_{z,i,t-1}) \tag{5.21}$$

5.2.4 Aggregate Consumption at Sectoral Structure

Consumption is determined at the aggregate sectoral level and faces a saturation limit. The existence of this limit is a tendency also described by Pasinetti (Pasinetti, 1981, p. 77). He argues that the expenditure on any particular good cannot increase forever, there is always an upper limit on the amount of expenditure that is allocated by households to any one particular good or service, regardless of how much household income grows. Although expenditure on different commodities display this limit at different levels of real income, its attainment is inevitable. Once the household reaches this upper limit its expenditure ceases to increase in response to increasing income.

In the present model, each sector $z \in \{1, 2, 3, ...Z\}$ has a different hierarchical logistic consumption function. Aggregate sectoral consumption is asymmetrically affected by two components: wage and interest rate. Wage has a positive impact on consumption while the interest rate has a negative impact. The behaviour of the consumption function can be illustrated by figure (5.1). Figures (5.1a) and (5.1b) show how sectoral consumption evolves according to income growth (W). In figure (5.1a) all the sectors have the same saturation limit, while in figure (5.1b) they have different limits. Figure (5.1c) illustrates how sectoral consumption evolves with respect to the interest rate. As the interest rate rises, consumption declines.

Figura 5.1: Consumption evolution to Income (W) and Interest Rate (i)



(a) (b) (c)

Aggregate sectoral consumption is computed by equation (5.22). The share α of the consumption that is determined by wages W depends on a minimum and a maximum level of consumption C_z^{min} and C_z^{max} respectively, which are exogenous and constant. The maximum consumption level C_z^{max} is the saturation limit which, in this model, is different for each of the three sectors. The share of the consumption that depends on the interest rate $(1-\alpha)$ depends on wages W_{t-1} from the previous period and on the difference between the interest rate adjusted by mark-up of the banks i_{t-1} and the deposit interest rate i_t^*.

$$C_{z,t} = \alpha C_{z,t}(W_{t-1}) + (1-\alpha) C_{z,t}(W_{t-1}, i_t) \tag{5.22a}$$

$$C_{z,t}(W_{t-1}) = C_z^{min} + \frac{(C_z^{max} - C_z^{min})}{\left[1 + q_z^1 \exp(-\frac{W_{t-1}}{g_z^1})\right]^{\psi_z^1}} \tag{5.22b}$$

$$C_{z,t}(W_{t-1}, i_t) = C_{z,t}(W_{t-1}) \left[1 - \frac{1}{[1 + q_z^2 \exp(-g_z^2(i_{t-1} - i_t^*))]^{\psi_z^2}}\right] \tag{5.22c}$$

The parameters q_z^1, g_z^1, ψ_z^1, q_z^2, g_z^2 and ψ_z^2 are exogenous and adjust the shape of the demand curve and the speed of saturation. Some of these parameters are equal to all sectors and some are different, their values are in table (5.1). The minimum level of consumption C_z^{min} is the same for all three sectors.

Sectors differ in their income elasticities of demand and in their productivity growth rates. These differences combined can explain the process of structural change observed throughout the simulation, where labour is reallocated amongst the three sectors. Sectoral productivity is calculated by the average of that sector firms' productivities weighted by their market share. In the model, firms in sector 1 have the lowest variance of innovation, which results in small increases in productivity in the event of a successful innovation based on R&D. Thus, sector 1's productivity rate ends up being the lowest of the three sectors. Firms in sector 2 have a medium variance of innovation and firms in sector 3 have a high variance of innovation. Higher variance of innovation contributes to make sectors 2 and 3's productivity rates higher than sector 1's. Sectoral demand evolves in a hierarchical way. Demand in sector 1 starts to grow before the other two sectors, only after a certain level of income has been reached that demand in the other two sectors starts to grow at a significant rate.

5.2.5 The Financing of the Firm and the Banking Sector

In the present model, firms not only produce goods and invest in R&D but also interact with the banking system, financing their losses in the period by taking out loans to finance their negative cash flows. The loan operation lasts only one period and, if the firm does not obtain enough profit to pay the interest on the debt and/or to write it off, a new loan is taken out in the next period and the process goes on until the firm is able to eliminate its debt. If a firm accumulates more debt than a certain multiple of its total revenue, then the firm is eliminated from the market. In our simulation, if a firm accumulates a debt ten times higher then its total revenue then the firm is eliminated from the market.

Equations (5.23) to (5.26) formalise the mechanism through which the banking system finances the firms. In this model the banking system is represented in a simple and straightforward manner. It can be understood as a pool of representative banks or as one bank that receives demand deposits and grant loans to firms. The deposit interest rate (i^*) is the rate banks pay firms on their accumulated profits invested in the financial system. In the present model, the deposit interest rate is assumed to be constant and exogenous. The lending interest rate (i_t) is the rate charged by banks for loans to firms. The difference between the two rates ($i_t - i^*$) is the net interest spread. This mechanism assumes an endogenous money supply in the sense of Kaldor (1982, 1985) and Moore (1988). This approach to the money supply is also known as the "horizontalist approach", according to which banks are passive and adjust the quantity of money to a given interest rate, money has an infinity elasticity of supply. Therefore, credit is restricted by means of price (the interest rate) not quantity.

The supply of credit is endogenous and determined by the firm's demand for credit. The firm's demand for credit is equal to its losses or negative profits $D_{z,i,t} = \Pi^{-}_{z,i,t}$. A firm's negative profit needs to be covered by bank loans. Since all the firm's losses automatically become debt, the firm's accumulated debt $D^{S}_{z,i,t-1}$ is equal to its accumulated negative profit. The economy's aggregate demand for credit (also the economy's total debt) in period t can be calculated by the sum of all the firms' individual demand, formally given by:

$$D_t = \sum_z \sum_i \Pi^{-}_t \tag{5.23}$$

The lending interest rate for the loan operations is calculated by applying a mark-up (h_t) over the deposit interest rate, according to the following equation:

$$i_t = (1 + h_t)i^* \tag{5.24}$$

Banks set the lending interest rate (i_t) based on their evaluation of the economy's degree of indebtedness. Once set, it is applied to all firms, independently of their individual degree of indebtedness. The banks' mark-up (h_t) is adjustable and might change from one period to the next depending on a loan payment default indicator (d_t), which is ratio of the economy's total debt to its total accumulated profits,

$$d_t = \frac{\sum_z \sum_i \Pi^{-}_t}{\sum_z \sum_i \Pi^{S}_t} \tag{5.25}$$

The risk adjusted banking mark-up is given by:

$$h_t = \frac{h^{max}}{[1 + \theta_1 e^{\theta_2 d_{t-1}}]^{\theta_3}} \tag{5.26}$$

where h^{max} is the maximum mark-up set by the banks and $\theta_1, \theta_2, \theta_3$ are parameters that control the sensibility of the mark-up to the degree of risk perceived by the banking system at each period. It is assumed that h^{max} is exogenously fixed. An increase in the default rate at any period raises the expected default rate for the next period. Banks react by increasing their risk adjusted mark-up for the next period. Empirical evidence for this behaviour may be found in Saunders & Schumacher (2000), Angbazo (1997) and Brock & Rojas-Suarez (2000).

The present ACE model, though having a relatively simple general structural, being comprised of a number of heterogeneous firms grouped in sectors and a pool of identical financial institutions, due to its evolutionary behaviour and complex interactions, is capable of producing interesting emergent macroeconomic dynamics.

5.3 Simulation and Results

In order to evaluate the impacts of endogenous financing on sectoral growth and dynamics we conducted a simulation assuming the evolution of three sectors[8]. Sectors differ in some of their demand curve parameters that control the shape and speed of saturation of demand, on the saturation limit or maximum consumption of each sector C_z^{max} and on the variance of innovation σ_2^2. Sector 1 has the lowest variance of innovation, sector 2 has an intermediate value and sector 3 has the highest variance of innovation. Their variance of innovation are reported in table (5.1). Each sector is composed of 100 firms at the beginning of the simulation. The simulation is run through 500 periods. The banking system provide financing to all the firms in all three sectors.

The firms ability to finance themselves derives from their profitability, which in turn depends on their success on innovate or on imitate their competitors. The deposit interest rate i is fixed at 1%. The economy and sectors' initial conditions are so that, each sector starts with effective demand set at 100.000 units, at a price of \$ 1.00. Sectors 1, 2 and 3 have their saturation limits set at 300.000, 400.000 and 500.000 units respectively. All firms in all sectors start with market shares of 1%, which then evolve as firms adjust their mark-ups according to 5.9. Firms' market shares change by a percentage β of the difference between their prices and the sector's average price. In this simulation β is set at 0.1 for all three sectors. All the firms start with accumulated profits of \$ 1.000. Lastly the banks' mark-up is set initially at 1%.

Figure 5.2 shows, as expected, that the sectoral consumption evolution follows a logistic form. This is due to the functional form chosen for the demand curve. The different shapes of the sectoral demand curves represent the different income elasticities of demand of each sector. Sectoral consumption and production fluctuate very closely but are not equal. This is because firms accumulate (decrease) inventory when their expected

[8]The computational simulation was computed with the Laboratory for Simulation and Development (LSD) software, version 6.4, developed by Valente (2008).

demand is higher (lower) than effective demand.

The simulation resulted in two financial crises, a smaller one starting around period 280 and a bigger one starting around period 374. These crises can be seen in figure (5.5). A financial crisis is characterised here by an increase in the lending interest rate charged by banks. When the interest rate rises, consumption declines. This is due to the functional form chosen for the demand curve, that conditions a share $(1 - a)$ of consumption to vary according to the interest rate. In both crises there is a decline in consumption and in production in all sectors, though in different intensities because sectors differ in their weight on total consumption and production at the moment of the crises. Both crises happen after sectoral demand reaches saturation. This pattern emerges even with different micro calibrations. One explanation is that, interest rate rises when firms demand more financing for R&D. After demand saturates, production stagnates and technological progress based on "learning by doing"is reduced, thus firms start to compete more based on innovation through R&D which demands more financial resources. Firms in sector 3 have a higher variance of innovation. Consequently, they innovate more base on R&D, but they also demand more financing and accumulate more debt. One of the consequences is that at the end of the simulation sectors 1, had 97 firms, sector 2, had 93 and sector 3 had 73 firms. Sector 3 lost more firms then the other two. This pattern is also recurrent in simulations with other micro calibrations, the most innovative sector loses the most firms.

As demand reaches saturation and firms continue to increase their productivities they need less workers to produce the same amount of goods, so employment in each sector starts to decline after consumption saturation point. The speed of employment decline in each sector is different depending on their productivities. Sector 3 with the fastest increase in productivity due to its high rate of innovation has the fastest decline in employment as it can be seen in figure (5.3a). Moreover, productivity increases are reflected in prices. As it can be seen in figures (5.2d) and (5.2c) the higher the increase in productivity the lower the price. Sector 1, where increases in productivity are small, experiences the largest increase in price.

Another macroeconomic property that emerges from the simulation is the behaviour of effective and expected demand during the crises. These two variables tend to move closely together due to the adaptive characteristics of the model's equations. During the period of rapid expansion of consumption, effective demand grows faster than expected demand for all sectors. After consumption reaches the saturation point the two variables match. However, during the crises they behave differently. At the beginning of the crises effective demand declines faster then expected demand. When the economy starts to recovery from the crises, at around period 399, effective demand grows faster than expected demand. This can be seen in figure (5.4), which depicts the effects of the two financial crises on effective and expected demand in sector 3. The same pattern happens in sectors 1 and 2. This property shows that when consumption changes in either direction, firms take time to adjust to the new scenario. This property is the result of the adaptive expectational characteristic of the model. Figure (5.4) also shows that the lowest point in both crises match the highest value of the lending interest rate with one period lag. In both crises, as the interest rate start to fall, effective demand starts to increase and returns to its previous saturation level.

The model also generates a process of structural change. The reallocation of resources, in this case labour, across the three sectors is depicted in figure (5.3). Structural change derives from demand and supply factors simultaneously, as sectors differ in their income elasticities of demand and in their productivity rates. The sectoral employment evolution is related to the evolution of demand, but is also affected by the evolution of the sectoral productivity. When we look at employment in absolute terms, the three sectors seem to behave in similar ways. However, when we analyse the evolution of each sector's share of the economy's total employment we can observe an intense structural change until around period 250. If we select the observation between periods 220 and 280, the dynamics of the structural change in the sectors' share of the economy's total employment approximates the patterns described in figure (3.1) of chapter 3 and found by Foellmi & Zweimüeller (2008). After all three sectors have reached their demand saturation limits, structural change is significantly reduced. Employment also fluctuates during the two financial crises as demand and production declines and later increases along the crises.

Some variables in the model are determined by the dynamics of the economy as a whole, such as nominal and real wages. They are affected by increases in the economy's average productivity rate, which in turn is affected by the level of innovation and competition among firms in all three sectors and by the unemployment rate. In the simulation, both wages show an increasing trend, as we can see in figure (5.5d). At first they increase due to increased demand and later, after demand saturates, even with declining employment they continue to rise due to increased labour productivity, which are transferred to higher wages.

Figures (5.6) and (5.7) show the evolution of the market share and the mark-up of each firm in each of the three sectors. The figures depict the evolution of the variables for all firms, and also to make the visualization easier, depict the same variables without the dominant firm's data. All three sectors start with 100 firms. At the end of the 500 period simulation sectors 1, 2 and 3 are composed of 97, 93 and 73 firms respectively. In all three sectors we observe that as time passes, a dominant firm emerges. However, the degree of market concentration is very different among the three sectors. In sector 3 where the variance of innovation is the highest, the dominant firm's market share rises to around 80% at the end of the simulation, whereas sectors 1 and 2's dominant firm's market shares rise to around 25% and 10% respectively. This shows a possible positive relationship between the sectoral degree of innovativeness or productivity and the degree of market concentration. Figure (5.7) shows the evolution of the firms' mark-ups. The dominant firm in each sector is also the one with the highest mark-up. In both figures the lines that suddenly drop to zero are the firms that left the market. It can be seen that sector 3 was the one that lost the most firms. There seems to a be a relation between the degree of innovativeness and financial fragility. Since sector 3 is the most innovative one, it appears to be the most financially fragile, accumulating the most debt as can be seen in figure (5.5c). This last relation needs to be more thoroughly analysed before any affirmative can be made, for now we can only speculate about the existence of a positive relationship.

Regarding the firms' technological strategy, they have three options of technology available at each period: a technology deriving from 'learning by doing', one from imitation and one from innovation based on the firm's own R&D. The third option might not be available to all firms at all times because some firms may not have accumulated enough profits to invest in R&D and might not be able to finance their research expenses in the financial system. Firms evaluate the productivity of each of the three technologies and choose the one that provides the highest labour productivity. Then, they compare the productivity of the new technology with the productivity of the technology used in the previous period. If the new technology delivers a higher productivity, firms switch to the new technology, if not, they continue using the old one and no innovation is done.

Figure (5.8) portrays all the choices made by all the firms in all three sectors in all periods. The height of the rectangles are represent the 500 periods of the simulation and its width the 100 firms in each sector. At the top of the rectangles is period 1 and at the bottom period 500. The red squares with number 1 represent the adoption of the technology from 'learning by doing', the blue ones with number 2 the technology from imitation, the black ones with the number 3 the technology from innovation based on the firm's own R&D and the white ones with the number 0 means that the firm kept the technology from the previous period and no innovation was done. The blank areas are the firms that disappeared in the process. The higher concentration of firms adopting 'learning by doing' on the left side of each rectangle and the firms that disappear on the right side is just the way the data in organized internally by the LSD software used in the simulation.

In figure (5.8) we can observe that technical progress based on 'learning by doing' is intense among firms in periods of rapid expansion of production. As demands reaches saturation, increases in productivity due to 'learning by doing' are significantly reduced. The two horizontal red lines that appear on the lower halves of the rectangles are the periods corresponding to the recovering from the two financial crises, when there was a brief increase in production in all sectors. When we compare de technological dynamics of the three sectors we can observe that sector 3, where the variance of innovation based on firms' own R&D is the highest has the most number of periods with no innovation (with squares). Table 5.2 shows the total number of each type of innovation in each sector. It confirms that sector 3 is the one with the most cases with no innovation. However, in terms of sectoral average productivity sector 3 is far the most productive, as we can see in figure (5.2d). Due to the technological micro calibration of sector 3, when innovations occur they have a greater impact on productivity, this means that it will take longer for a new technology to be able to deliver a higher productivity. Therefore, innovations in sector 3 are less frequent but have a greater impact on labour productivity then in the other sectors.

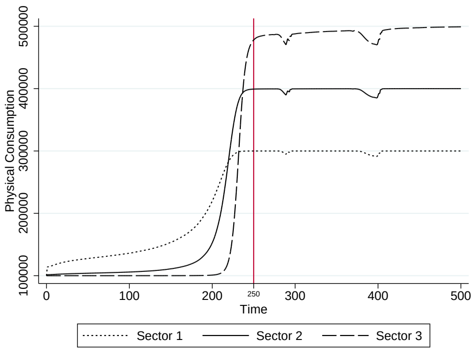
Differently from aggregate analytical models, in the present model the macroeconomic and sectoral dynamics emerge from a cumulative process based on the interactions of heterogeneous agents. Economic growth and business cycles are emergent phenomena of complex, interactive and evolutionary behaviour of agents. In the simulation presented in this section we showed it to be possible to theoretically reproduce complex macroeconomic patterns of growth, structural change and business cycles from a microeconomic dynamics.

The present model only explores one aspect of technological progress, the innovation of process. It was shown that if one assumes demand saturation, one of the consequences of continuous increase in productivity is the decline in employment. In order to absorb the displaced labour, new products and/or sectors have to be introduced to create new demand and sustain the growth process. This point was emphasized in previous chapters and by many works already cited[9]. Product innovation is thus a crucial aspect in the process of sustained economic growth.

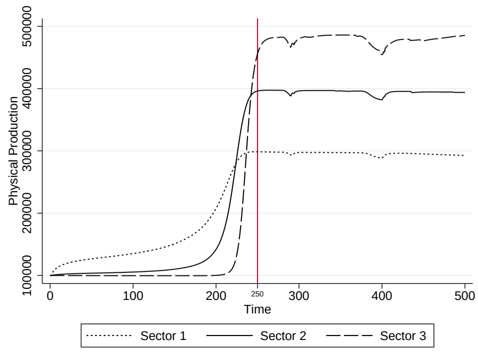
In order to fully analyse all the aspects of sustained growth proposed throughout this thesis the present model would have to be extended to incorporate some extra elements. The first of those elements is a mechanism where new firms in the existent sectors enter the market. This could avoid or reduce excessive market concentration. The second element would be the emergence of new sectors with new goods through product innovation. This would create new demand and counteract the effects of demand saturation on employment. A third element would be the addition of a mechanism of product destruction, where goods cease to exist after going though a cycle of launch, expansion, maturity and decline. These extensions will be the object of future research. The present framework could also be extended to analyse international production specialisation patterns, contributing to the New Latin American Structuralist (NLAS) growth theory.

[9] Frey (1969), Aoki & Yoshikawa (2002), Saviotti & Pyka (2004), Foellmi & Zweimüeller (2008).

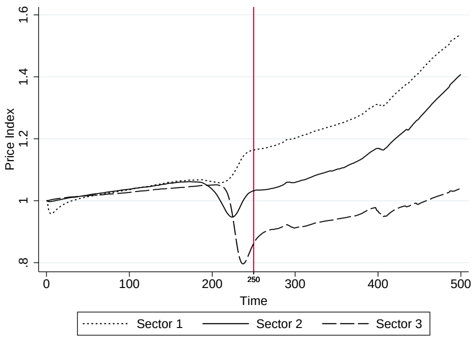
Figura 5.2: Sectoral Variables and Employment Evolution



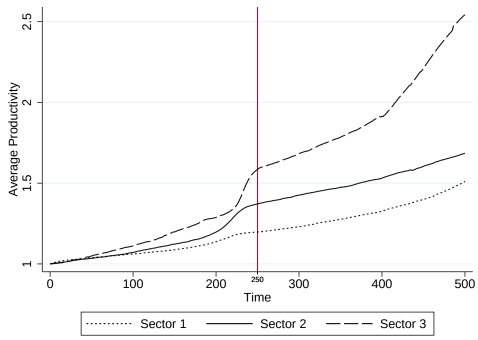
(a) Sectoral Consumption



(b) Sectoral Production

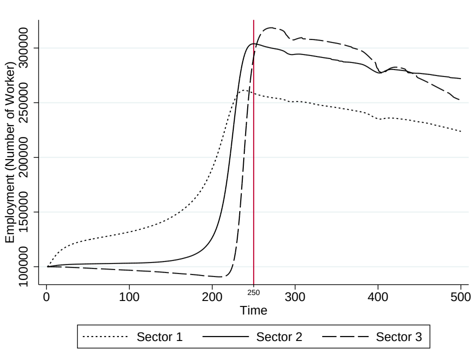


(c) Sectoral Price Index

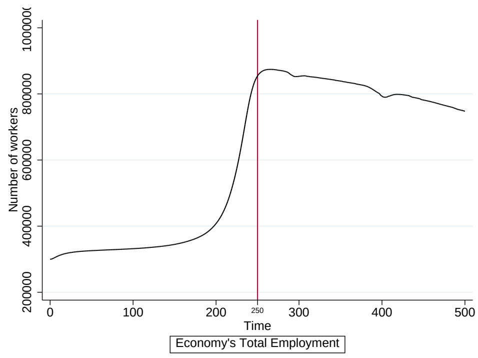


(d) Average Productivity weighted by Market-share

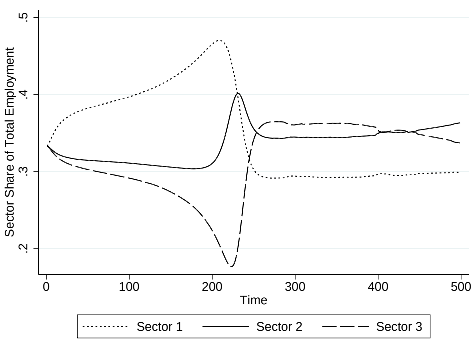
Figura 5.3: Employment Evolution



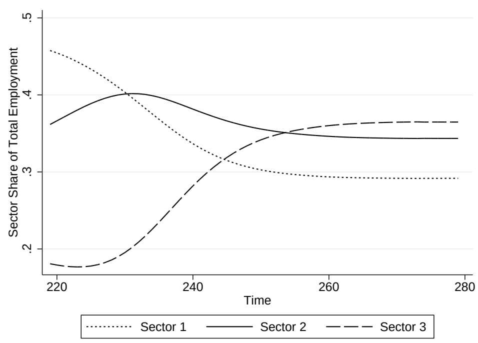
(a) Sectoral Employment



(b)

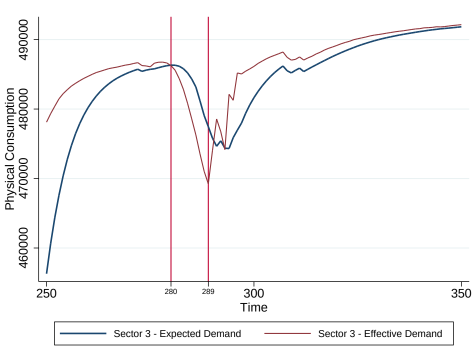


(c) Sector Labour Share

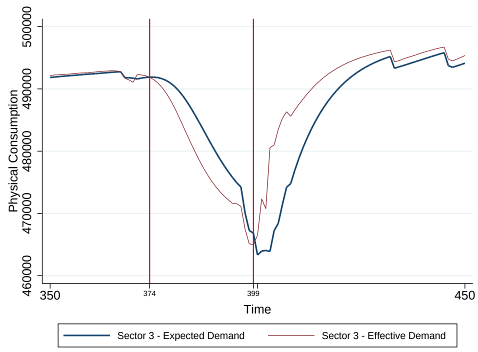


(d) Sector Labour Share (Selected Period)

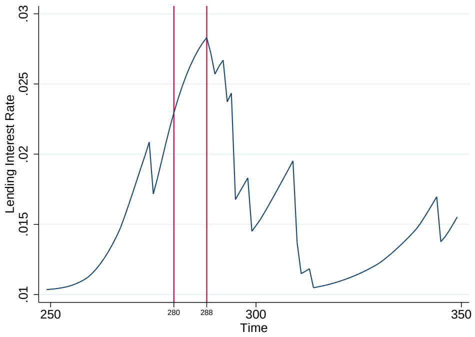
Figura 5.4: Sector 3 Effective v.s Expected Demand During Crisis



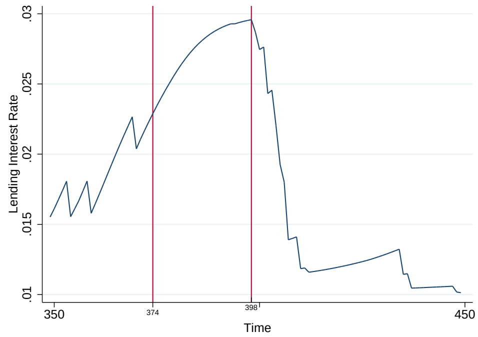
(a) Effective v.s Expected Demand First Crises



(b) Effective v.s Expected Demand Second Crises

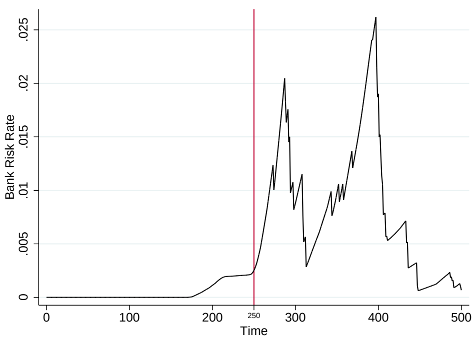


(c) Lending Interest Rate During First Crisis

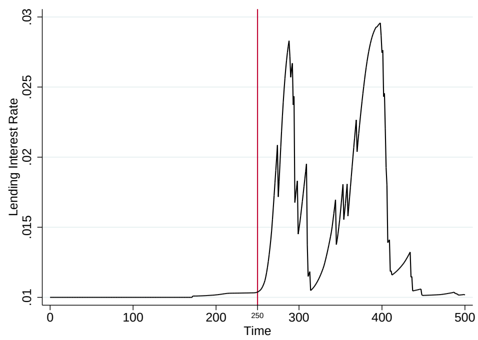


(d) Lending Interest Rate During Second Crisis

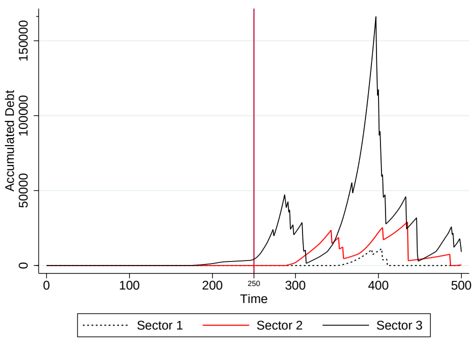
Figura 5.5: Financial System Economy's Aggregate Variables



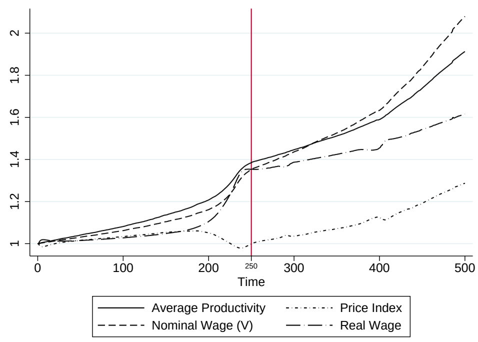
(a) Loan Payment Default Indicator (Bank's Risk Rate)



(b) Interest rate Adjusted by Mark-up of the Banks (Lending Interest Rate)

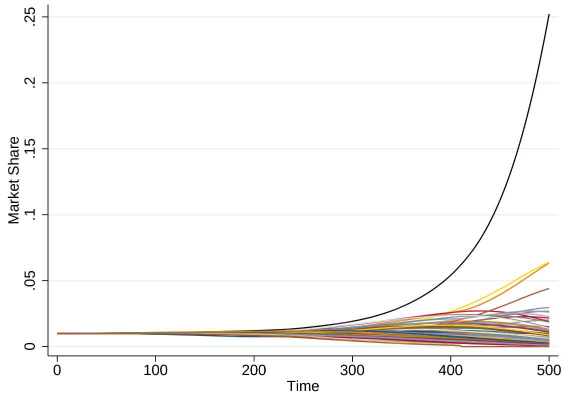


(c)

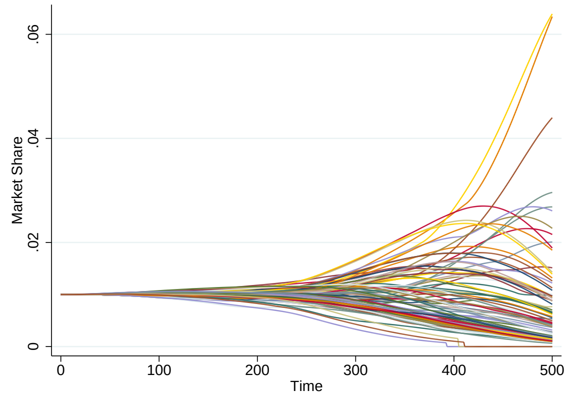


(d)

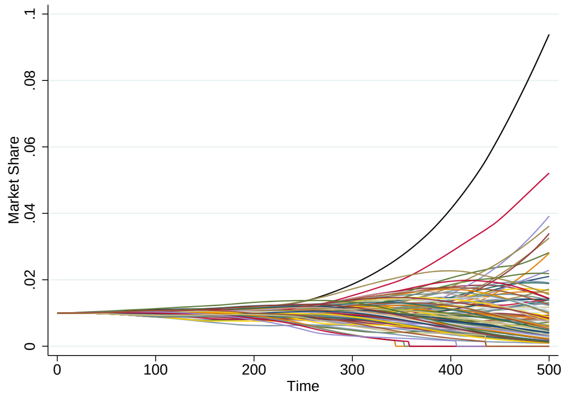
Figura 5.6: Firm's Market Share Evolution



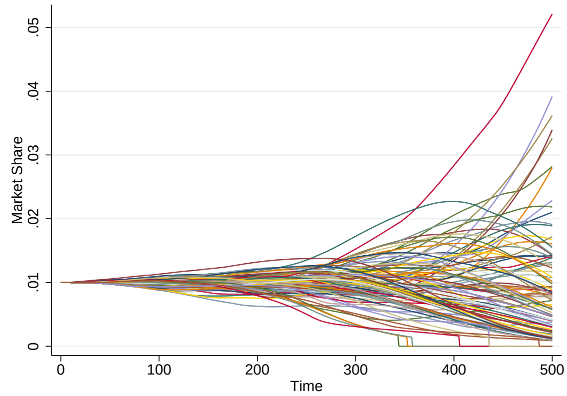
(a) Sector 1 - All Firms



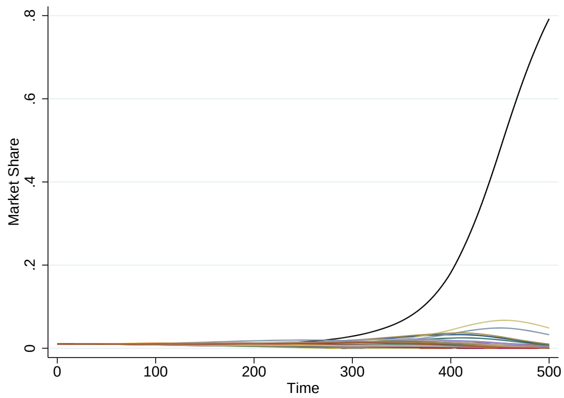
(b) Sector 1 - Excluded Dominant Firm



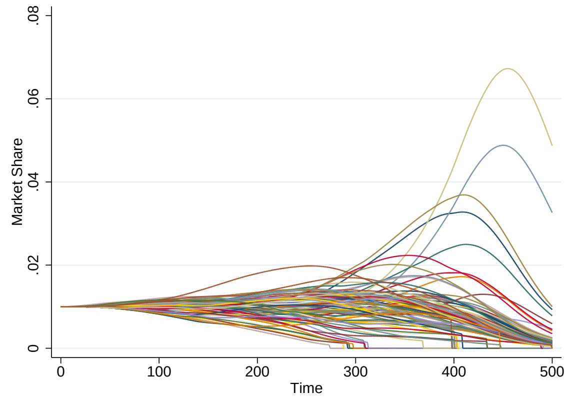
(c) Sector 2 - All Firms



(d) Sector 2 - Excluded Dominant Firm

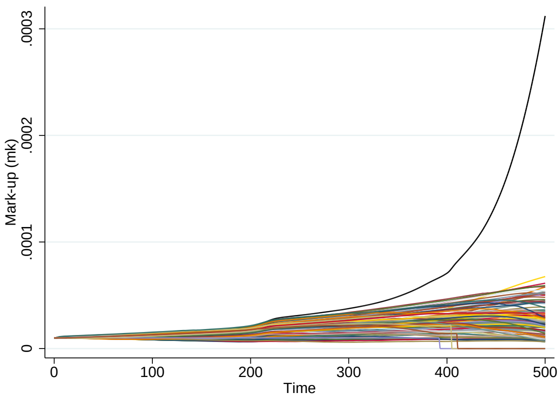


(e) Sector 3 - All Firms

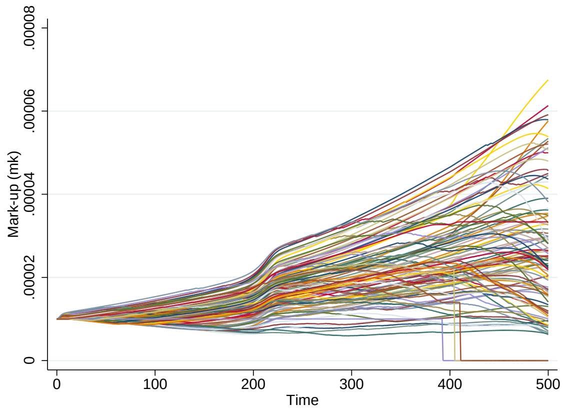


(f) Sector 3 - Excluded Dominant Firm

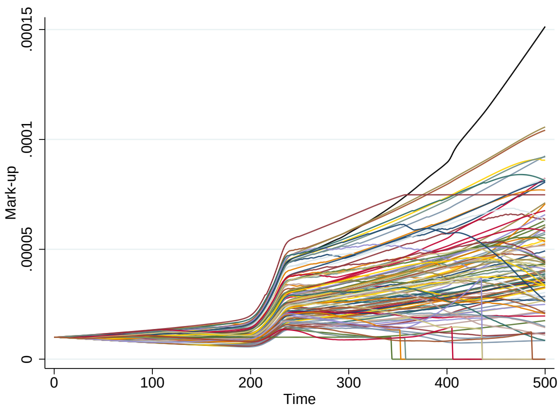
Figura 5.7: Firm's Mark-up Evolution



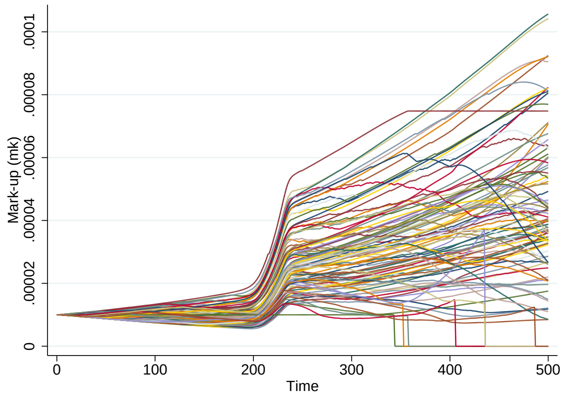
(a) Sector 1 - All Firms



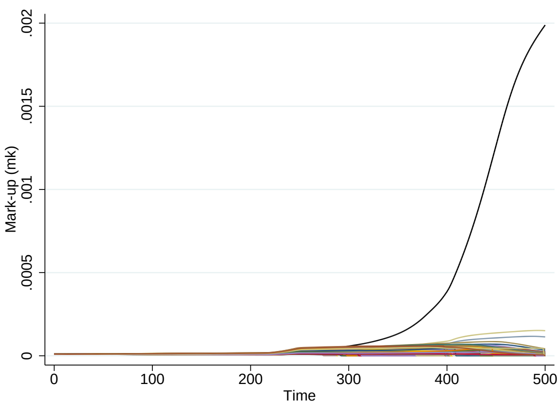
(b) Sector 1 - Excluded Dominant Firm



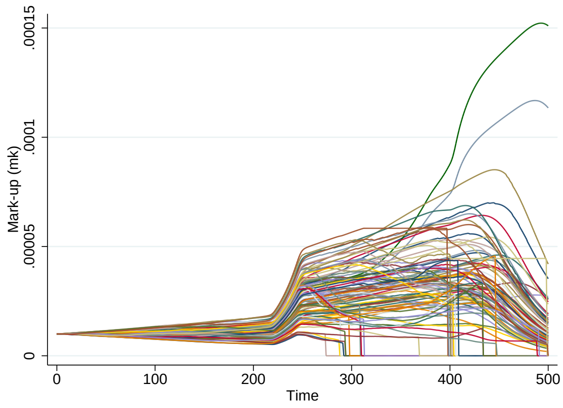
(c) Sector 2 - All Firms



(d) Sector 2 - Excluded Dominant Firm



(e) Sector 3 - All Firms



(f) Sector 3 - Excluded Dominant Firm

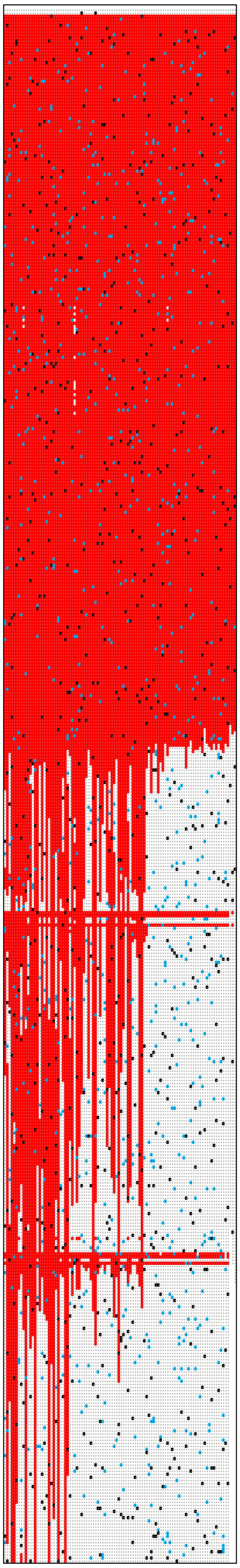
Tabela 5.1: List of Parameters by Sector

Description	Par.	Equa.	Sect.1	Sect.2	Sect.3
Same values for all Sectors					
Desirable Mark-up Parameter	λ_1	5.8	8	8	8
Desirable Mark-up Parameter	λ_2	5.8	-40	-40	-40
Desirable Mark-up Parameter	λ_3	5.8	3	3	3
Desirable Mark-up Parameter	λ_4	5.8	0.01	0.01	0.01
Desirable Mark-up Parameter	λ_5	5.8	-0.2	-0.2	-0.2
Desirable Mark-up Parameter	λ_6	5.8	0.5	0.5	0.5
Desirable Mark-up Parameter	$\check{mk}_1$	5.8	0.03	0.03	0.03
Desirable Mark-up Parameter	$\check{mk}_2$	5.8	-0.03	-0.03	-0.03
Desirable Mark-up Parameter	f	5.8	80	80	80
Firms Mark-up adjustment Par.	ρ	5.9	0.03	0.03	0.03
Firm's Market-share Gain	β	5.11	0.1	0.1	0.1
Percentage of Remuneration of i	κ	5.12	0.8	0.8	0.8
% Profit Devoted to R&D	φ	5.12	0.1	0.1	0.1
Labour Demand Adjustment	ξ	5.3	0.8	0.8	0.8
Labour Demand Adjustment Parameter	ι	5.3	0.5	0.5	0.5
Expected Demand Parameter	η	5.4	0.8	0.8	0.8
Nominal Wage Adjustment Parameter	ζ	5.14	0.6	0.6	0.6
Share of Demand Derived from Wages	α	5.22	0.9	0.9	0.9
Demand Curve Parameter	q_z^2	5.22	100	100	100
Demand Curve Parameter	g_z^2	5.22	300	300	300
Kaldor-Verdoorn Coefficient	δ_1	5.15	0.1	0.1	0.1
Imitation Productivity Absorption	δ_2	5.18	0.9	0.9	0.9
Probability of Innovating Parameter	γ_0	5.19	0.075	0.075	0.075
Probability of Innovating Parameter	γ_1	5.19	20	20	20
Probability of Innovating Parameter	γ_2	5.19	200	200	200
Probability of Innovating Parameter	γ_3	5.19	5	5	5
Probability of Innovating Parameter	γ_4	5.19	0.15	0.15	0.15
Probability of Innovating Parameter	Ω_1	5.19	2	2	2
Probability of Innovating Parameter	Ω_2	5.19	2	2	2
Deposit Interest Rate	i^*	5.24	0.01	0.01	0.01
Bank's maximum mark-up	h^{max}	5.26	2	2	2
Bank's Mark-up Parameter	θ_1	5.26	5	5	5
Bank's Mark-up Parameter	θ_2	5.26	-250	-250	-250
Bank's Mark-up Parameter	θ_3	5.26	3	3	3
Sector specific values					
Demand Curve Parameter	q_z^1	5.22	80	70	120
Demand Curve Parameter	g_z^1	5.22	1.25e-5	1e-5	8e-6
Demand Curve Parameter	ψ_z^1	5.22	2.5	3.5	4.5
Demand Curve Parameter	ψ_z^2	5.22	5.0	4.0	3.0
Variance of Innovation	σ_2^2	5.20	0.008	0.015	0.023

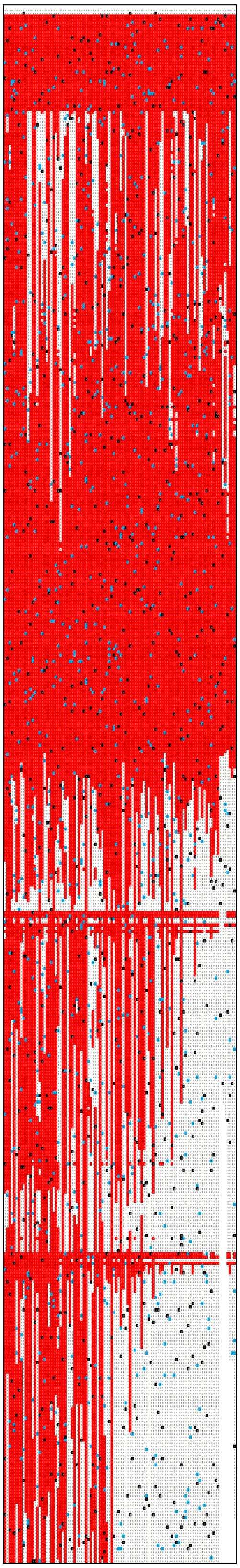
Tabela 5.2: Firms Innovation Strategies

Number of Cases	Sector 1	Sector 2	Sector 3
No innovation	17112	16193	24033
Learning by Doing	30892	31327	20968
Imitation	900	976	980
Innovation based on R&D	802	817	785
Empty cases due to firm disappearance	294	687	3234
Total	50000	50000	50000

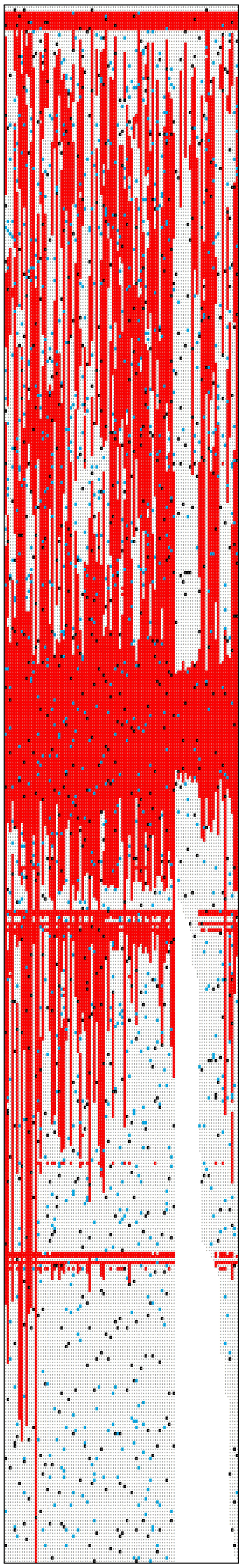
Figura 5.8: Firm's Innovation Strategy



(a) Sector 1



(b) Sector 2



(c) Sector 3

Red(1)=L.by.D; Blue(2)=Imitation; Black(3)=Innovation from R&D; White(0)=No innovation; Blank area=firms that disappeared

6. CONCLUDING REMARKS

Modern growth theory has gone through a series of transformations since its birth. The focus of its analysis has expanded and the features of the models have become more complex. What we have seen in recent years is a new wave of models that incorporate elements that were once left out of the analyses of growth. Structural change and demand saturation are some of these elements that have changed the way sustained growth is modelled. Rather than being a mere by-product of the growth process, structural change can retard growth if its pace is too slow or its direction inefficient, but it can contribute to growth if it improves the allocation of resources. Demand saturation in the absence of product innovation coupled with continues productivity increase leads to unemployment and stagnation. These new models have contributed to the understanding of the mechanisms behind the relationship between growth and these variables and have pushed further the frontier of the field of growth theory. However, regarding the advances in the understanding of sectoral dynamics Acemoglu points out that "[...] we are still far from a satisfactory framework for understanding the process of sectoral reallocation of factors [...]"(Acemoglu, 2009, p. 720).

Regarding the way structural change is defined, the classical trichotomy among agriculture, manufacturing, and services may have lost most of its relevance due to the enormous heterogeneity among different services subsectors, largely ignored in the previous literature, something that calls for greater attention to individual service sectors to understand the process of economic growth and structural change. Finding better ways to divide and classify the sectors in the economy that better account for their heterogeneity is one of the challenges ahead.

The study of demand evolution, structural change and the emergence of new sectors which creates new demand, is essential if one wants to comprehensively understand the process of long-run economic growth. However, many growth models that address the phenomenon of structural change assume the number of sectors and/or products in the economy to be constant. In order to understand the interactions between sectoral dynamics and growth, models should account for the increase/decrease in the number of sector/products in the economy. Moreover, the emergence of new sectors, demand saturation and technological progress are elements that must be analysed simultaneously.

Agent based computational economic (ACE) models offer a more flexible framework to deal with these issues.

In the model developed in chapter 5, the macroeconomic and sectoral dynamics emerge from a cumulative process based on the interactions of heterogeneous agents. Economic growth, business cycles and structural change are emergent phenomena of complex, interactive and evolutionary behaviour of agents. In the simulation presented hereinbefore, we showed that it is possible to theoretically reproduce complex macroeconomic patterns of growth, structural change and business cycles from microeconomic dynamics. The model developed replicates the dynamics of structural change where production factors (labour) is reallocated among the three sectors. The process of structural change, as in Boppart (2014), is driven by demand and supply factor simultaneously, as sectors differ in their income elasticities of demand and in their productivity rates. The results approximate, for a selected period of the simulation, the pattern of structural change of the share of employment described in Herrendorf et al. (2014) and Foellmi & Zweimüeller (2008).

The computational model developed in the present thesis only explores the aspects of innovation of process. However, it can be observed that when demand is allowed to saturate, one of the consequences of continuous increases in productivity is an increase in unemployment. In this scenario, new products and/or sectors that elicit new demand have to emerge so that they can absorb the displaced labour. Therefore, product innovation and new sector creation are essential elements in order to sustain economic growth with full employment of factors in the long run.

Lastly, adding a financial dimension to the analysis of growth and structural change creates a channel through which microeconomic dynamics at the firm level can explain the emergence of crises in technologically developed economies. Technologically intensive sectors tend to be more affected in the event of a crisis as they are more indebted due to high rates of R&D financing. This is an area of research that remains little explored in the literature.

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APPENDIX

Model Code

```
/*******************************************
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Prof. João Basilio Pereima
Francisco Gabardo
Model: Structural Change with exogenous structure of 3 sectors
Update: 08/03/2016
Balance Sheet (Demonstrativo de Resultado)

(=) RT               Total revenue
 +  RO             Operating revenue
 +  RF             Financial revenue   0.8*H*WorthNet
 -  W              Wages  (Variable cost)
 -  RD             R&D expenses as an share of profits
 =  ProfitOp       Operating Profit
 -  DF             Financial expenses DF = H*Debt
 =  ProfitNet      Net Profit, after interest
 =+ Profit_Acc     ProfitNet accumulated
    ------------
    Debt     If Profit_Acc < 0  Third part liability (Passivo de Terceiros)
    WorthNet  If Profit_Acc > 0  Liquid Assest        (Patrimonio Liquido)

********************************************/
#include "fun_head.h"

MODELBEGIN

EQUATION("IdFirm")
/* Firm's id number */
v[0]=1;
CYCLE(cur,"Firmas")
  WRITES(cur,"IdFirmas",v[0]++);
PARAMETER                // Transform idFirm in parameter
                          and never compute it again
RESULT(1)

EQUATION("T")
/* Time */
v[0]=t;
RESULT(v[0])

/* 1)EQUATIONS AT ECONOMY LEVEL
   1.1 - General Equations
   ------------------------------- */

EQUATION("TX")
v[0] = SUM("SX");
RESULT(v[0])

EQUATION("TWage")
v[0] = SUM("SWage");
RESULT(v[0])

EQUATION("TConsumo")
v[0] = SUM("SConsumo");
RESULT(v[0])

EQUATION("TA")
/* Total productivity of economy */
v[0] = SUM("SA")/3;
RESULT(v[0])

EQUATION("gTA")
/* Total productivity of economy */
v[0] = V("TA")/VL("TA",1)-1;
RESULT(v[0])

EQUATION("Unemployment")
/* Global Unemployment */
```

```
RESULT(1-V("TL")/V("Pop") )

EQUATION("WageBase")
v[0] = V("TA")/VL("TA",1)-1;
if (v[0]>0)
{  v[1] = pow(1-VL("Unemployment",1),0.6);
   v[2] = VL("WageBase",1);
   v[3] = (1+v[0]*v[1])*v[2];
}
else
   v[3] = VL("WageBase",1);

RESULT(v[3])

EQUATION("WageReal")
/* Global/total Real Wage */
v[0]=V("WageBase");
v[1]=V("TPrice");
RESULT(v[0]/v[1])

EQUATION("TPrice")
/* Global/total price index */
v[0]=V("WageBase");
v[1]=0;
v[2]=0;
CYCLE(cur,"Sector")
{
  v[1]=v[1]+VS(cur,"SX")*VS(cur,"SPrice");
  v[2]=v[2]+VS(cur,"SX");
}
v[3]=v[1]/v[2];
RESULT(v[3])

EQUATION("TL")
/* Global/total Labour */
RESULT(SUM("SL"))

EQUATION("TProfitNet")
v[0] = SUM("SProfitNet");
RESULT(v[0])

EQUATION("TDebt")
v[0] = SUM("SDebt");
RESULT(v[0])

EQUATION("TWorthNet")
v[0] = SUM("SWorthNet");
RESULT(v[0])

/* 1.2 - Financial Market
   ------------------------------- */
EQUATION("d")
/* Bank risk rate */
v[0]=V("TDebt");
v[1]=V("TWorthNet");
if (v[1]>0)
   v[2]=v[0]/v[1];
else
   v[2]=999;
RESULT(v[2])

EQUATION("h")
/* Mark up of bank adjusted by risk rate
(indebtedness) using a Richard's curve */
v[0]=VL("d",1);
if (v[0]>0)
{    v[1]=2;  // If v[1]=2 then interest rate can triplicate H=1+2=3
     v[2]=pow(1+5*exp(-250*v[0]),3);//alterado de 50  para 5
```

```
    v[3]=v[1]/v[2];
}
else
    v[3]=0;
RESULT(v[3])

EQUATION("H")
/* Interest rate ajusted by mark-up of the banks */
v[0]=V("h");
v[1]=(1+v[0])*V("ib");    //Basic interest rate ib=0.01
RESULT(v[1])

/* 2)EQUATIONS AT SECTOR LEVEL
   ------------------------------------------- */

EQUATION("SSatur")
/* Sectorial Saturation of market*/
v[0]=V("SConsumo")/V("SMax");
RESULT(v[0])

EQUATION("SL")
/* Sectorial Employment level*/
v[0]=SUM("L");
RESULT(v[0])

EQUATION("ICMHH")
/* Market Concentration Index */
v[0]=0;
CYCLE(cur,"Firmas")
{      v[1]=VS(cur,"ms");
       v[0]=v[0]+v[1]*v[1];
}
RESULT(v[0])

EQUATION("SX")
/* Sectorial Aggregated production */
v[0]=SUM("X");
RESULT(v[0])

EQUATION("gSX")
/* Product sectorial growth rate */
v[0]=VL("SX",1);
v[1]=V("SX");
v[2]=v[1]/v[0]-1;
RESULT(v[2])

EQUATION("SXstock")
/* Not planned stock aggregated */
v[0]=SUM("Xstock");
RESULT(v[0])

EQUATION("EM")
/* Competitivity Average weighted by 'ms'*/
RESULT(WHTAVE("E","ms"))

EQUATION("SA")
/* Sectorial Average Produtivity weighted by market-share */
RESULT(WHTAVE("A","ms"))

EQUATION("gSA")
/* Productivity growth rate */
v[0]=VL("SA",1);
v[1]=V("SA");
v[2]=v[1]-v[0];
v[3]=v[2]/v[0];
RESULT(v[3])

EQUATION("SPrice")
```

```
/* Average price weighted by market-share */
RESULT(WHTAVE("P","ms"))

EQUATION("gSPrice")
/* Inflation */
v[0]=VL("SPrice",1);
v[1]=V("SPrice");
v[2]=v[1]/v[0]-1;
RESULT(v[2])

EQUATION("SWage")
/* Sectorial total nominal wage */
v[0]=SUM("W");
RESULT(v[0])

EQUATION("SConsumo")
/* based on a generalized logistic function
   C(W) = A + (K-A)/{[1+Q.exp(-gW)]^c}
   Where     A = minimum consumption
             K = maximum consumption
          q = depends on C(0)
          g = growth rate
          c = affect near which maximum growth occur (inflection point) */
v[0] = V("SCmin");    // A
v[1] = V("SCmax");    // K
v[2] = VL("TWage",1); // +(0.1)*VL("TProfitNet",1);
v[3] = pow(1+V("q")*exp(-V("g")*v[2]),V("psi1"));
v[4] = v[0] + (v[1]-v[0])/v[3];

/* A share 1-a is affected by interest rate according to
C = a.v[4] + (1-a)*[v[4]/[(1+b(Ht-1-Ht))^c]*/
v[5] = 0.9;
v[6] = (1-v[5])*v[4];
v[7] = VL("H",1)-V("ib");
v[8] = pow(1+100*exp(-300*v[7]),V("psi2"));
v[9] = v[6]-v[6]/v[8];
v[10] = v[5]*v[4]+v[9];
WRITE("SConsWage", v[5]*v[4]);
WRITE("SConsInter",v[9]);
RESULT(v[10])

EQUATION("SC_exp")
RESULT(SUM("C_exp"))

EQUATION("SC_eff")
RESULT(SUM("C_eff"))

EQUATION("PMgC")
v[0]=V("SConsumo")/VL("SConsumo",1)-1;
v[1]=(V("SWage")/V("SPrice"))/(VL("SWage",1)/VL("SPrice",1))-1;
RESULT(v[0]/v[1])

EQUATION("SRT")
/* Sectorial Aggregated Operating Revenue */
v[0]=SUM("RT");
RESULT(v[0])

EQUATION("SProfitOp")
/* Sectorial Aggregated Operating profit */
v[0]=SUM("ProfitOp");
RESULT(v[0])

EQUATION("SProfitNet")
/* Sectorial Aggregated Operating profit */
v[0]=SUM("ProfitNet");
RESULT(v[0])

EQUATION("SProfit_Acc")
```

```
/* Aggregated free cash flow accumulated */
v[0]=SUM("Profit_Acc");
RESULT(v[0])

EQUATION("SDebt")
/* Aggregated debt (only firms with negative Profit_Acc) */
v[0]=SUM("Debt");
RESULT(v[0])

EQUATION("SWorthNet")
/* Aggregated WorthNet (only firms with positive Profit_Acc) */
v[0]=SUM("WorthNet");
RESULT(v[0])

EQUATION("SRD")
/* Expediture in R&D */
v[0]=SUM("RD");
RESULT(v[0])

EQUATION("SProfitWage")
v[0]=V("SProfitOp");
v[1]=V("SWage");
RESULT(v[0]/v[1])

/* 3)EQUATIONS AT FIRM'S LEVEL
   3.1)Demand, Production and Prices
   -------------------------------------------- */
EQUATION("FirmAge")
/* Age of firm */
v[0]=VL("FirmAge",1)+1;
RESULT(v[0])

EQUATION("C_eff")
/* Effective Consumption/Demand of the firms */
v[0]=VL("ms",1);
v[1]=V("SConsumo");
v[2]=v[0]*v[1];
RESULT(v[2])

EQUATION("C_exp")
/* Expected consumption/demand is a slow adaptation
in sales expectations as an outcome of firms
conservative behaviour aimed at smoothing short term cycles.
See Ciarli(2010) Structural transformation in production */
v[0]=0.8;
v[1]=VL("C_exp",1);
v[2]=VL("C_eff",1);
v[3]=v[0]*v[1]+(1-v[0])*v[2];
RESULT(v[3])

EQUATION("X")
/* Physical production of the firms */
v[0]=V("C_exp");
v[1]=VL("Xstock",1);
if(v[0]>v[1])
  v[2]=v[0]-v[1];
else
      v[2]=0;
RESULT(v[2])

EQUATION("Xstock")
/* Not planned stock of the firms */
v[0]=V("C_eff");
v[1]=V("X");
v[2]=VL("Xstock",1);
v[3]=v[1]+v[2];
if (v[0]<v[3])
      v[4]=v[2]+v[1]-v[0];
```

```
else
      v[4]=0;
RESULT(v[4])

EQUATION("L")
/* Labour demand by the firm */
v[0]=1-VL("Unemployment",1);
if (v[0]>0.02)
{  v[1]=V("C_exp");
   v[2]=VL("A",1);
   v[3]=VL("L",1);
   v[4]=0.8*v[3]+(1-0.8)*v[1]/pow(v[2],v[0]*V("iota"));
}
else
   v[4]=VL("L",1);
RESULT(v[4])

EQUATION("W")
/* Total wage paid by the firm W=wL. */
v[0]=VL("WageBase",1);
v[1]=V("L");
v[2]=v[0]*v[1];
RESULT(v[2])

EQUATION("P")
v[0]=V("W");
v[1]=V("C_exp");
v[2]=V("M");
v[4]=(1+v[2])*v[0]/v[1];   // V("V")*VL("A",1);
RESULT(v[4])

EQUATION("M")
v[0]=VL("PM",1);
v[1]=VL("P",1);
v[2]=V("m");
v[3]=VL("M",1);
v[4]=V("rho");
if(v[0]>v[1])
      v[5]=(1+v[4]+v[2])*v[3];
else if (v[0]<v[1])
      v[5]=(1-v[4]+v[2])*v[3];
else
   v[5]=v[3];
RESULT(v[5])

EQUATION("m")
/* Changing of the Mark up motivated by
demand and to pay for (as much as possible)
the debts using Richard's curve (generalized logist)
with min at -0.1 and max at 0.1*/
v[0]=V("FirmAge");
v[1]=VL("X",1)+VL("Xstock",1);
v[2]=VL("X",2)+VL("Xstock",2);
v[3]=VL("X",3)+VL("Xstock",3);
v[4]=VL("C_eff",1);
v[5]=VL("C_eff",2);
v[6]=VL("C_eff",3);
if (v[0]<=3)
{  v[7]=v[1];
   v[8]=v[4];
}
else
{   v[7]=(v[1]+v[2]+v[3])/3;
    v[8]=(v[4]+v[5]+v[6])/3;
}
if (v[8]>v[7] && v[7]>=0)      // Demand motive --> if DEF>X+XS
{   v[9] =v[8]/v[7]-1;         // Significative range[0,0.10] ou 10%
    v[10]=1+8*exp(-40*(v[9]));
```

```
    v[11]=pow(v[10],3);
    v[12]=0.03/v[11];          // at the moment range = 1%
}
else if (v[8]<v[7] && v[7]>0)  // if DEF<X+XS
{   v[9] =v[8]/v[7]-1;         // Significative range [-0.10,0]
    v[10]=1+8*exp(-40*(-v[9]));
    v[11]=pow(v[10],3);
    v[12]=-0.03/v[11];
}
else                       // if DEF=X+XS
    v[12]=0.0;            // Don't change mark up by demand motive

v[13]=VL("DF",1);         // Financial expense motive --> [0,0.1]
if (v[13]>0)
{  v[14]=1+0.01*exp(-0.2*(v[13]-80));
   v[15]=pow(v[14],0.5);
   v[16]=0.01/v[15];
}
else
   v[16]=0;
v[17]=v[12]+v[16];       // Demand + financial effect on mark up
RESULT(v[17])

EQUATION("E")
/* Competitivity */
v[0]=V("P");
v[1]=VL("P",1);
if (v[0]>0)
   v[2]=1/v[0];
else
   v[2]=1/v[1];
RESULT(v[2])

EQUATION("ms")
/* market share */
v[0]=VL("ms",1);
v[1]=VL("E",1);
v[2]=VL("EM",1);
v[3]=V("beta");                    // beta = 0.20
if (v[2]>0)
{   v[4]=v[3]*(v[1]/v[2]-1);
    v[5]=(1+v[4])*v[0];
}
else
    v[5]=0;
RESULT(v[5])

/* 3.2)Firm's Balance Sheet = Revenue, Cost, Debts and Profit
   -------------------------------------------------------- */
EQUATION("RT")
/* Total Revenue */
v[0]=V("RO");
v[1]=V("RF");
v[2]=v[0]+v[1];
RESULT(v[2])

EQUATION("RO")
/* Operating Revenue  */
v[0]=V("P");
v[1]=V("C_eff");
v[2]=V("X")+VL("Xstock",1);
v[3]=v[0]*v[1];
v[4]=v[0]*v[2];
if(v[1]<=v[2])
      v[5]=v[3];
else
      v[5]=v[4];
RESULT(v[5])
```

```
EQUATION("RF")
/* Financial income */
v[0]=VL("Profit_Acc",1);
if(v[0]>0)
  v[1]=0.80*V("H")*v[0]; //alterado de 0.8 para 0.7
else
      v[1]=0;
RESULT(v[1])

EQUATION("RD")
/* Spent on innovation */
v[0]=VL("ProfitNet",1);
v[1]=VL("ProfitNet",2);
v[2]=VL("ProfitNet",3);
v[3]=(v[0]+v[1]+v[2])/3;
v[4]=V("FirmAge");
if(v[3]>0 && v[4]>3)
      v[5]=V("phi")*v[3];
else
      v[5]=0;
RESULT(v[5])

EQUATION("RDB")
/* Spent on innovation */
v[0]=VL("ProfitOp",1);
v[1]=VL("ProfitOp",2);
v[2]=VL("ProfitOp",3);
v[3]=(v[0]+v[1]+v[2])/3;
v[4]=V("FirmAge");
if(v[3]>0 && v[4]>3)
      v[5]=V("phi")*v[3];
else
      v[5]=0;
RESULT(v[5])

EQUATION("RDRate")
v[0]=V("RD");
v[1]=V("RT");
if (v[1]>0)
    v[2]=v[0]/v[1];
else
    v[2]=0;
RESULT(v[2])

EQUATION("ProfitOp")
/* Operating Profit */
v[0]=V("RT");
v[1]=V("W");
v[2]=V("RD");
v[3]=v[0]-v[1]-v[2];
RESULT(v[3])

EQUATION("DF")
/* Financial expense */
v[0]=VL("Profit_Acc",1);
if (v[0]<0)
{  v[1]=V("H");
   v[2]=(-1)*v[1]*v[0];
}
else
   v[2]=0;
RESULT(v[2])

EQUATION("ProfitNet")
/* Net Profit, after financial expense */
v[0]=V("ProfitOp");
v[1]=V("DF");
```

```
v[2]=v[0]-v[1];
RESULT(v[2])

EQUATION("Profit_Acc")
/* Time cumulative Total Free Cash Flow */
v[0]=VL("Profit_Acc",1);
v[1]=V("ProfitNet");
v[2]=v[0]+v[1];
RESULT(v[2])

EQUATION("Debt")
/* Debt: if Profit_Acc is negative than
Profit_Acc is interpreted as Debt */
v[0]=V("Profit_Acc");
if (v[0]<0)
   v[1]= (-1)*v[0];
else
   v[1]=0;
RESULT(v[1])

EQUATION("WorthNet")
/* Liquidity Asset (Patrimonio liquido):
   if Profit_Acc is negative than Profit_Acc
is interpreted as Worth Net */
v[0]=V("Profit_Acc");
if (v[0]>0)
   v[1]= v[0];
else
   v[1]=0;
RESULT(v[1])

/* 3.3) Price searching
   ------------------------ */

EQUATION("PF")
/* Peso de firmas na pesquisa de preço */
v[0]=1;
RESULT(v[0])

EQUATION("EAP1")
/* Pesquisa  aleatória de preços 1 */
cur=RNDDRAW("Firmas","PF");
RESULT(VS(cur,"P"))

EQUATION("EAP2")
/* Pesquisa aleatória de preços 2 */
cur=RNDDRAW("Firmas","PF");
RESULT(VS(cur,"P"))

EQUATION("EAP3")
/* Pesquisa aleatória de preços 3 */
cur=RNDDRAW("Firmas","PF");
RESULT(VS(cur,"P"))

EQUATION("EAP4")
/* Pesquisa aleatória de preços 4 */
cur=RNDDRAW("Firmas","PF");
RESULT(VS(cur,"P"))

EQUATION("PM")
v[0]=V("EAP1");
v[1]=V("EAP2");
v[2]=V("EAP3");
v[3]=V("EAP4");
v[4]=v[0]+v[1]+v[2]+v[3];
v[5]=V("NT");
v[6]=v[4]/v[5];
RESULT(v[6])
```

```
/* 3.4) TECHNOLOGICAL CHANGE:
Learning by doing, Imitation and innovation
   ----------------------------------------------/
EQUATION("CX")
/* Production growth rate of the firms */
v[0]=VL("X",1);
v[1]=V("X");
if (v[0]==0)
   v[2]=0;
else
   v[2]=v[1]/v[0]-1;
RESULT(v[2])

EQUATION("ALD")
/* Productivity if learning by doing occur */
if (V("ALDhappen")==0)     // ALD do not happens
   v[3]=VL("A",1);
else
{  v[0]=V("delta1");  // delta1 = [0.2, 0.8] Kaldor-Verdoorn coefficient
   v[1]=V("CX");
   v[2]=VL("A",1);
   if (v[1]>0)
      v[3]=(1+v[0]*v[1])*v[2];
   else
      v[3]=v[2];
}
RESULT(v[3])

EQUATION("A1")
/* Random choice of firm which will be imitated */
cur=RNDDRAW("Firmas","PF");
RESULT(VS(cur,"A"))

EQUATION("A2")
/* Random choice of firm which will be imitated */
cur=RNDDRAW("Firmas","PF");
RESULT(VS(cur,"A"))

EQUATION("A3")
/* Random choice of firm which will be imitated */
cur=RNDDRAW("Firmas","PF");
RESULT(VS(cur,"A"))

EQUATION("AIM")
/* Productivity if imitation occur
Firms are able to imitate only the technology existing 3 period before */
v[0]=V("PIN");
if (RND>v[0])                 // AIM occurs
   v[7]=VL("A",1);
else
{  v[0]=VL("A",1);
   v[1]=VL("A1",1);
   v[2]=VL("A2",1);
   v[3]=VL("A3",1);
   v[4]=max(v[1],v[2]);
   v[5]=max(v[3],v[4]);
   if (v[5]>v[0])
   {  v[6]=exp(-log(v[5]/v[0]));  // effects of the technological
                                 distance on learning
      v[7]=v[0]+V("delta2")*v[6]*(v[5]-v[0]);
   }
   else
      v[7]=v[0];
}
RESULT(v[7])

EQUATION("AIN")
```

```
/* Productivity if innovation occur */
v[0]=V("PIN");
v[1]=RND;
v[2]=VL("A",1);
if(v[1]<=v[0])
{  v[2]=norm(v[2],V("sigma"));
   WRITE("AINtime",0);
}
else
{  v[2]=0;
   v[3]=V("AINtime")+1;
   WRITE("AINtime",v[3]);
}
RESULT(v[2])

EQUATION("PIN")
/* The prob of the innovation results from expenditure in
R&D and from cumulative effects of productivity. */
v[0]=VL("RDRate",1);
v[1]=VL("AINtime",1);
v[2]=V("gama0");
v[5]=v[2]/( pow(1+V("gama1")*exp(-V("gama2")*v[0]),2) );   //RD
v[6]=v[2]/( pow(1+V("gama3")*exp(-V("gama4")*v[1]),2) );   //AINtime
RESULT(v[5]+v[6])

EQUATION("A")
/* Choose the max of innovation, imitation and learning by doing
v[0]=VL("A",1);
v[1]=V("ALD");
v[2]=V("AIM");
v[3]=V("AIN");
v[4]=max(v[1],v[2]);
v[5]=max(v[3],v[4]);
if (v[5]==v[1] && v[5]>v[0])           // If ALD is chosen
    WRITE("Atype",1);
else if (v[5]==v[2]  && v[5]>v[0])     // If AIM is chosen
    WRITE("Atype",2);
else if (v[5]==v[3]  && v[5]>v[0])     // If AIN is chosen
    WRITE("Atype",3);
else
    WRITE("Atype",0);
RESULT(v[5])

/* 4) ENTRY AND EXIT OF FIRMS
   ------------------------------------------- */
EQUATION("FirmExit")
/* Delete an overly indebted firm. This avoid "d" explode on time.
   Return the number of firms deleted in each time step.
   The threshold destruction is Debt 10 times higher than RT.*/

if (V("FirmDestroy")<1)
   v[0] = 0;
else
{  v[0]=0;
   CYCLE_SAFE(cur,"Firmas")
   { v[1]=VS(cur,"ms");
     v[2]=VS(cur,"Debt")/VS(cur,"RT");
     if (v[2]>=10.0)
        {DELETE(cur);
         v[0]++;
        }
   }
}
RESULT(v[0])
MODELEND
void close_sim(void)
{
}
```