

1 Prologue

1.1 Introduction

Most introductory textbooks on economic growth theory reserve few pages, or at least few paragraphs, to explain the difference between the impact of one-time changes and continuous changes on long-run path of macro variables. These textbooks argue that only continuous changes have the potential to make a difference in the long-run equilibrium while a one-time change can hardly have any effect on long-run equilibrium in a growth framework.

Historical evidence is consistent with this argument. An example is the quick recovery of German and Japanese economies from the ashes of Second World War. John Stuart Mill (1904, Book I, Ch.5) has noted the ultimate recovery from shocks a long time ago, indeed:¹

“ (...) what has so often excited wonder, the great rapidity with which countries recover from a state of devastation; the disappearance, in a short time, of all traces of the mischiefs done

¹ We took this excerpt from Hirshleifer (1991).

by earthquakes, floods, hurricanes, and the ravages of war. An enemy lays waste a country by fire and sword, and destroys or carries away nearly all the moveable wealth existing in it: all the inhabitants are ruined, and yet in a few years after, everything is much as it was before”.

This dissertation neither objects to the theory nor to the historical evidence but argues that shocks, and especially those that are purely unexpected, deserve to be studied more thoroughly and systematically. This is so because of several reasons. First, shocks are unexpected! The unexpected character of shocks implies that economic actors (including policymakers) would not be able to take measures to cushion against shocks. Hence, skyrocketing oil prices, new general-purpose technologies, and diseases will have stronger impact on the economy than changes that are expected, at least with some probability. Second, shocks affect an economy via alternative channels. Some implications of shocks are direct while others are indirect. Interestingly, direct and indirect effects of shocks can be contradictory in terms of their impacts on an economy. For example, an unexpected increase in oil prices may induce R&D in alternative energy technologies while slowing growth performance of an economy. An earthquake striking the housing stock of an economy may have severe welfare implications, but may also lead to higher income (and growth rates) transitionally or even in the long-run if indirect effects of an earthquake is rightly managed. A systematic treatment allows us to elaborate not only direct but also indirect effects of shocks. Third, a systematic treatment is indeed needed to raise more profound questions that have been rarely asked.

Among the many others, some of them can be enumerated.² (1) Are all shocks recoverable? (2) Which one is better to rely on during recovery? Market forces or government? (3) Is there any indispensable role of government during recovery from a shock? (4) Which are more vulnerable to shocks, advanced or developing economies? (5) Are there different implications if the primary impact is upon physical resources (e.g., labor supply and capital) or financial items (e.g., prices)? A systematic treatment will invoke these and similar questions in a framework, that may give way to a more coherent study of shocks.

Our aim in this manuscript is to make a *preliminary* research on the growth impact of shocks, which are also stimulated by the *raison d'être* raised above. In that respect, we do not engage in any specific question brought up above but give pieces of or findings to this and that. We hope that our initiation will stimulate further research in that direction that will shed light on the fundamental questions brought up above in a more consistent way.

There are two (additional) interrelated reasons to look at the impact of shocks in growth framework. First, understanding the impact of shocks requires a long-run analysis, though the shock itself may be one-time, because shocks have indirect as much as direct effects, and thus have long-run as much as short-run effects, as indirect effects do not show up immediately. A growth framework, which in general allows for both transitional and long-run equilibrium analyses and hence provides a suitable environment to study direct and indirect effects of shocks, is possibly the best structure in order to study shocks. Second, growth theory itself ignored the growth impact of shocks to a large extent in the past. In particular, these

² Some of these questions were originally asked in Hirshleifer (1991) within the context of

analyses are relegated to business cycle literature, by and large (see also the discussion in the next section). For that reason, the relationship between shocks and the growth process is still not very clear. As a result, a further analysis of shocks in the context of growth is needed.

This dissertation consists of papers analyzing transitional and/or long-run implications of shocks in alternative growth frameworks at the theoretical level. The next section is an attempt in identifying shocks in the growth literature in a taxonomy. The third section introduces the various essays in this dissertation, and relates them to the taxonomy advanced in the second section. The last section concludes the chapter.

1.2 Defining Shocks in the Growth Context

Perhaps a very useful step before starting to review the use of shocks in growth literature is to define shocks. Oxford English Dictionary defines a shock as “the disturbance of equilibrium or the internal oscillation resulting from this [distribution]”.³ A more practical definition is perhaps “shocks are drastic changes”. By “drastic changes” we mean a sufficiently substantial “disturbance of an equilibrium or of permanence of a trail” from the viewpoint of the system. As an example, suppose that population growth rate is one percent. A one thousandth increase in that rate is a change but perhaps not sufficiently substantial to consider it a shock. However, a rise from one percent to two percent (a hundred percent increase) may be a sufficiently substantial change to make it drastic. Evidently, the benchmark

disasters. We adapted them to our context in this paper.

³ Available at <http://dictionary.oed.com/>

difference in terms of its impact, especially when the long-run as well as *short-run* is considered. Accordingly, defining shocks in the taxonomy of duration makes sense.

Third, shocks can be defined according to their *nature*. Most shocks are *exogenous* by their nature. An earthquake is a good example. Some shocks can be purely *endogenous*, arising from the intrinsic character of a system. Technological shocks can be considered such, as new technologies cannot be generated unless a significant amount of investment in R&D is made. Evidently, in many instances, it is matter of model construction whether a shock is exogenous or not.

We consider that the three taxonomies of shocks presented above are sufficiently comprehensive in defining shocks, even though our list is possibly not an exhaustive one. In addition to this, we are aware of the fact that there is some overlapping among taxonomies. For example, natural shocks are exogenous (almost) by definition. In that respect, we believe that it is not useful to review the literature in accordance with each possible combination of these taxonomies such as one-time exogenous natural shocks or continuous endogenous market shocks, as it would complicate our understanding of shocks. For the very same reason, reviewing the literature for each categorization separately is not very fruitful. We would argue that a better approach is to refer to a basic taxonomy in the review, and mention other merits of shocks at proper instances. In particular, we will refer to the sources of shocks as our *reference taxonomy* and mention others (endogenous/exogenous, one-time/continuous) when feasible and appropriate.

We need to discuss three critical limitations of our review before we set off the argument. As was mentioned earlier, this review and this dissertation

are about unexpected shocks. Evidently, one should always keep in mind that it is often possible to assign some expectations to shocks. For example, an area that has high flooding record in the past will possibly have a high probability of flooding in the future. Similarly, productivity shocks can be legitimately associated with a statistical rule. Actually, the recent wave of literature linking the business cycle and economic growth explicitly studies the impacts that productivity and policy shocks can have on the growth performance of an economy.⁴ These models, however, use a stochastic framework, which is a significant methodological deviation from the deterministic framework that we exploit in this dissertation.

Second, the conventional perfect foresight economic growth literature has rarely studied shocks *explicitly*. Perhaps one reason has been the very existence of the (real) business cycle literature dealing explicitly with shocks. Whatever the source of this ignorance may be, we can safely argue that unexpected shocks have not been analyzed sufficiently in the perfect foresight growth models. For that reason, a new focus on the growth impact of shocks poses a major challenge. A first step in that process is to re-interpret the very use of the “changes” concept in growth models. Most

⁴ A short introduction to this literature is as follows. It is an empirical regularity that the output growth rate has never been steady. The evidence is that expansions and recessions have been alternating over time. The necessity to explain the determinants of these output fluctuations gave rise to what we know as Business Cycle Theory. Until the 1980s, economists generally believed that business cycles were temporary events: once the economy recovers from a recession it returns to the level that it would have reached had the recession not occurred. In other words, business cycles were thought to have a short- but not long-run effect on a country's standard of living. Three papers published in the 1980s changed this perspective. First, in their well-known 1982 article, Nelson and Plosser showed that business cycles are not entirely temporary events but, instead, have permanent effects on the economy. Second, Kydland and Prescott (1982) and Long and Plosser (1983) offered new models for analyzing economic fluctuations that integrated growth and business cycle theory. Since then, a body of empirical and theoretical literature has been growing, analyzing the impact of volatility of growth (in business cycle sense) on the growth process. A recent example of an effort linking Business Cycle literature to the Growth literature is Jones *et al.* (2000).

growth studies undertake some “growth impact of changes” analyses, including comparative statics. If we re-interpret this use of changes as drastic changes, then it is possible to review a large part of the growth literature. One source that backs our interpretation is Galor and Tsiddon (1992), in which the effects of transitory productivity shocks on long-run equilibrium (comparative statics!) is studied and shown that an adverse transitory productivity shock may result in a lower long-run equilibrium. As we only have a handful explicit works studying the implications of shocks in deterministic frameworks, this is considered to be the best among the alternatives in this exploratory work.

Third, it is not possible to cover all research areas of the growth theory in a single review. For that reason, we will focus on only one “good” representative of each shock, notably earthquakes, technology shocks, and fiscal shocks as examples of natural shocks, market shocks, and policy shocks, respectively. We study the impact of earthquakes as the representative of natural shocks because (i) a catastrophic earthquake has drastic direct and indirect impacts on an economy, (ii) an earthquake is not predictable (it can be said that an earthquake would hit a region in the next 30 years, but an exact timing cannot be given). In that respect, the earthquake is one of the best representatives of natural shocks. We use technology as the example of market shocks because (i) the linkage between the technology and market has been deepening at micro and macro level for centuries and therefore examining technological shocks also stands for examining other market shocks, *i.e.*, the *backward linkages* of technological shocks are very strong, (ii) similarly, the very same reason implies a very strong *forward linkages* between technological changes and other market shocks, and (iii) the growth literature is very exclusive on the issue of

technological change. Finally, we focus on fiscal shocks as the representative of policy shocks because (i) fiscal policy is one of the most frequently used tools of the government, and (ii) the impact of fiscal shocks has been intensively studied in the growth literature.

We are aware of the fact that our heuristic “representative” approach has pros and cons. On the one hand, we miss the opportunity to review some other prominent research areas like human capital, trade, and technology transfers. We know that each of these issues, named or unnamed, would have enriched our understanding on the growth impact of shocks, had they had been included. On the other hand, we gain in terms of clarity in our presentation. We believe that referring to a single representative issue to discuss the growth impact of shocks would still produce a comprehensive review that would allow us to understand what have been and could have been done in the growth literature in terms of our research question. We elaborate below the place of shocks in deterministic growth frameworks using sources of shocks as the reference taxonomy. We start our review with natural shocks.

1.2.1 Natural Shocks

Natural shocks are defined as “uncontrollable, exogenous ‘acts of God’ (...), which produce devastating blows to a region’s people and economy” (Iacobucci *et al.*, 2001, p.5). In a *narrower sense*, natural shocks are created by natural disasters, which are defined as sudden and widespread events like earthquakes, windstorms (hurricanes, cyclones and typhoons), floods, droughts, famines, fires, avalanche, chemical and nuclear accidents,

epidemics, volcanic eruptions, *etc.*, causing loss of human life and damage to social and economic systems.⁵ Natural disasters run along a continuum, ranging from regularly occurring, predictable events to sudden, catastrophic ones. Predictable natural disasters most often include events such as floods, infestations, and droughts. These events usually display warning signs from months to years in advance, so there is time to prevent, or at least minimize, the damage.⁶ Catastrophic natural disasters, on the other hand, can occur with little or no warning. They may cause significant human and property loss, and there is a greater sense of danger and helplessness than in case of predictable disasters. Examples of catastrophic disasters are tornadoes, earthquakes, and hurricanes. In this review, we consider any large-scale unexpected shock triggered by nature as a natural shock.

Natural disasters can and do cause large human and economic losses.⁷ The economic impact of natural disasters not only remains with its one-time physical damages. Bull (1994) states that it is common to identify *direct*, *indirect*, and *secondary* effects when estimating the economic consequences

⁵ Albala-Bertrand (1993a) states that a natural disaster is one induced by a natural event, whereas a man-made disaster is one resulting from the breakdown of regular processes within the social system (*e.g.*, war, recession). We conjecture that a *broader interpretation* of natural shocks may indeed include some shocks that are triggered by human beings such as epidemic diseases and forest fires. Furthermore, some natural disasters (in the narrower sense) like floods actually take place due to mismanagement of land-use planning.

⁶ However, under certain conditions, normally predictable events may turn out into unpredictable ones. For example, a flash flood can occur without warning and cause great destruction. The same would hold true for fires—forest fires and wildfires.

⁷ For example, Birkland (1997) estimates that hurricane Hugo and the Loma Prieta earthquake, which both occurred in 1989, were responsible for more than US\$15 billion in direct property damage in South Carolina and Northern California, respectively. More severe costs of natural disasters have been experienced in the history indeed. For example, the 1995 Kobe earthquake “destroyed or severely damaged tens of thousands of businesses, disrupted highways and rail lines along one of Japan’s busiest transportation corridors, and crippled the port of Kobe”, resulting in direct losses of about US\$120 billion (Tierney, Nigg, and Dahlhamer, 1996).

resulting from a disaster.⁸ Direct effects include damage to property and loss of income to persons, business enterprises, and communities. Each of these direct losses may have indirect effects. For example, if a factory is closed because of an earthquake there will be a (i) reduction in activity of suppliers without alternative markets; (ii) reduction in purchases of goods and services by people who have lost their jobs; (iii) reduction in national income through reduction in tax revenues. Further, both direct and indirect effects result in secondary effects, which may appear some time after the disaster. These may include (i) epidemics inflation; (ii) an increase in individual and family income disparities and imbalances in the economic health of different regions in the country; (iii) economic opportunities lost as a result of the redirection of economic activity; (iv) ecological changes; or (v) negative changes in the balance of payments.

Engineers, disaster managers, and researchers from governmental and non-governmental organizations have put a lot of effort in understanding the economic impacts of natural shocks, while economists, instead, on average, have shown very little interest in studying the impact of these phenomena. One could argue that the growing “economics of disasters” literature is a sub-field of disaster management literature that economists hardly contribute to. The disadvantage of that trend is that researchers from disaster management do often fail to exploit powerful tools offered by economic modeling.⁹ The strength of economic models is based on the fact that indirect (and secondary) effects of physical shocks can be easily studied

⁸ Albala-Bertrand (1993a) prefers to categorize the impact of natural disasters as direct and indirect effects. By default, in that case, his indirect-effects definition covers the secondary effects.

⁹ A relatively up-to-date bibliography of economics of disasters can be found at www.geo.umass.edu/courses/geo510/economics.htm. It would be immediately recognized that almost all works in this list could be considered as part of disaster management literature.

would be different depending on the size and specific circumstances. In this study, we assume that the change is sufficiently large and hence a shock.

We need to go further than dictionary definitions in order to understand the impact of shocks. A fruitful approach to define shocks is to classify them. It is possible to classify shocks in alternative ways. First, shocks can be grouped according to their *sources*. Iacobucci, Trebilcock, and Haider (2001) suggest collecting shocks under natural, market, and government shocks according to their sources. In the category of natural shocks lie natural disasters such as droughts and floods, each of which is triggered by nature. Notably, it would not be wrong to argue that all natural shocks are physical shocks. Market shocks are shocks that are set off within markets like technology shocks, input price shocks, demographic shocks, *etc.* The final category of shocks arises from policy changes like trade liberalization, government mismanagement, and monetary policy changes, each of which is activated by policymakers (government).

Second, shocks can be classified according to their *duration* (the level of permanence), which suggests by definition two headings: one-time shocks and continuous shocks. One-time shocks are short-period shocks that cease eventually. Note that the shock itself but *not* its effect is ending according to this classification. One-time shocks can be further classified as one-time transitory shocks and one-time permanent shocks. While the former refers to a shock in a model that “retreats” to the original “position”, the latter shock is meant to stay permanently. Capital outflow after a temporary inflow is a good example of one-time transitory shocks. An earthquake is perhaps the best example of one-time permanent shocks. Good example of continuous shocks is technology shocks in general and, *e.g.*, the introduction of electricity in particular. The duration of a shock in general makes a big

(*e.g.*, the third essay of this manuscript). In that respect, there are plenty of research opportunities for economists in that direction.

A reflection of the ignorance of the economic implications of natural shocks is the very few number of works in this issue in the (growth) literature. In addition to this, the available literature mainly focuses on one single issue only, namely earthquakes, to our best knowledge. On the theoretical side Albala-Bertrand (1993a, 1993b), Oulton (1993), and Chapters four and five of this manuscript can be named. At the empirical level, a recent one among the very few is Selcuk and Yeldan (2001). Finally, Horwich (2000) and Bibbee *et al.* (2000) can be referred to as case studies discussing the economic losses of earthquakes. The common finding of all these theoretical studies is that an economy that experienced a one-time exogenous natural shock will return to its long-run equilibrium, even though the shock may put off the economy into disequilibrium in the short-run.¹⁰ The basic reason of the convergence of the economy to the ‘normal path’ is essentially the diminishing marginal productivity character of capital in the production technology (see Chapter five this dissertation to spot how the “global convergence” mechanism may fail to work when that assumption is removed). The remaining part of this subsection focuses on this issue.

We will show why and how economies return to their original position after a physical shock by using the most standard Solow (1956) framework. Our first and foremost motivation for using this framework is that it holds the diminishing marginal productivity of capital assumption. Secondly, it is the most basic framework in the growth literature. Finally, it is simple. In the standard Solow (1956) framework, an aggregate production technology is represented by

Let us call the path of capital generated by equation (1.3) the *normal path* (Figure 1.1.a below). That path shows that capital accumulates relatively quickly in the initial stages of development but that the pace decelerates in time. The reason of this fall is the declining marginal productivity of capital, which is reflected in Figure 1.1.b below.

Natural shocks can be examined by using this simple framework. Before doing this, let us recall that natural shocks can be classified as one-time transitory (the shocked variable returns to the pre-shock value), one-time permanent (the shocked variable takes the after-shock value as the new ‘initial value’), and continuous (a sequence of shocks applies on the variable). As natural events are not reversible, no natural shock falls into the one-time transitory shock classification. Furthermore, most natural shocks (*e.g.*, earthquakes) are discrete shocks. Hence, continuous natural shocks are not common. For that reason, we will only consider one-time permanent natural shocks in our review.

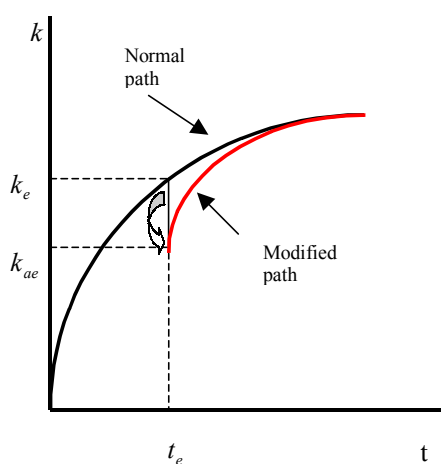


Figure 1.1.a. The capital path

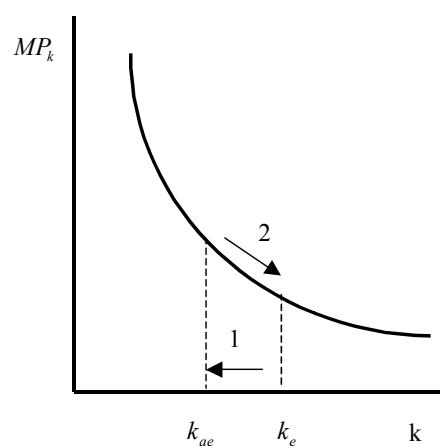


Figure 1.1.b. Marginal productivity of capital

Suppose now that an earthquake hits the capital stock at time t_e (in the transitional period) and the stock falls from k_e to k_{ae} . The fall in the capital stock implies a movement from k_e to k_{ae} in the marginal productivity of capital (see figure 1.1.b above), which means an increase in the marginal productivity of capital after a physical shock. The latter is at work because a marginal addition of capital stock is inversely related with the level of that stock. Hence, an unexpected physical shock on the capital stock decreases the stock to a lower level but, on the other hand, increases the economy's ability to accelerate capital accumulation. The increase in marginal productivity generates the so-called modified path that will catch up with the normal path in the steady state.¹¹ Evidently, the same mechanism will be at work when the economy is at its long-run equilibrium. In conclusion, the diminishing marginal productivity property of these models ensures the full recovery of a quantity to the before-shock level sooner or later. We believe that our argument must also apply to other natural shocks. In the next section, we look at market shocks, in which returning to the original equilibrium is not as straightforward as in natural shocks.

¹¹ We also 'tested' our argument by running equation (1.3) for 150 periods under a Cobb-Douglas technology assumption. We assume that $s=0.20$, $n=0.01$, $\delta=0.03$, $k(0)=1$, and $\alpha=0.30$. We find that the hypothetical economy reaches 93% of steady state in 100 periods and 98% of steady state in 150 periods. Next, we introduce a once-and-for-all shock into the model in terms of a 50% percent reduction in the initial capital stock. Our calculations show that the modified path catches-up 99 percent of the normal path in 100 periods (*i.e.*, 92 percent of steady state value of capital stock).

1.2.2 Market Shocks

Market shocks are the result of market activities or of (drastic) changes in activities of human agents (cf., Iacobucci *et al.*, 2001). The sources of market shocks are many: technological changes, variations in input prices, shifts in comparative advantage, or changes in demographics are among them.¹² It is beyond the aim of this review to analyze all market shocks. For that reason, we will select a representative theme of market shocks. As we argued above, technology is a good representative, because the backward and forward linkages between the technology and other market-related quantities are very strong, and technological change is intensively studied in the growth literature. Below, we present a review of technology and technology shocks in growth literature.

Technology Shocks

Technological change is an important source of market shocks. Much of the income generating economic activities lies in knowledge, information, and technology-intensive manufacturing industries in the modern age. The impact of technological change has been investigated extensively in the growth literature in several contexts.¹³ This body of literature essentially aims at showing the contribution of technology and of technological change on generating positive rates of growth and of changes of that rate. Perfect foresight and hence a deterministic set up is a common character of this sub-

¹² Some shocks may fall into more than one classification. Demographic shock is an example. On the one hand, demographic quantities, such as birth rate, can be considered a result of nature. On the other hand, the growth literature has already established, both theoretically and empirically, the relationship between economic development and several demographic variables. In our study, we will stick to Iacobucci *et al.* (2001) and consider demographic changes as an element of market shocks.

literature. A natural starting point is to glance at what the first-generation growth literature has said on technology shocks. Below, we first look at the basic properties of the first-generation growth models and next we examine the growth impact of technology shocks within this framework.

*Technology Shocks in First-Generation Growth Models*¹⁴

The formal growth theory was initially under Keynesian inspiration, as in the case of Harrod (1939) and Domar (1946), but subsequently more neoclassical in spirit, as with the work of Solow (1956), Swan (1956) and Uzawa (1961). That tradition of growth studies, started with Solow (1956) and ended with Romer (1986), can be called the first-generation growth theory. In this framework, an aggregate production technology can be represented by equation (1.1). Let us continue to assume that there is no *exogenous* technological change in the model (hence, changes in productivity parameter A are shocks). In figure 1.1.a, we have illustrated the time path of capital. Below, we illustrate the Solow ‘mechanism’ by considering the model in a four-quadrant diagram.¹⁵

¹³ A relatively recent survey on “technology in growth” is Keely and Quah (1998).

¹⁴ Some surveys in the first-generation growth models are Hahn and Matthews (1964) and Solow (1999). A critical survey is Cesaratto (1999).

¹⁵ The illustration comes from Van Zon (1997).

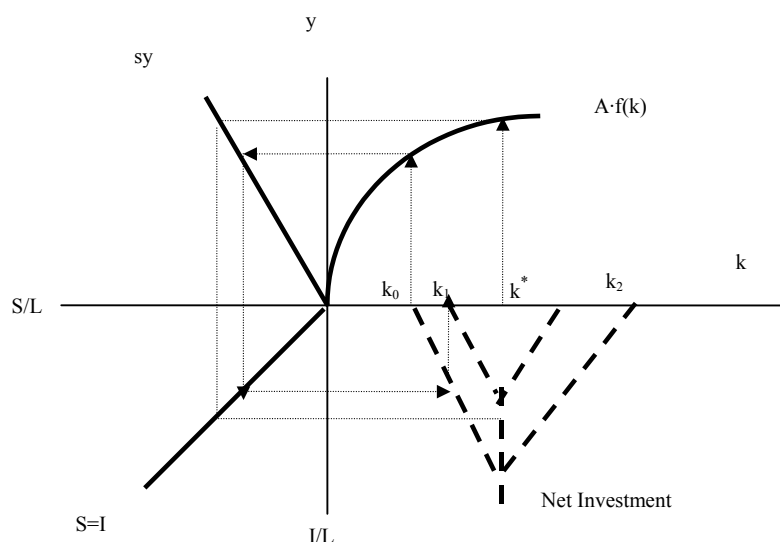


Figure 1.2. The neoclassical growth mechanism

The concave shape of the production function in the Northeast quadrant arises from the neoclassical technology assumption. Note that the concave curve is getting more and more vertical as the curve is closer to origin and more and more horizontal as the capital stock accumulates (cf. Inada (1963) conditions). The Northwest quadrant represents the exogenous relationship between income per capita and savings per capita. The saving-investment balance is satisfied at all times; hence the linear line in Southwest is 45 degree. Last, the Southeast quadrant defines the net investment behavior of the model. Since net investment equals gross investment minus the ‘effective depreciation’, $(n + \delta)k$, the slope between gross and net investment is *one* up to the kink. At the point where gross investment equals the effective depreciation, however, net investment becomes zero. Therefore

the line kinks at that point. The kink implies that capital per capita does not increase anymore irrespective of the size of gross investment. The “right hand” of the kink shows that a reverse mechanism is at work if an economy “overshoots” steady state capital k^* , e.g., by starting from initial capital k_2 . We can now examine the impact of technology shocks on growth (for clarity purposes, we reproduce figure 1.2 below as figure 1.3).

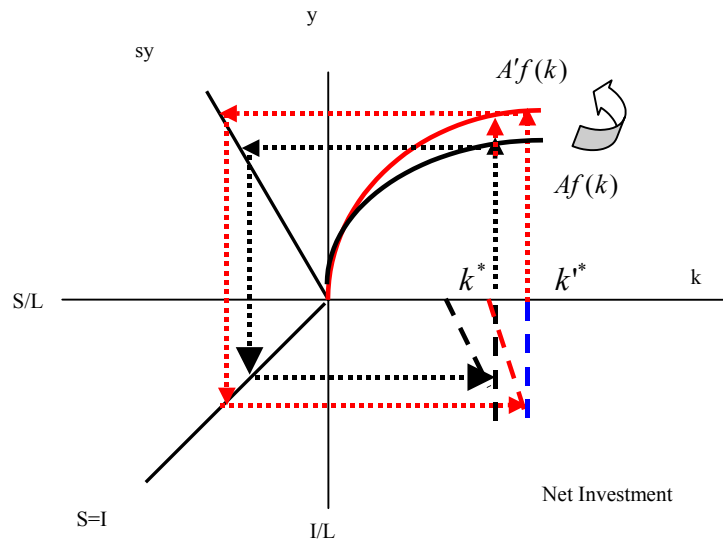


Figure 1.3. Technology shocks in the Solow framework

A technological shock may have a temporary or permanent effect on levels and growth rates, depending on the duration of the shock in the Solow framework. Suppose that the economy is in its *long-run equilibrium*. We can easily observe from figure 1.3 that a one-time *transitory* productivity shock (first an increase from A to A' and then an immediate fall-back to

the original value) implies first a one-time increase in levels and growth rates of output but that the system returns to its original long-run equilibrium when the shock “retreats” (recall that Galor and Tsiddon (1992) show a case that generates a contrary result). The intuition is simple. Consider the long-run equilibrium (k^*, y^*) . Suppose that an unanticipated positive transitory productivity shock occurs at time t^* . Since the shock is unanticipated, it has no effect on the investment decisions prior to t^* . In particular, capital is at its long-run equilibrium level k^* . Consequently, the marginal productivity of capital is increased proportional to A'/A , where $A' > A$, and hence income (and capital) increases. At time t^*+1 , productivity returns to its long-run level, A . Consequently, the system returns to its original equilibrium by realizing a one-time decrease in levels and a negative growth rate (recall that the right-hand side of the kink becomes active when k overshoots k^*).

If the productivity shock would stay permanently, even though it would be a one-time shock, then the output level would increase permanently. The growth rate, however, would be zero after some ‘transitional’ increase. Figure 1.3 indicates that a permanent one-time technological shock causes an upward (permanent) shift of the production function. This implies that the same output can be produced by less capital, and that higher investment level will eventually lead to a higher steady state level of capital per capita.

Finally, we can show that exogenous but continuous increases in the technology stock would not only imply permanent increases in levels of growth but also a permanent positive rate of growth. The underlying mechanism can be illustrated with the help of Figure 1.3. Permanent increases in technology stock imply permanent upward shifts in output, in gross savings, and in gross investment for a given capital stock. Hence, net

capital accumulation will always stay at positive rates, which is represented by a continuous shift of the vertical part of the net investment line to the right. This is indeed what exogenous technological change generates.

The impact of a technology shock during the transitional period is not very different from its impact in the steady state. Firstly, from equation (1.3), one can easily derive that a one-time transitory increase in productivity implies a spike in the transitory path of the capital. This means a rise at time t and a fall at time $t+1$ in the level and growth rate of capital per capita. Clearly, the capital accumulation path follows the normal path at other times, given that the shock is a transitory one-time phenomenon. Secondly, a one-time permanent shock implies a shift in levels and in growth rates initially. However, the initial rise in growth declines in time and converges to zero at the steady state. Finally, a shock in terms of continuous increases in productivity implies a positive rate of growth and an ever-increasing stock of capital per capita. Again, this is what we call the exogenous technological change. Table 1.1 below compactly presents the response to technology shocks in the Solow framework.

Table 1.1. The impact of shocks in a Solow framework

State of the Economy	One-time Transitory	One-time Permanent	Continuous
Steady State	One-time spike in levels and growth rates at steady state	A permanent increase in output No change in growth rate but a one-time rise initially	Permanent change in output and growth rate
Transitional period	One-time spike on normal path	A permanent increase in output Growth rate increases first but converges to long-run equilibrium in time	Permanent change in output and growth rate

The main difference in the response of the Solow model to technology shocks in the steady state and transitional-period seems to be that the shock is absorbed at once in the steady state, while it may take some time to absorb it in the transitional period, at least in some instances.

We may conclude that the first-generation growth models were rich enough to show the impact of technological shocks but weak in explaining the source and/or channels of the growth impact. Indeed, the reason for the downfall of the first generation growth models in the early 1970s was the fact that these models were unable to explain the intrinsic sources of growth. The second-generation growth models, also called endogenous growth models, have made significant contributions in that direction. Below, we review how technology shocks can be represented in some of the fundamental second-generation growth frameworks.

*Technology Shocks in Second Generation Growth Models*¹⁶

The second-generation growth literature started with Romer (1986). The main property of this literature is its achievement in generating endogenous growth. This is usually done by eliminating the assumption of diminishing marginal productivity of inputs in the production technology. One of the central elements in generating endogenous growth has been technology. Several interpretations of technology have played a significant role in that respect. A good example of the broader interpretation of technology can indeed be found in Romer (1986) itself. Romer (1986) eliminates diminishing returns by assuming that creation of knowledge is a side-

¹⁶ Refer to, for example, Verspagen (1992), Romer (1994), Grossman and Helpman (1994), and Jones and Manuelli (1997) for grasping several aspects of that literature. A critical survey is Fine (2000).

product of investment. This assumption reduces his model to an AK model, although only under a critical assumption (see below).¹⁷

The basics of Romer (1986) are as follows. Suppose that a firm exploits not only its own physical capital but also the average knowledge stock of the economy, which is a public good that the firm can access at zero cost. Starting from a neoclassical production function defined in equation (1.1) at firm level, and assuming that average capital (knowledge) stock augments labor, the production technology turns out to be

$$Y_i = AF(K_i, K \cdot L_i). \quad (1.4)$$

In (1.4), i indexes firms. In equilibrium, all firms make the same choices, so that $k_i = k$, where $k_i = K_i / L_i$ and $k = K / L$. Under the critical assumption that $y_i = f(k_i, k)$ is homogenous of degree one in k_i and k , the production function turns into essentially an AK model for $L = 1$. In that case, via eliminating the diminishing returns in capital productivity, Romer (1986) ends up with a mechanism that generates ever-positive growth rates in the model economy. Indeed, it is straightforward to apply Romer (1986) to the neoclassical scheme we illustrated in figure 1.2:

¹⁷ Indeed, a large number of models in endogenous growth theory, independent of the source of endogenous growth, turns out to be an AK model in reduced form.

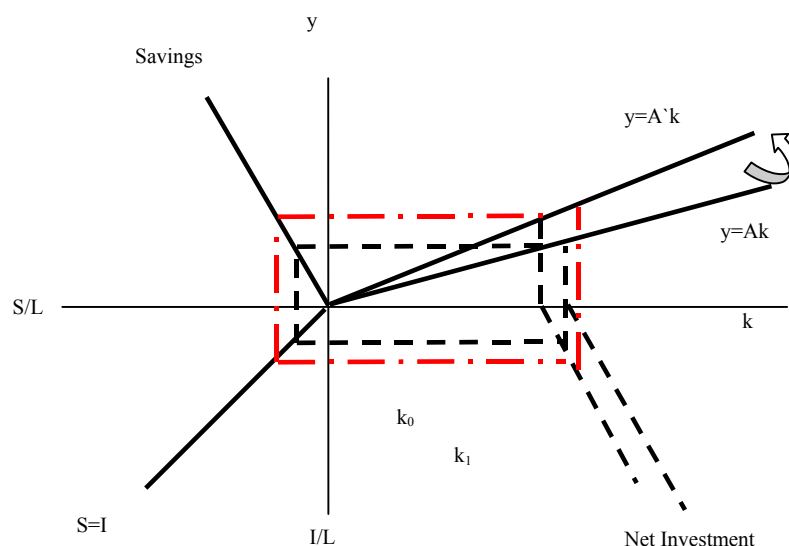


Figure 1.4. Technology shocks in the AK mechanism (in a Solow setup)

As Figure 1.4 shows, there is *continuous* growth from the start (*i.e.*, without any transitional dynamics). Hence, the model is at “long-run equilibrium” from the start. The impact of technology shocks can be captured by examining the impact of changes in capital (knowledge) productivity A .¹⁸

A productivity shock may have different impacts depending upon the type of shock. First, a one-time transitory technology shock implies a spike at the long-run growth rate. Second, a one-time permanent productivity shock entails a higher value in output levels and in the growth rate. Examining figure 1.4 reveals that a one-time permanent increase in

¹⁸ Note that the broader interpretation of k represents knowledge stock, which can expose to shocks as well. However, it is hard to analyze the impact of shocks to physical quantities

technology implies a higher capital accumulation, which does not endure any diminishing returns. Hence, a higher growth rate is achieved permanently, which is also reflected in levels. Finally, if A starts to grow at an exogenous rate, the rate of growth of the economy increases at that rate (which is not very realistic). A quick comparison of first-generation growth models with the AK frame reveals that technology shocks have a transitional impact on growth rates in the former (unless the shock is continuous), while it directly affects the growth rate in the latter. Notably, AK type growth models are not richer than first-generation growth models in indicating the source of productivity shocks, even if these models generate continuous (endogenous!?) growth.

A rather more common representation of endogenous growth due to technological change (knowledge accumulation) has been derived from the endogenous technological change body of research. The most prominent studies in this strand of literature, albeit with different frameworks and aims, are Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). The advantage of this framework is its richness in illustrating the source of technological change and hence endogenous growth. A common argument of these models is that R&D (R&D labor) is the source of endogenous technological change (these models are also called R&D-driven endogenous growth models). In Romer (1990), for instance, the tradeoff is between the final good sector and R&D sector on the employment of skilled labor. He derives that any increase in skilled labor is reflected proportionally in the growth rate of the economy. Aghion and Howitt (1992) is based on a similar idea, but now new inventions replace old ones, and hence technological change takes the form of ‘creative destruction’. The critical

in AK models due to several reasons. We depict them in the fifth chapter of this

characteristic of such models is that profit opportunities do work both as an incentive to engage in R&D and a disincentive in the form of creative destruction. In this review, we will study Romer (1990) in order to show what technology shocks imply for the (endogenous) growth behavior of an economy. Our motivation for emphasizing this framework is twofold. First, Romer (1990) is based on the idea of horizontal product differentiation while Aghion and Howitt (1992) is based on vertical product differentiation, as creative destruction encapsulates quality-ladders within a single product. This difference implies that the Romer (1990) framework is indeed more “general” than Aghion and Howitt (1992) in terms of explaining long-run endogenous growth. Second, Romer’s (1990) framework is simple. This property of the Romer (1990) model becomes clearer especially when Grossman and Helpman (1991) framework is considered.

In Romer (1990), an R&D sector, operating under constant returns to scale technology, supplies new technologies to the intermediate sector. Intermediate good firms, each operating under monopoly due to patent rights, are specialized in producing a single intermediate, which are indispensable inputs in the production of final good. In this set up, Romer (1990) shows that the public good nature of (scientific) knowledge, subject to ever-positive growth due to continuous R&D, is the source of endogenous growth in an economy.

In order to illustrate the impact of technology shocks in the Romer framework, we need to elaborate the relations in this model more deeply. The basic relations in Romer (1990) are as follows. An Ethier production function describes the generation of final output Y :

$$Y = H_Y^{1-\alpha} \int_0^A x_i^\alpha di \quad (1.5)$$

where H_Y is human capital input used in final-good production, and x_i is the employment of the i^{th} type of specialized intermediate good. It is assumed that the intermediate-good producing sectors use only ‘raw’ capital in order to produce an intermediate good. In particular, it is assumed that ηx_i units of raw capital in the form of foregone output is needed, where η is the amount of raw capital embodied in one unit of the intermediate good. Romer assumes that the capital can be rented from the market at real interest rate r . Finally, the blueprint sector is assumed to use human capital in producing blueprints next to the experience accumulated during the production of all previous blueprints:

$$\frac{dA}{dt} = \delta A H_A \quad (1.6)$$

where δ represents the productivity of the blueprint generation process, and H_A the amount of human capital used in generating blueprints. Hence, there is a tradeoff between the final good sector and the R&D sector in using scarce skilled labor resources. The solution of this set up has already become part of textbooks (*e.g.*, Barro and Sala-i-Martin, 1995), and therefore we shall not elaborate it here. The five equations resulting from the solution procedure are as follows:

$$\hat{Y} = \hat{A} = \hat{K} \quad (1.7)$$

$$\hat{A} = \delta(H - H_Y) \quad (1.8)$$

$$H_Y = \frac{r}{\alpha\delta} \quad (1.9)$$

$$\hat{Y} = \delta H - r/\alpha \quad (1.10)$$

$$\hat{C} = \hat{Y} = \frac{r - \rho}{\theta} \quad (1.11)$$

where equation (1.10) is indeed derived from (1.7)-(1.9). A graphical illustration of these relationships is presented in Figure 1.5 below.¹⁹

In Figure 1.5, equations (1.10) and (1.11) determine equilibrium r and the growth rate \hat{Y} . We have already noted that equation (1.10) is derived from equations (1.7)-(1.9). Given equilibrium r and the growth rate \hat{Y} , it is straightforward to derive equilibrium values of \hat{A} and H_Y from equation (1.7) and (1.8), respectively. Note that Figure 1.5 also indicates corner solutions, *i.e.*, the cases where r or \hat{Y} is zero.

Hence, a shock to the technology stock is indeed due to a shock onto the stock of human capital stock.²⁰ We can trace the impact of such shocks from figure 1.5 above. Suppose that we are at steady state. We observe from figure 1.5 that an unexpected increase in human capital stock leads to an

¹⁹ Inspiration of this figure comes from van Zon and Yetkiner (2003).

²⁰ This characteristic of Romer (1990) has led to a debate, which is called the scale-effects issue in the literature. Romer-type R&D-based growth models conclude that if the level of resources devoted to R&D, say, doubled, then the growth rate of per capita output also doubles, at least in the steady state. Empirically, such a prediction receives little support. For example, growth rates have either exhibited a constant mean or declined on average, even if the number of scientists engaged in R&D in advanced countries has largely grown since 1960s. Jones (1995), Kortum (1997), and Segerstrom (1998), among others, attempt to remove the odd result of the impact of levels of human capital (or population) on growth rate. See also Jones (1999) and Dinopoulos and Thompson (1999) for a detailed review of the studies on scale-effects. Finally, it is worthwhile to note that the second essay of this dissertation shows that the scale-effects critique may not be valid.

outward shift in equations (1.8) and (1.10), where the direction of movement of equations is indicated by arrows. If the shock is a one-time transitory shock, then the change in growth rate will also be transitory. A permanent shock implies a permanent increase in the rate. Finally, a continuous increase in the stock of human capital implies a continuous rise in growth rates, which contradicts with the empirical regularity (see footnote 20).

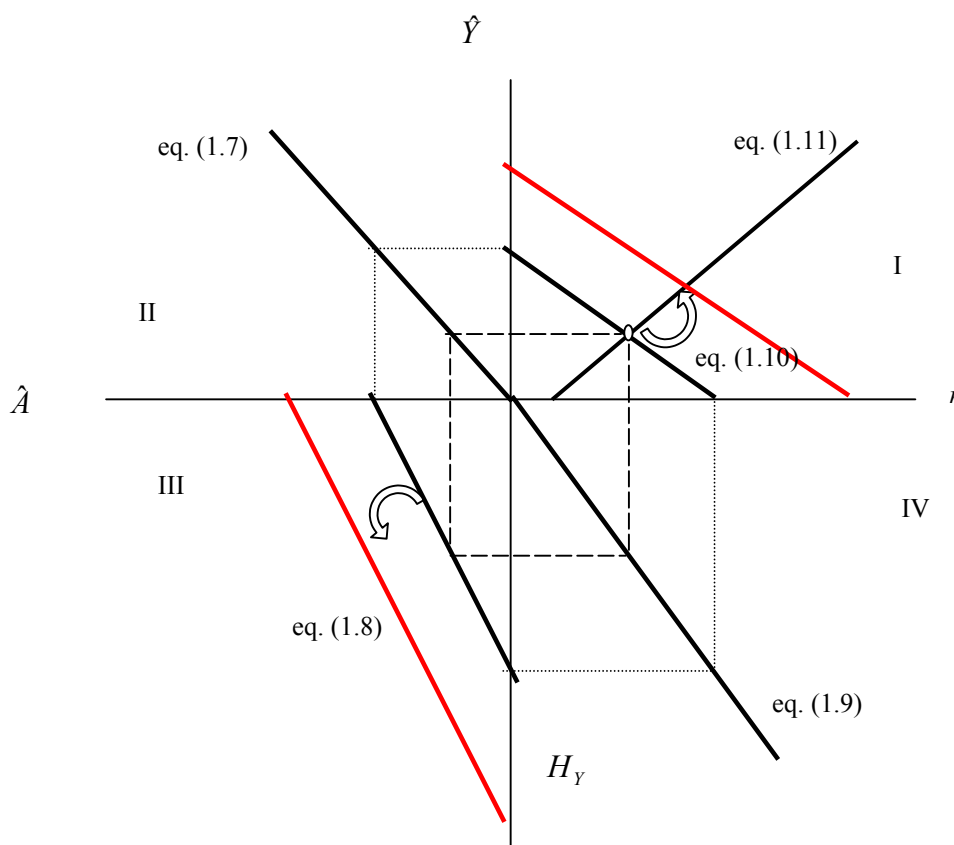


Figure 1.5. Shocks in the Endogenous Technological Change Setup

When we compare figure 1.3 with figure 1.5, we observe that the endogenous technological change framework (which is a good representative of the second-generation growth literature) is richer than the first-generation growth framework in indicating sources and channels of technology shocks. One may induce from our analysis that technology shocks have strong backward and forward linkages, even though we were able to discuss only few of them (knowledge accumulation, R&D labor) in this review. In that respect, a market shock diverge from a natural shock because the latter does hardly have backward linkages. Next, we will identify the place of policy shocks in the growth process.

1.2.3 Policy Change Shocks

Policy-making decisions are the third source of shocks in economic structures according to the taxonomy of Iacobucci *et al.* (2001). Examples to decisions that create shocks in economies include ‘strategic’ changes like trade liberalization, deregulation, and privatization, and ‘tactical’ changes like monetary and fiscal changes, including changes in taxes. Economic actors are exposed frequently to government policy shocks, and there is a tremendous amount of literature on the effects of these shocks. In this review, we will focus only on fiscal shocks due to two reasons. First, fiscal policy is one of the heavily used policy tools of governments, and second, the growth impact of fiscal shocks has been subject to intensive research compared to other policy shocks in the growth literature. We therefore believe that the wide range of studies of fiscal shocks legitimizes our selection of fiscal shocks as a good representative of policy shocks in our

review. The two key elements of fiscal shocks are taxes and government expenditures.

One strand of the relevant literature has concentrated on the search for an optimal tax structure in order to finance a *given size* of the public sector (*i.e.*, an exogenous path of public spending). Among others, we can name King and Rebelo (1990), Jones and Manuelli (1990), Jones, Manuelli and Rossi (1993), Devereux and Love (1994), Roubini and Milesi-Ferreti (1994), Bond, Wang and Yip (1996), Mendoza, Milesi-Ferretti, Asea (1997), Milesi-Ferreti and Roubini (1998), and Turnovsky (2000). These studies have shown the negative impact that capital, labor, and consumption taxes can have on welfare due to their distortionary effects on the accumulation of productive factors and on the income/leisure choice. However, the majority of this research does not analyze the problem of the optimal tax structure when the public sector affects the productivity of private production factors through public capital, or the utility of private agents by providing public goods. These aspects are especially relevant, since besides the distortionary effects of taxation, which cause inefficiencies in allocation, it is also necessary to consider the positive effects, which are generated: on the production of goods and services, on the accumulation of human capital and on the provision of consumer goods.

Specifically addressing the positive effects of taxation due to productive government services has been initiated by Barro (1990) in the growth literature. Some other early studies in this direction are Devereux and Love (1995), and Turnovsky (1995, 1996). Turnovsky (1995, 1996) analyses the optimal choice between capital and consumption taxes in a model similar to the one used by Devereux and Love (1995). The main result is that, in general, the optimum taxation policy should include both capital and labor

taxation in financing government spending. The work of Corsetti and Roubini (1996) complements that of Turnovsky (1995). These authors find that in general, the optimum policy implies that both taxes are different from zero.

Two natural extensions of the Barro (1990) model are introducing non-rival public goods and congestion issues. First, the government input may be a purely non-rival public good. In that case, the aggregate government services, G , enter the private production function of firm i instead of firm-specific government services (cf., interpret equation (1.12) below at the firm level while government spending is G instead of g). There are several contributing works on this issue. For example, Glomm and Ravikumar (1994) examine the implications for capital accumulation when infrastructure enters as an external input into private production functions (see also Glomm and Ravikumar (1997)). In this model, infrastructure is nonexclusive but may exhibit varying degrees of nonrivalry. They show that the optimal tax rate is independent of the degrees of nonrivalry.

Second, public goods may be subject to congestion (such as highways, airports, or courts of law). For example, in Turnovsky (1997), public capital subject to congestion is introduced into an endogenous growth model and the transitional dynamic paths under alternative fiscal policies are characterized. Fisher and Turnovsky (1998) are also in the same spirit. Barro and Sala-i-Martin (1992) show that if public goods are subject to congestion and are therefore rival but to some extent non-excludable, then income taxation works approximately as a user fee and can therefore be superior to lump-sum taxation.

After this short introduction into the literature, we will elaborate the impact of policy change shocks on the rate of growth by studying Barro

(1990). Our motivation for employing this framework is its simplicity and generality. In his paper, Barro (1990) argued that government services could enhance production or utility, depending on the type of services. Barro (1990) added that this role of public services might create a potentially positive linkage between government and growth. The details are as follows. The Barro (1990) model assumes that per capita output is a function of capital per capita, k , and government expenditures per capita, g , under constant returns to scale:

$$y = \Phi(k, g) = k\phi(g/k) \quad \phi' > 0 \quad \phi'' < 0 \quad (1.12)$$

Barro (1990) next assumes that government expenditure is financed contemporaneously by a flat-rate income tax, $g = T = \tau \cdot k \cdot \phi(g/k)$, where T is government tax revenue and τ is the tax rate. Under the assumption that government expenditures are financed by (income) taxation and that the government budget is always balanced, Barro showed that his model generates endogenous growth, $\gamma = 1/\theta((1-\tau)\phi(g/k)(1-\eta) - \rho)$, which depends negatively on the tax rate, τ , and positively on the share of government expenditures in gross domestic product, g/y (η is the elasticity of y with respect to g , and θ is the elasticity of marginal utility). We illustrate the relationship between taxes and the growth rate of the model-economy below:

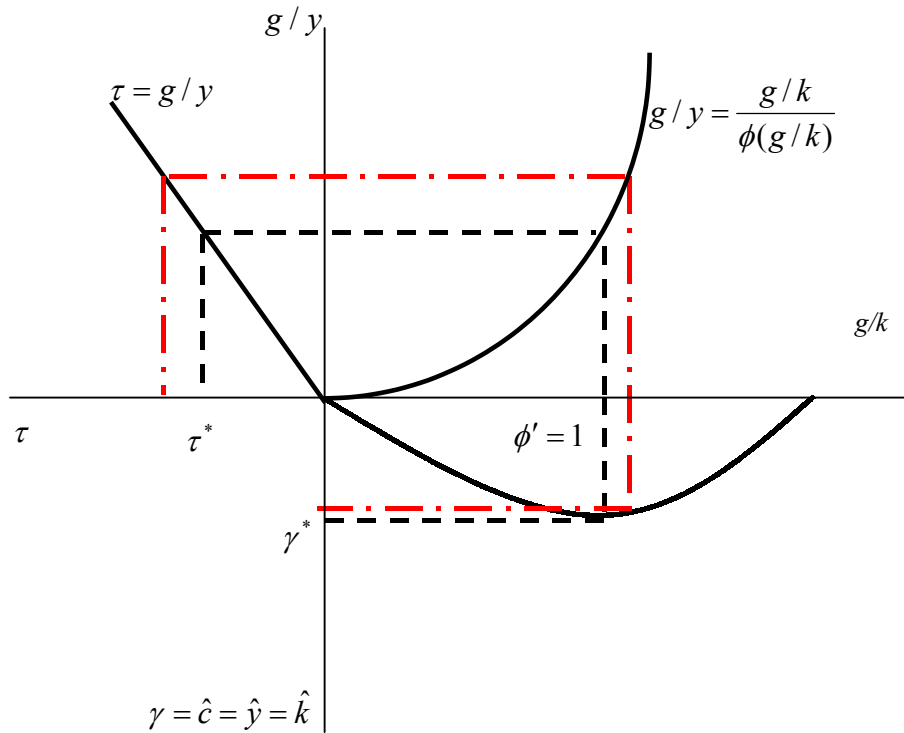


Figure 1.6 Governmental Shocks (in Barro (1990) setup)

In figure 1.6, the Northeast quadrant indicates the relationship between g/y and g/k , which is derived from equation (1.12). The Northwest quadrant captures the balanced budget assumption. Finally, the Southeast quadrant represents the relationship between the growth rate and g/k (cf., Barro (1990)). It is now straightforward to follow the growth impact of shocks in tax rates. At low g/k rates, an increase in tax rates is beneficial to the growth rate, because the negative effect of rising taxes is less than the positive effect of rising government input in production. Similarly, at high

g/k rates, increases in tax rates cause a decrease in growth rates as the negative impact of taxes outweigh the positive impact of higher g in production. Figure 1.6 illustrates that there is a unique tax rate that generates the highest growth rate in the model economy. We understand from Barro (1990) that policy shocks in terms of fiscal policies are not necessarily harmful to the economic performance. Indeed, there is a positive optimal rate of tax rate that maximizes the rate of growth. Below, we produce a table summarizing the impact of changes in tax rates on growth rate (there is no transitional dynamics in the model):

Table 1.2. The impact of shocks in Barro (1990)

State of the Economy	One-time Transitory	One-time Permanent	Continuous changes
Steady State	One-time increase (decrease) in the growth rate if the new tax rate moves towards (moves away) the 'optimal' rate	A permanent increase (decrease) in the growth rate if the new tax rate moves towards (moves away) the 'optimal' rate	The growth rate will rise or fall depending on whether or not the change makes the new rate closer to the optimal tax rate

We conclude that the growth impact of policy shocks in Barro (1990) type models deviates from AK models as taxing policy involves a unique optimal growth rate, even though the model is essentially an AK model for a Cobb-Douglas technology.

As we have identified the place of shocks in the growth literature according to their sources, we can now move to spot the place of the four essays of this dissertation in the same taxonomy of shocks. The next section is all about this.

1.3 The Place of This Dissertation in Theory on Shocks

This dissertation is composed of four essays, each of which examines one or more shocks and its/ their consequences in a deterministic growth framework. The essays have their own peculiarities. First, they cover a wide variety of frameworks of growth literature, ranging from endogenous technological change to two-sector neoclassical growth frameworks. Second, each essay is an inquiry into an economic problem by itself. In that respect, each essay can be considered ‘independent’ of others. Third, contrary to the former peculiarity, essays are interlinked closely from the viewpoint of the main research question of this dissertation because each essay studies one or more types of shocks. For all these distinctive reasons, we prefer to maintain the self-sufficiency of each essay within the manuscript, while using the subsequent pages in this introduction to identify the contribution of each essay into the general theme of this dissertation. The subsequent pages are all about this. Table 1.3 below summarizes the use of shocks within each essay as a quick reference to the section.

Table 1.3. The association of chapters with the review

	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Framework	ETC ^a	ETC	Two-sector	AK model
Reference work	Romer (1990)	Romer (1990)	Uzawa (1963)	Rebelo (1991)
Shocks				
Natural			A physical shock on the housing sector. It is shown that (i) the direct effects are recoverable and the indirect effects lead to lower output levels transitionally; (ii) Stimulating capital accumulation leads to a higher long-run output.	A physical shock on the housing sector. The model generates the so-called constancy conditions. It is shown that welfare losses are inevitable, and that the conditions can be restored only if the government intervenes.
Market	Endogenous technology shocks and exogenous energy-price shocks. It is shown that the former generates endogenous growth and the latter decreases the steady state growth rate.	Endogenous technology shocks and exogenous skilled and unskilled labor shocks. The former generates endogenous growth in cycles and the latter results in exogenous changes in the growth rate.		
Government	Government shocks in the form of taxes, either recycled to the R&D sector or not. It is shown that the rate of growth is affected positively (negatively) in the former (latter).			Government shocks in the form of restricting 'undisturbed' variables.

^a: ETC stands for Endogenous Technological Change

The first essay is on three things: technology shocks, energy price shocks (as an input of intermediate good production), and policy shocks. As the relationship between technology shocks and endogenous growth has been the focus of previous section, we shall not elaborate it here again. It may be useful to give a short review of the literature on energy-growth literature and on the growth impact of energy price shocks. The impact of energy on growth has been a popular topic in ‘old’ growth theory, mainly in the context of exhaustible resources.²¹ In the ‘new’ growth theory, however, energy has so far not been a serious issue. There are a handful studies at theoretical level on the growth impact of energy. One of the few examples is chapter 5 of Aghion and Howitt (1998), in which the authors incorporate in their model of creative destruction energy (nonrenewable resources) and environmental pollution. Aghion and Howitt (1998) first indicate that (even) an *AK* framework is not able to generate endogenous growth when a nonrenewable resource is an argument of production. Next, they show that unlimited growth is sustainable in a Schumpeterian approach if output and tangible capital grow at the same rate in a steady state, provided that intellectual capital grows sufficiently faster than tangible capital, and fast enough to offset the inevitable decline in the use of the natural resource. A main critique on their argument that *AK* frameworks fail to generate endogenous growth when (nonrenewable) energy augments it is perhaps that, by construction, that framework does not introduce any offsetting mechanism between knowledge (capital) accumulation and declining energy flows. Ironically, the same critique applies to the authors’ Schumpeterian framework, in the sense that it is too simplistic to generate endogenous

²¹ See the seminal work of Dasgupta and Heal (1974).

growth by overweighing the decline of a nonrenewable resource via an excessively growing variable.

We believe that it is still vital to extend the endogenous growth framework in the way Dasgupta and Heal (1974) did for the first generation growth framework, by linking energy (exhaustible resources) and economic growth process. Notably, the energy-growth literature seems in need for further expansion in many directions.

We would argue that there are two potential areas of research where the growth impact of energy price shocks should be considered more extensively. First, in accordance with the energy-economy literature, rising energy prices must have a negative effect on the rate of growth. Studies like Rasche and Tatom (1981), Darby (1982), Hamilton (1983, 1996), Burbidge and Harrison (1984), Gisser and Goodwin (1986), Mork (1989), Jones and Leiby (1996), Carruth, Hooker and Oswald (1998), and Brown and Yucel (2002) have either shown that there is an inverse relationship between energy (oil) price increases and aggregate economic activity, or have argued that the former has been responsible for fluctuations in aggregate quantities. Second, increasing energy prices may lead to (i) substitution of capital, technology, and alternative energy sources for the (nonrenewable) energy, (ii) induced technological change, a biased change that stimulates energy-saving technologies in response to rising energy prices.²²

It is interesting to note that these two (countervailing) research areas can be considered as the direct and indirect effects of energy-price shocks. Direct effects would be the growth effects of an energy-price shock, while indirect effects would be the response of an economy to these shocks.

²² Energy-economy modellers have also shown a renewed interest in the 'induced technological change' argument after the resurgence of endogenous technological change.

The growth literature on the direct and indirect effects of energy price increases is rather incomplete. Moon and Sonn (1996) and van Zon and Yetkiner (2003, also the next chapter in this manuscript) are examples of the former trend, studying the direct (*i.e.*, growth) effects of energy price increases. Tahvonen and Salo (2001) show (by simulations) the switch between renewable and nonrenewable energy resources in a growth/resource depletion framework. Smulders and Nooij (2003), on the other hand, is a study on induced technological change. They study the effects of energy conservation by *exogenously* reducing either the level or the growth rate of energy inputs in the model. Energy becomes scarcer and producers are willing to pay higher prices for energy services. The returns to investment in quality improvements of energy-related intermediates rise relatively to other (labor-augmenting) innovations. This spurs energy-related innovation. In the new equilibrium, the direction of innovation shifts to energy. Evidently, the literature is substantially incomplete in the two directions mentioned above, and further research is needed.

Below we present our heuristic (and rough) representation of the negative impact of rising energy prices on the rate of growth, despite the fact that there is wide evidence on the potential negative growth effects of energy-price shocks in the existing literature. Figure 1.7 below plots the rate of change in fossil fuel price and GDP growth rate for US between 1950 and 2001.

See Ruttan (2001) as a recent comprehensive work on ITC-related issues in energy-economy framework.

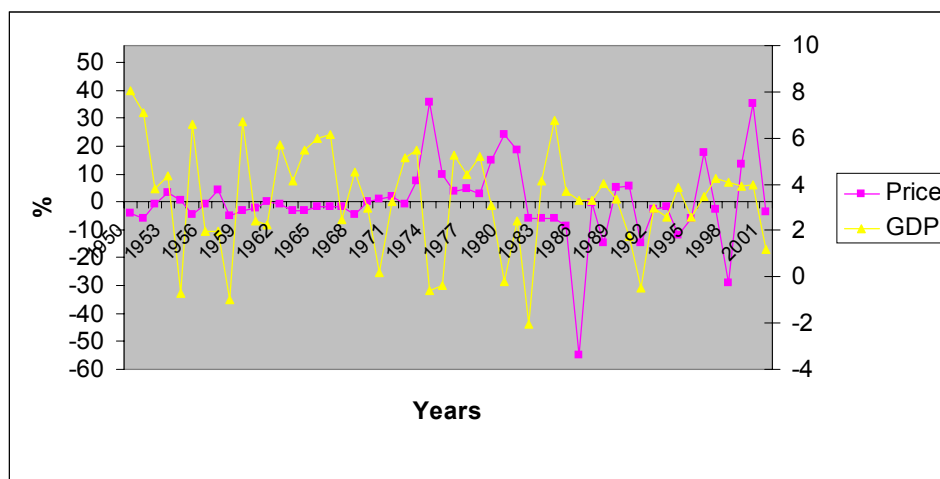


Figure 1.7. The time plot of growth of fossil fuel composite prices and GDP
(Source: U.S. Energy Information Administration)

From figure 1.7, *heuristically speaking*, we observe that the GDP growth rate (indicated by the lighter color and its values correspond to the vertical axis on the right-hand side) and the rate of changes in fossil fuel prices move in the opposite direction in several *instances*. Some eye-catching time spots/intervals where energy prices and growth rates move in the opposite direction (with some possible delays) are 1956, 1959, 1962-67, 1977 and 1983.²³ Interestingly, in spite of the relatively voluminous empirical literature looking at the impact of oil price shocks on economic activity, there is little research on the theoretical side why this is so. Our first essay is motivated by this shortness.

²³ We are aware of the fact that even making a statement like this is too heuristic, as even a simple correlation coefficient test is not valid unless it is known that variables have normal distribution. We do not want to go further than this 'primitive' eye-catching piece of evidence in this study, and we take it as given that rising energy prices have a negative impact on economic growth, based on the above-mentioned empirical literature.

Our paper is an extension of the Romer (1990) endogenous technological model. Our motivation to use this approach is that it allows us to introduce energy input into the intermediate good production in a straightforward manner in an endogenous growth framework. In essence, we extend the Romer model in two ways. First, we include energy consumption of intermediates. Second, intermediates become heterogeneous due to endogenous energy saving technical change. The model elaborates the impact of input price shocks and taxes on input prices as examples of market shocks and policy shocks. The details on the use of shocks are as follows.

We study input price shocks in the form of energy prices. An increase in energy prices is exogenous in the model and can be considered as one-time transitory, one-time permanent, or continuous. The model shows that a continuous energy-price rise will have negative growth effects on the growth rate of economy due to the following mechanism. Increasing real energy prices lead to corresponding rises in the user costs of intermediates and hence to a fall in profits on those intermediates. This diminishes the incentive to produce newer, more productive intermediates. The decrease in this incentive is cushioned to some extent by the substitution possibilities between raw capital and energy implied by the Cobb-Douglas function (if actual substitution possibilities between capital and energy are lower, then the rise in the user costs of intermediates would be higher, *ceteris paribus*, and the detrimental effects on research incentives would of course be stronger than what our model suggests). The model shows that there will be less growth when the growth rate of real energy prices rises, unless policy measures are taken that counteract the negative effects on research incentives arising from a positive growth rate of real energy prices.

Additionally, we study fiscal shocks (taxation) that may stimulate further R&D in the model in two forms. In particular, we investigate the impact of the introduction of an energy tax, with and without recycling in the form of an R&D subsidy (these shocks can be associated with non-productive and productive government-involvement assumptions, cf. the policy-shocks section). Such policy actions would be necessary to mitigate the drop in growth following a rise in the rate of growth of real energy prices. The introduction of a tax will change the profitability of producing intermediates. Changes in profitability will affect the allocation of labor over its two uses: R&D and final output generation. This will change the steady state growth rate, apart from having level effects as well. The study shows that growth will be negatively affected and a reallocation of labor from R&D towards final output will be observed in case of non-recycling taxes. In contrast, when taxes are recycled towards the R&D sector, we observe that the introduction of an energy tax will raise the growth rate of output, while the tax would not work for a high share of R&D employment in total employment. An important conclusion from input price and policy shocks is that increasing input prices (with or without taxation) is not enough by itself to induce R&D efforts, which could have been compensated the rising energy prices.

The second essay in the manuscript is an investigation on the empirical regularity that drastic technological changes are introduced in clusters and on the impact of such technology shocks on long-run output growth. Empirical evidence denotes that drastic technological changes are introduced in clusters rather than having a regular sequence. One recent piece of evidence to this argument is shown by Olsson (2001). As figure 1.8 shows below, a bunch of drastic technologies have been introduced within

each 45-60 years, such as the 1830s, 1880s, and 1930s (see also figure 1.9, which shows the same cyclical activity by referring to three different sources).

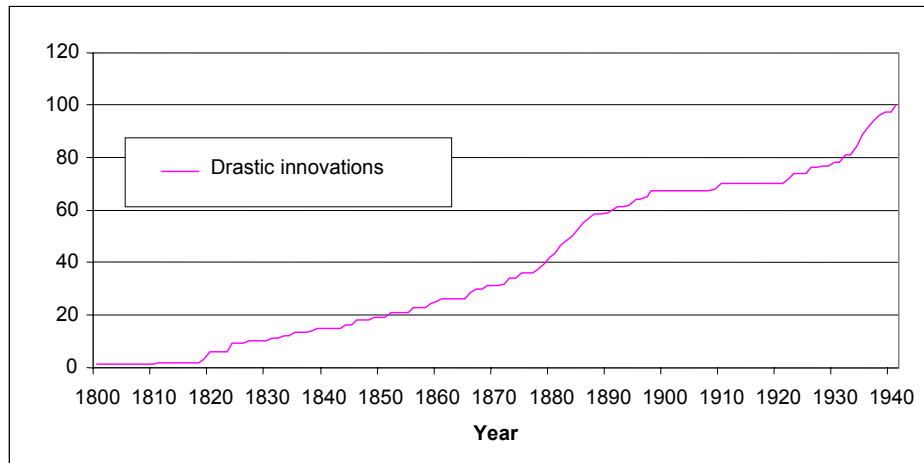


Figure 1.8. Cumulative distribution of drastic innovations, based on the Mensch sample, 1800-1941 (Source: Olsson (2001))

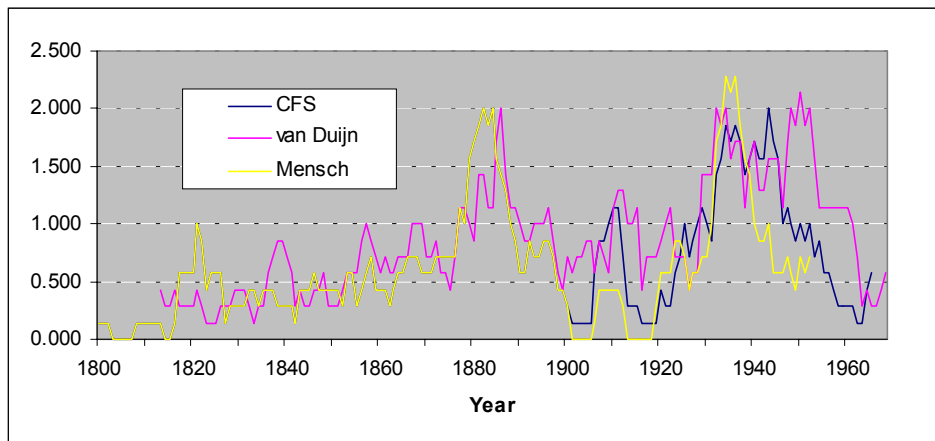


Figure 1.9. Drastic innovation activity, 1800-1968 (Source: Olsson (2001))
(Seven-year moving averages of drastic innovations per year)

Clearly, many questions arise from this empirical regularity. Why does the introduction of drastic technologies fail to follow a regular trend? Is that the result of market or of non-market forces? If markets drive such a result, what is it then? Many questions like this can be enumerated. The second essay of this manuscript offers answers to these questions.

This paper conjectures that drastic technological changes are cyclical because basic R&D is carried on only at times when entrepreneurial profits for incremental technologies of the prevailing technological paradigm falls close to zero. The model is essentially an endogenous technological change framework. Varieties, input to the final good production, are composite goods. Each composite good is produced by a set of intermediaries, outgrowths of basic R&D and applied R&D. The basic intermediate, product of basic R&D, is modeled as in Romer (1990). Complementary intermediates, the outgrowths of applied R&D, do show the property of falling profits. The falling character of profits implies that basic R&D becomes more yielding than applied R&D at certain points in time. Research people switch back and forth between the applied and basic research sectors, creating cycles in the advancement of drastic technologies and economic activity.

The paper is interesting for several reasons from the viewpoint of shocks. First, technological shocks are continuous but cyclical, alternating between applied technologies and drastic technologies. The model shows that profit opportunities for incremental technologies of the prevailing technological paradigm are decreasing. When the profits decline sufficiently, the R&D labor, capturing positive profits of the intermediate sectors, switch to basic R&D. Thus, it is shown that market opportunities are the actual source of

shocks. Second, the shocks (cycles) are endogenous, which is rarely studied in the growth literature. The falling profits character of the complementary sector is not due to an assumption, but a property that the model generates intrinsically. Since technology shocks are positive shocks, at least in terms of growth rates, a policy-maker's central question would be how to accelerate it. That question also pinpoints the third characteristic of the model in terms of shocks. Growth in our model is still generated by R&D labor, but the stock does play that role cyclically. In particular, the R&D labor generates growth rate only at times when they are specifically employed in basic R&D activities. This is a significant deviation from the standard R&D-based growth models as it implies that there are certain *market-determined* time 'intervals' in which economies that have larger-scale R&D labor will realize higher 'jumps' in growth rates. At other times, a larger scale means a quicker generation of blueprints of complementary intermediates. From the policy perspective, this finding implies that it is better to have more R&D people at all times, independent of whether they work on basic R&D or on applied R&D. Note that this conclusion also entails that the 'scale effects critique' is not valid as the scale of R&D people has a dual role in our model.

The third essay is an example of the impact of natural (physical) disturbances on the transitional and long-run growth performance. On the one hand, strong, large-scale earthquakes may cause substantial costs of life and capital. On the other hand, casual observation shows us that economies recover from catastrophic earthquakes relatively quickly. This argument can be denoted by the recent experience of Turkey, in a heuristic manner. In 1999, a large-scale earthquake hit the Marmara region of Turkey, which includes Izmit and Istanbul, the two most advanced cities of Turkey in terms

of manufacturing. As these cities and the region contribute significantly to the gross domestic production of the Turkish economy, and as the scale of the destruction was large, we deem it legitimate to consider this particular event a good example of catastrophic earthquakes. Figure 1.10 below shows the growth impact of the earthquake on Izmit, Istanbul, and the Turkish economy, at least partially, in 1999 (other troughs are due to economic crises, which indicates that the three have similar responses to shocks, physical or financial).

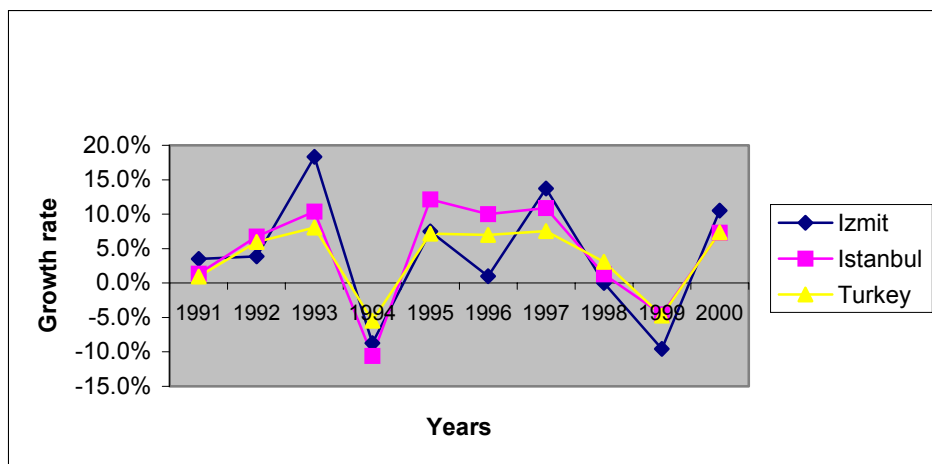


Figure 1.10 The Turkish GDP Growth Rate, 1991-2000 (1987 Prices)

(Source: State Planning Organization, Turkey)

Evidently, there may be other reasons that led to such a decline in 1999 than the earthquake that hit the Marmara region. Nonetheless, still it seems plausible to assign the large decline in the growth rate in Izmit and Istanbul to the earthquake, at least partially.

This paper opens the block-box concerning the growth implications of an earthquake by employing Uzawa's two-sector growth model. Our motivation behind using this particular framework is its global convergence property. As we have mentioned above, we know that economies recover pretty quickly after physical shocks, even after devastating ones. In that respect, the Uzawa model offers a framework that ensures 'automatic' convergence to steady state values, which is an empirical regularity, by and large. It also provides a proper environment to study asymmetric impacts of earthquakes on physical goods. For these reasons, we choose the Uzawa framework, which is essentially a two-sector Solow model. The paper shows that (i) the direct effects of earthquakes are mainly transitional, (ii) earthquakes may have serious negative indirect effects on an economy in the transitional period as well as in the long-run.

This paper is an explicit study of physical shocks. In the model, an earthquake hits the housing stock. Clearly, this is a one-time permanent shock. We studied the direct and indirect impacts of shocks at transitional and steady state levels. First, direct effects of earthquakes are studied during the transitional period, and it is shown that the direct effects of an earthquake on housing are quickly recovered by the model economy. This finding is obviously due to the neoclassical production technology assumption of diminishing marginal productivity (cf. our discussion on physical shocks in the previous section). This rule ensures global convergence of the model, and hence, any shock to any stock variable is recovered in time. Second, we study the indirect effects of earthquakes in the transitional period. In the model, we conjecture that (exogenous) savings rates, which denote the allocation of income between alternative uses, are proper tools of measuring indirect effects of an earthquake. One result of a

devastating earthquake is the destruction of housing stock (the literature supports the idea that the housing stock is more open to the detrimental effects of earthquakes). Then, more resources are needed to be transferred into the housing stock in order to recover the loss. Hence, exogenous changes in saving rates in favor of investment in the housing sector at the cost of investment in other sectors capture the indirect effects of an earthquake. The model investigates growth impacts of these changes in the transitional period. We find that it may be ‘better’ to ‘transfer’ more resources to capital production rather than to the housing sector after an earthquake. This is because investment into the productive sector means more output in the future, even though the immediate welfare implications of a housing loss can be high. Hence, a shock creates a tradeoff between short-run and long-run welfare effects, where policymakers must make a decision. Third, the model looks at shocks at the steady state (i.e., comparative statics). It is assumed that permanent changes in saving rates and depreciation rates mean permanent changes in the quality of housing (the former is the cause, and the latter is the effect). Consequently, these permanent changes must have (strong) implications on the long-run values of output (and its components). We show, among others, that an increase in the saving rate out of national income for investment goods increases the steady state level of the economy-wide capital stock per capita, while increases in savings out of national income for housing decreases the long-run capital stock, *ceteris paribus*.

The fourth essay of this dissertation studies a special case, in which the (neoclassical) conjecture that “all (physical) shocks will be recovered unconditionally” fails, at least in the long-run. To this end, we use an AK model, which produces the so-called constancy conditions among variables

of the model. Constancy conditions imply that all variables must keep a fixed proportion among them (note that the condition implies that quantities must grow at the same rate from the start by definition). This property delimits these types of growth models from other growth studies because an ‘automatic recovery mechanism’ (the global convergence property) is not ‘at work’ after disturbances like wars, diseases, and earthquakes in such models. We elaborate theoretically what would be adjustment policies in order to restore constancy conditions after a one-time permanent shock. We show that market forces are not able to restore equilibrium automatically. This finding brings us into the critical question whether there is some indispensable role for the government to ‘steer’ the process of recovery from a shock. The paper indicates, at least implicitly, that it is a theoretical possibility that the intervention of the social planner (government) can be key to restoring pre-shock values. The contribution of this paper is that (i) it offers a scheme for how to deal with restoring constancy conditions after a physical disturbance, and (ii) it demonstrates that the government’s role in restoring the pre-shock situation can be essential.

1.4 Conclusion

In this review, we raised the argument that a more systematic study on shocks is needed. Our review of the growth literature within a taxonomy indeed revealed that this need is imperative, because “shocks” and “changes” analyses in the current growth literature are used often but usually in an *ad hoc* manner. Given that shocks may have strong implications on transitional and even long-run growth performances of an

economy, as shown by our review, a systematic treatment of these concepts may produce a better understanding of the theory and its implications first and foremost. In the second part of the review, we identify the place of four essays of this dissertation within the growth literature and within a taxonomy of shocks. We showed that each essay contributes to the main aim of this dissertation in a unique way.

The main conclusion from this chapter is that shocks deserve more research effort in growth frameworks, and the essays in this manuscript are an attempt in that direction.

$$Y = F(K, AL), \quad (1.1)$$

where Y represents aggregate output, K is capital stock, L is labor stock, A denotes technology, and $F(\bullet)$ is a constant returns to scale function satisfying Inada (1963) conditions. The labor stock grows at rate n if it ever grows. The economy accumulates capital according to

$$\dot{K} = s \cdot F(K, AL) - \delta K, \quad (1.2)$$

where a dot over a variable represents time derivative of the variable, s is the exogenous saving rate and δ is the depreciation rate. The capital accumulation equation is generally called the *fundamental equation of growth* in the literature. It has been shown long time ago that the Solow ‘mechanism’ is unable to produce a positive rate of growth in the long-run unless *exogenous* technological change is assumed. Suppose for the moment that A is constant. Furthermore, assume that the $F(\bullet)$ function is represented by a Cobb-Douglas technology, $Y = K^\alpha (AL)^{1-\alpha}$. Then, solving the fundamental equation of growth would give us

$$k(t) = \left[\frac{s}{n + \delta} A^{1-\alpha} + \left(k_0^{1-\alpha} - \frac{s}{n + \delta} A^{1-\alpha} \right) \cdot e^{-(1-\alpha)(n+\delta)t} \right]^{\frac{1}{1-\alpha}}. \quad (1.3)$$

¹⁰ Albala-Bertrand (1993a, 1993b) uses Keynesian multiplier analysis instead of a growth framework. Still, his results can be interpreted as reflecting steady state.