On Technology, Uncertainty and Economic Growth

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On Technology, Uncertainty and Economic Growth

Over Technologie, Onzekerheid en Economische Groei

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Koen Berden
November, 2006

“Growth may be everything, but it’s not the only thing”

Joseph E. Stiglitz, Foreign Affairs (December 2005)

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Chapter 1: Introduction

1.1. Pakistan

It is January 2006. As representative of Erasmus School of Economics, I am visiting Pakistan together with colleagues from the Graduate School of Business Economics (Warsaw – Poland) to look for international cooperation possibilities in higher education.

One of the trips takes us to Peshawar – a city with roughly 1 million inhabitants – and its surroundings. Peshawar – which means *'City on the Frontier'* in Urdu – is a city in the west of Pakistan not far from the Afghan border (the Khyber Pass). Peshawar was – for a large share of its history – an important trading city located on the famous 'silk route' and a link between cultures in the west and Asia.[1] 'This is as far west as you should go,' explained our driver, 'further west takes you into the tribal areas towards the Khyber Pass where there is a 'different' rule of law and where you are not safe as Westerners – especially not since 9/11'.

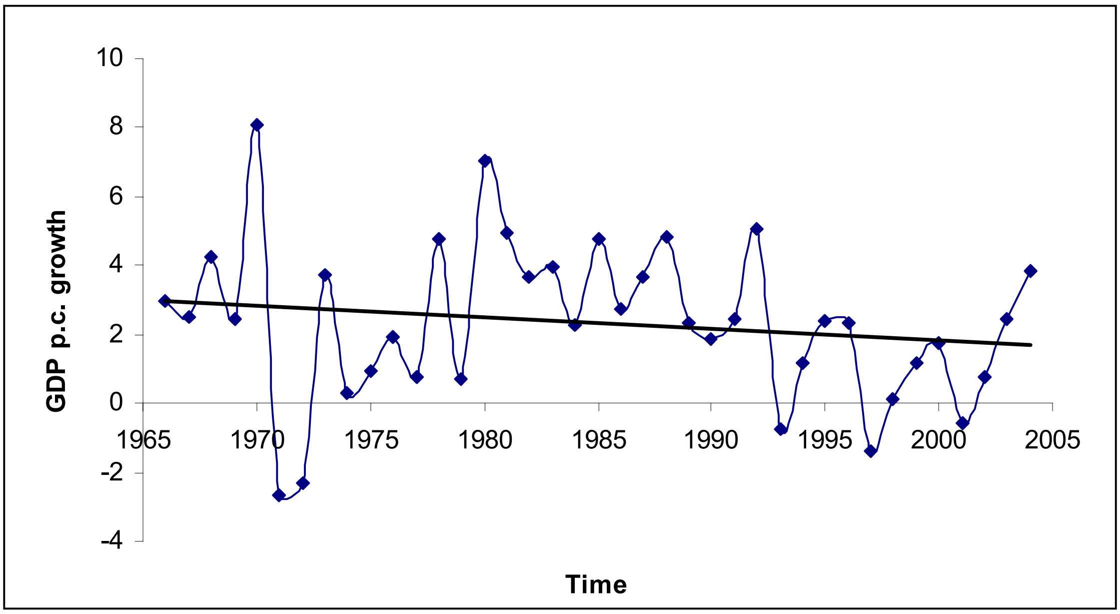
During our stay, our friendly hosts take us to visit Buddhist remains near Mardan. Driving at high speeds wherever possible, occasionally slowing down for crossing cattle or donkeys with trolleys, we drive over the local 'roads'. Having seen the impressive remains, upon our return, we stop for something to eat in a little place called Mayar. In Mayar I talk to our host – while having a good look around. The people are very friendly, offering us lassi and meat. The lassi is full of flies and so is the meat, but I eat and drink both not to disappoint those warm and friendly faces looking carefully whether we like it or not. The children – boys and girls – stare at us in amazement and make fun of our behaviour, white and burnt faces and way of eating and drinking. Except for an occasional woman in burka, the adults I see walking around are men. In Pakistan there are more men than women, which is surprising given the fact that women have greater longevity than men. It shows the divide between men and women in rural Pakistani society and the discrimination against girls in terms of nutrition and medical care. Infant mortality rates are just

[1] Hopkirk, P. (1984)

below 200 out of every 1000 births. The children die from dehydration caused by diarrhea or from polio, tetanus and measles. Millions of children are infected by intestinal parasites – which comes as no surprise to me when I look at the hygienic standards people can afford, the quality of the water and the rotting dirt and rubbish that is covering the sides of the sand-roads and bigger 'streets'. What really shocks me is that all these diseases are easily cured if basic medical care can be provided for the poor.

Pakistan is one of the worlds' poorest countries, with an average GDP per capita of $521 (2000 Dollars, World Bank WDI 2005) comparable to income levels in Senegal, Mongolia and Lesotho. On top of that (as figure 1.1. shows) Pakistan has a growth rate of GDP per capita from 1966 until 2004 which over the entire period exhibits a negative (linear) trend: Pakistan has a decreasing level of growth over time (despite a 21st century revival). In reality this picture can be even more grim because we show here World Bank average growth rates, not to whom the growth benefits accrue.

Figure 1.1 Pakistan's GDP p.c. Growth (annual %)



Source: WB, WDI 2005

In rural Pakistan outside Peshawar the people are poor relative to the Pakistani average. When I ask him about it, Mr. Malik says that many families are in their current situation for decades and expect to remain there for decades more to come.

Our driver from Mardan says that he has to support his entire family, parents, wife and five children with his job paying him around $120 per month.

I ask Mr. Malik, our host, about primary and secondary education in Pakistan in general and in Mayar in particular. He explains that in the very small villages like Mayar, large parts of the population cannot read or write and do not have access to education at all. The government is trying to improve this but is definitely more successful in the larger villages and cities in spite of widespread corruption in all layers of society. On top of that, the earthquake in Kashmir of October 8, 2005 is drawing away much needed financial resources from other areas in Pakistan, worsening the situation. Mr. Malik: 'It is the lucky individual who gets a chance to study or even better go abroad to improve life for himself and his family. That is why your visit to Pakistan is so important for us'. It does not make me feel better, rather worse, realising the division in richess and the very few people we can actually help. Most likely none of the inhabitants of Mayar will ever see Poland or The Netherlands.

There is a large economic literature investigating economic growth and many policy prescriptions have been given over the past decades to developing countries. All of this looks into the issues mentioned above or to working towards alleviating poverty, promoting education for the poor, promoting better hygiene and watching infant mortality rates drop. As Easterly (2002) puts it very to-the-point: 'Poverty is not just low GDP; it is dying babies, starving children, and oppression of women and the downtrodden. The well-being of the next generation in poor countries depends on whether our quest to make poor countries rich is successful'.[2] It is indeed this goal that should inspire us to look into the economic mechanisms and dynamics of growth and development.

1.2. A short history of economic growth

Since the entire work of this thesis centres around economic growth and its various models, before explaining in detail the aims and structure of this work, we will give a short historical overview of economic growth.

[2] Easterly (2002), 'The Elusive Quest for Growth', p. 14-15.

For over 200 years, economists have wondered about economic growth, its origins and consequences for wealth accumulation. In his 'Wealth of Nations' (1776), Adam Smith saw three causes for growth: a stable government[3], division of labour[4] and the creation of capital. David Ricardo developed these ideas further in the beginning of the nineteenth century (Ricardo, 1817) while Robert Malthus (1798) contributed to growth theory by claiming that population had the tendency to increase following an exponential sequence while food production would only increase along a linear sequence. In the second half of the nineteenth century, Karl Marx (1890) developed a theory in which he proclaimed the end of capitalism due to increasing wage inequality.

The Solow model

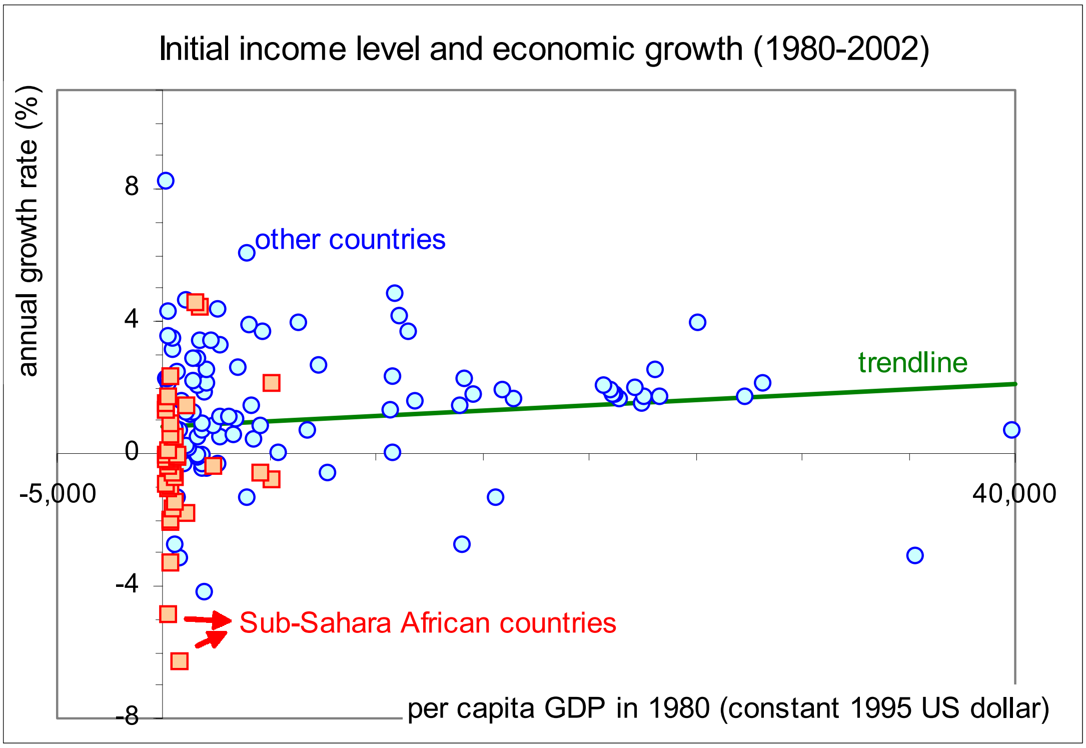
In the 1940s, 1950s and 1960s with the works of Harrod (1939), Domar (1946) and Solow (1956) a revival of growth theory occurred. These economists developed a series of exogenous growth models. In these models, population growth is equal to the long run growth of per capita income. Technological advancements are treated as a function of elapsed calendar time and provide the only source for long-run growth. Savings and investments may raise growth levels temporarily, when an economy grows from one steady-state to another, but not in the long-run. The Solow model was seen in the 1960s and 1970s as an adequate model to describe and predict economic growth in countries all over the world and today still is the 'workhorse' of growth theories used in modelling because of its relative simplicity.

After a while, it became evident that empirical tests did not fully support the original Solow model. Differentiation in levels of technology was not possible due to the adopted model specifications, resulting in predictions about differences in savings levels which were prone to be not born out empirically. Next to the TFP issue, the convergence controversy appears to be a real test for all the developed types of growth models. The Solow model asserts that countries that are far behind would be expected to grow faster due to the fact they can generate much higher returns to capital in their early stages of production (that only start to diminish over time when they 'catch up') and due to the fact they merely need to copy/buy the already

[3] Smith calls this 'order and good government' (1776).
[4] This aspect is illustrated by famous example of the 'pin factory'.

developed technology instead of spending large amounts of resources on domestic R&D. In reality – as is shown in figure 1.2, we do not see this (absolute) convergence taking place. However, when we correct for population growth, depreciation rates and savings rates (i.e. apply conditional convergence), we do find that poor countries are catching up with the richer ones, showing a downward trend in annual average growth of income as their income levels start to reach the income per capita levels of the United States (the benchmark).

Figure 1.2: Testing for convergence



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To solve for the challenges to the Solow model, two theoretical solutions have been proposed: one side of the economics discipline (Mankiw, Romer & Weil, 1992) would prefer the use of adapted neo-classical exogenous growth models, changing the production function to include aspects of Human Capital besides the originally used Capital (K) and Labour (L). In these models, technological progress was still coming like 'manna from heaven'. On the other hand a 'new' strand of literature developed (Romer, 1986; Grossman and Helpman, 1991; Aghion and Howitt, 1992 and 1998) when technological progress was looked at from a different perspective: the endogenous growth models.

Endogenous growth literature and its policy implications

In the exogenous growth models, inventions are treated as a function of elapsed calendar time. Endogenous growth models were treating technological advancements as endogenous to the system, depending on for example the effectiveness of research, R&D-spending levels and/or the levels of Human Capital in the country. In these models, resources are devoted to R&D by profit-seeking entrepreneurs. R&D then results in the development of new goods (Romer, 1990; Grossman & Helpman, 1991; Barro and Sala-I-Martin, 1995), improving the quality of the existing goods (Grossman & Helpman, 1991) or process innovation (Aghion & Howitt, 1992; Grossman & Helpman, 1991; and Barro and Sala-I-Martin, 1995). Though all these models look at the endogenous process of doing inventions, what has been underemphasised in the literature is how these processes work under uncertainty and what the growth consequences of innovation dynamics are. Living in a world where the future is uncertain, those implications are potentially large. There are several ways to categorise the family of endogenous growth models. Van Marrewijk (1999) uses the distinction between accumulable-rival (K), accumulable-non-rival (A) and non-accumulable-rival (L) for classification while Barro & Sala-I-Martin, 1995) use a categorisation into one-sector models (e.g. the AK-model), two-sector models, models of expanding product variety and models with endogenous quality improvements. For a detailed overview of these strands of models, we refer to Van Marrewijk (1999) and Barro and Sala-i-Martin (1995).

Openness and the introduction of new goods

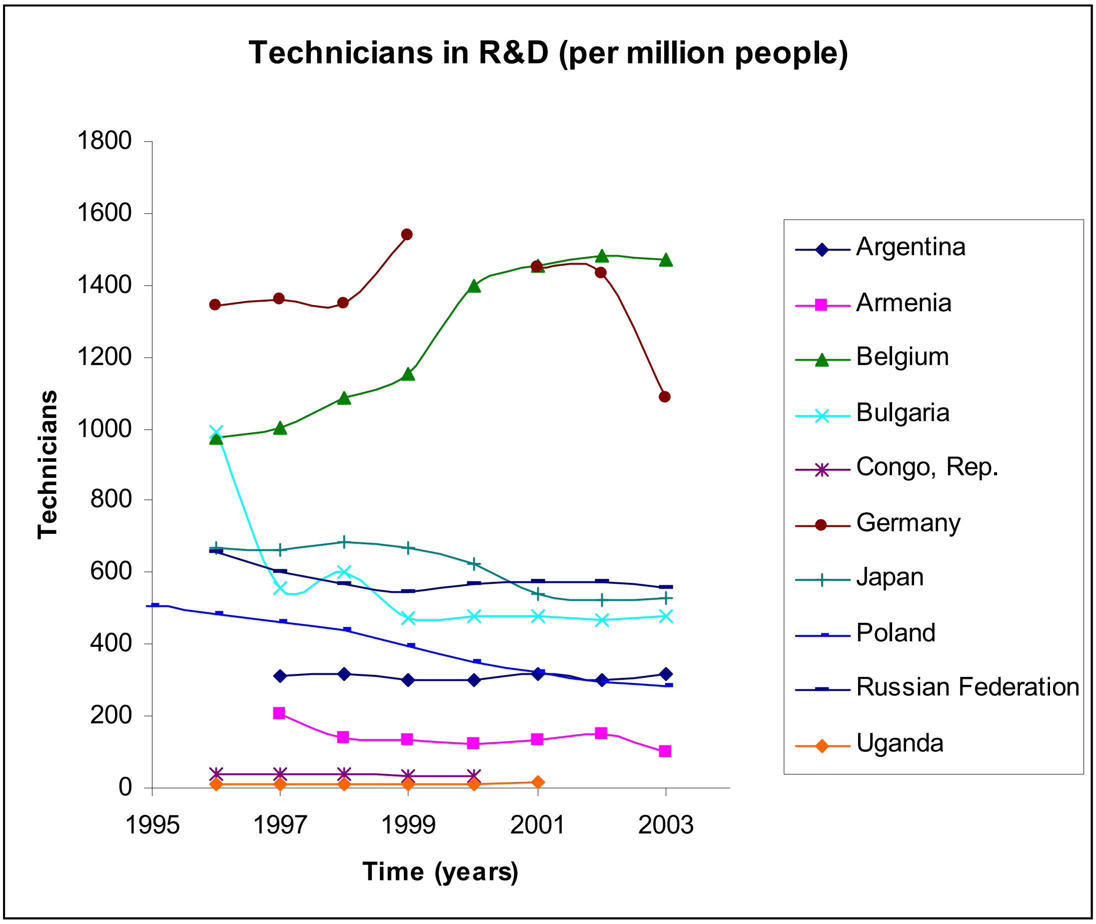
Growth models – whether exogenous or endogenous – try to explain what causes growth and to infer predictions about policies that may lead to higher economic growth to the benefit of societies and its peoples. In all the models, the level of technology growth is seen as crucial for economic development. In this PhD thesis much attention is given to technology growth and 'how it ticks'.

For 'small' developing countries the process of economic growth is not the same as for 'large' developed countries. This needs to be well understood in modelling their economic growth in growth models as well as in deriving government policies.

- A first difference is that poor countries have a catching up process to complete through accumulation of factors of production. They tend to have much lower levels of capital per capita and lower levels of human capital. Growth – for a part – needs to come from catching up. Empirically this means, for example, that we need to control for initial level of GDP as is shown in chapter three.

- A second difference is that generally speaking small developing countries do not have a strong domestic R&D sector. Rather they rely on the import of new technologies from the developed world to improve their production processes, increase efficiency and in general improve their standards or living. This is an important assumption underlying the models developed in chapter four which is supported by figure 1.3.

Figure 1.3: Technicians working in R&D (per million people)



Source: WB, WDI 2005

Figure 1.3 shows that the share of technicians working in the research and development sectors per million people differs a lot per country. Developing countries like Germany, Belgium have a relatively large share of technicians working in research and development while in developing countries like Uganda and the Democratic Republic of Congo this share is very low.

- A third difference is that small countries (developing and developed alike) do not have much influence on world prices of tradable goods and services which means that to a certain extent uncertainty and volatility is a 'fact of life' that cannot be avoided. Large countries also experience levels of uncertainty but through their market power tend to have more policy influence.

Romer (1994) argues that welfare losses, when not introducing goods for an extensive period of time, amount to much higher levels than have so far been measured using Harberger triangles and static welfare analysis. Especially for small developing countries – where technology is mainly imported – the failure to introduce new goods is dynamically destructive for a domestic economy.

1.3. Overview and structure

Aims

The aims of this PhD thesis in adding its contribution to economic science are threefold. Firstly, we aim to provide new answers and insights with respect to the roles of uncertainty and technology in economic growth of developing countries. Secondly, we aim to address some omissions or even misrepresentations in parts of the economic growth literature. Finally, this thesis aims to make additions to economic growth models to make them reflect more 'facts of everyday life'.

Methodologies

Throughout this work, different methodological approaches are used. In chapter two, the simple endogenous growth model of expanding product varieties is used as a basis for incorporating uncertainty. The model changes include introducing a variable for uncertainty and changing the basic model from a deterministic into a probabilistic setting, which, as we will see, will lead to a fundamentally different interpretation of the growth outcomes. In chapter three, an extensive literature overview on terms-of-trade trends and volatility serves as a basis for an Armington-type model that looks at terms-of-trade volatility and its effects on openness and growth. Additionally, the model outcomes are tested empirically, with mixed results. In chapter four, the idea of dynamic welfare effects, first mentioned by Romer (1994), is put to the test in an endogenous growth model. Many simulations are run – based on realistic assumptions regarding parameter- and variable-values – to look at the model predictions. Finally, in chapter five, we again turn to improving the endogenous growth model also used in chapter two, this time to incorporate a maintenance cost sector and to introduce the concept of obsolescence. Through extensive model simulations, also these results are researched and analysed.

Structure

Chapter two will analyse the effects of introducing uncertainty in the endogenous growth model of expanding product varieties which has not been attempted before. In an endogenous growth model, where R&D is endogenous to the process, we cannot stick to a deterministic environment, because R&D is uncertain by nature. We analyse carefully the effects the introduction of uncertainty has on economic growth (the final result) and via which mechanisms this outcome is influenced. The core issue is whether the rate of innovation in a probabilistic environment can be sustained and if so, under what circumstances.

Chapter three takes the uncertainty level one step further by looking at terms-of-trade uncertainty and its effects on economic growth by using an Armington specification with tradable and non-tradable sector. Openness already lurked around the corner slightly in chapter two (more openness leads to lower costs for R&D in a developing country) but now becomes a cornerstone of the model. There is a vast literature on the relationship between openness and growth and also on the relationship between terms-of-trade volatility on growth. We develop an Armington model with terms-of-trade uncertainty and then look at the mechanisms that operate under the surface. Next to the direct effect of terms-of-trade volatility we also find an indirect effect of volatility on growth through openness. This is an important result, not only because of the two-type of effect that terms-of-trade volatility has on economic growth, but also because uncertainty seems to endogenously reduce the level of openness. It is this level of openness that is so important for economic growth, either directly or in order to stimulate technological innovation (chapters two and four).

Chapter four looks at the dynamic costs of trade restrictions. We argue that classical micro-economics looks at the world in an oversimplified way that is excluding one of the most important processes in an open economy: innovation and the introduction of new goods. Furthermore, chapter four shows that the estimated static welfare costs of trade restrictions are smaller than the dynamic costs of trade restrictions if, and only if, the increase in trade restrictions reduces the *share* of invented capital goods introduced on the market. In this dynamic setting it is therefore not the fact that we ignore the Dupuit triangles of newly invented goods in estimating the effects of an increase in trade restrictions, as it is in the Romer (1994) model, but the fact that an increase in the trade restrictions affects the share of newly invented goods not introduced on the market. A second achievement of this chapter is that as a result of the sunk-cost nature of the introduction costs, there is an asymmetric adjustment path of the developing economy after a change in trade restrictions. An increase in the level of trade restrictions will slow-down economic growth and put the economy on a transition path to a new balanced growth rate. If the new level of trade restrictions exceeds a critical value, the new growth rate will be zero and stagnation occurs. If trade restrictions fall, the developing economy may embark on a rapid catch-up process of economic growth by benefiting from the backlog of previously-invented-but-not-yet-introduced capital goods which may now, as a result of the increase in operating profits resulting from the decrease in trade restrictions, be introduced on the market in the developing economy. The second effect, I believe, is one of the main reasons for the observation that economies that have been isolated and closed for prolonged periods of time (e.g. North-Korea) have failed to bring prosperity and growth to their citizens.

Chapter five first of all shows the effects of introducing the phenomenon of obsolescence into a horizontal growth model via the modelling of maintenance costs. In the horizontal endogenous growth literature the restrictive assumption is used that technological innovations last forever and do not get outdated, which is not realistic. In light of our insights from chapters two and four, where the introduction of new goods is important output growth, we analyse the consequences of dropping this assumption. By allowing firms to become obsolete via the introduction of maintenance costs of innovations we develop a three-sector endogenous growth model that shows the implications for economic performance of small developing countries of what we know to happen around us all the time: inventions lose their worth over time (some faster than others).[5]

Chapter six summarises the finding of the previous chapters, comes back to Pakistan for a moment, and concludes.

[5] We will define the concept of 'maintenance costs' in chapter five.

Chapter 2: Uncertainty in Endogenous Growth Models

"The only thing that makes life possible is permanent, intolerable uncertainty; not knowing what comes next"

Ursula Le Guin, writer

2.1. Introduction

Every day, in newspapers all over the world we read articles that deal with facts and problems concerning economic growth. We read about the financial problems in Russia, about the effects of the North American Free Trade Area on U.S. economic growth or about the prolonged recession in Japan and/or South East Asia and the possible negative impact this situation might have on the rest of the world economy. The importance of economic growth, also outlined in chapter one, seems to be stressed and recognised by many people over and over again.

An important problem we face in economics in general and with economic growth in particular is that we have to predict how economic situations will develop in the future, without *ex ante* knowing what that future has in store for us. Not only for individual people uncertainty is important, also for a company or for a country as a whole uncertainty can have a major impact. In reality we do not live in a deterministic world but rather in a stochastic world full of uncertainty (Pomery, 1984).

This chapter shows how to incorporate uncertainty in an endogenous growth model and investigates and analysis the growth implications of doing so.

When making investment decisions, firms have to form expectations about how total sales will develop, about the impact the introduction of a new good has on the market or about how much product development is going to cost. In section 2.2, we will start by looking at the process of product development and the characteristics of this process in order to determine the appropriate distribution for introducing uncertainty. In section 2.3, we build the specific-information model and look at a way to incorporate a component of uncertainty therein. Section 2.4 differs from section 2.3 in that it deals not only with the private but also with the public aspect of knowledge capital. Throughout both sections the implications of introducing uncertainty for the model are discussed. Section 2.5 concludes.

2.2. Uncertainty introduced

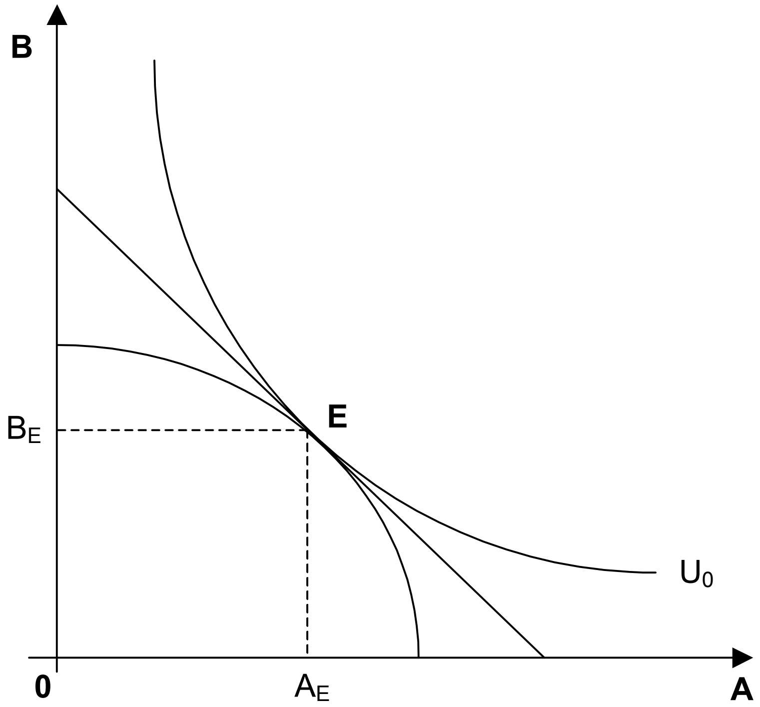
In the daily life of people, uncertainty plays an important role. The fact that people insure themselves for example has to do with guarding oneself for possible future injuries or accidents that cannot be predicted with certainty *ex ante*. The way a person or the economics profession deals with uncertainty has great effects on both the everyday world and (therefore) needs to be explained by and incorporated in economic theories and analyses.

2.2.1. Uncertainty in an economy

In economics many theories and models assume uncertainty away, ignoring the large consequences that follow from this restriction. It is convenient and necessary for economic analysis to be able to draw certain conclusions from a model or a situation. Take for example basic economic theory: very often it is stated that economics is about the distribution of scarce resources. Figure 2.1 depicts the situation in which we have goods A and B.[6] It is shown that in this case, A and B are both being produced because consumer preferences are tangent to the production possibility frontier in point E, a point in which quantities A_E and B_E are being produced. In this case it is assumed that all goods are present in an economy with only distributional problems left to solve.

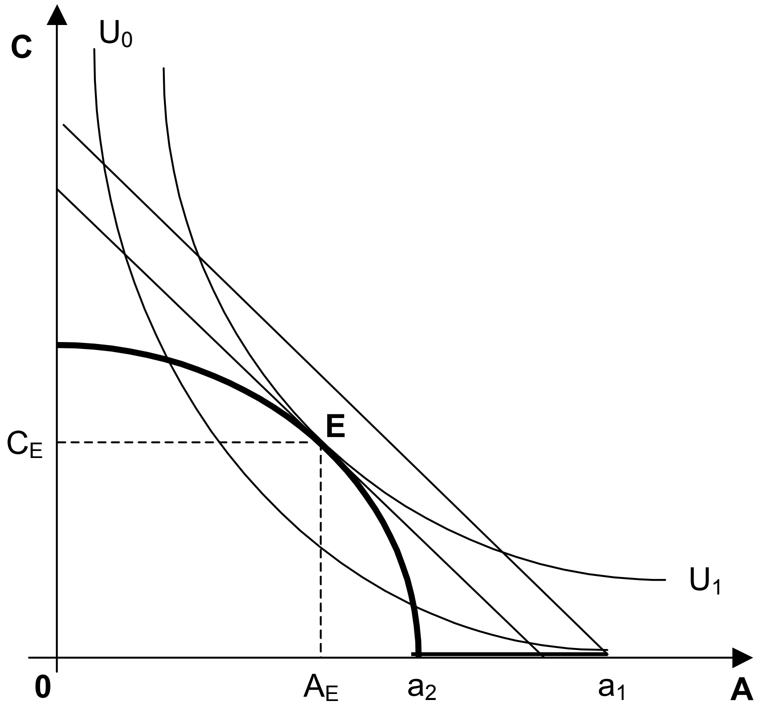
[6] This analysis follows Romer (1994).

Figure 2.1: Production and consumption equilibrium



However, it is also possible to imagine a valuable good C that has not yet been introduced; it still has to be invented. In order to invent this good C, fixed initial costs need to be made. Let's assume that this can be done at fixed cost (a_1-a_2). Figure 2.2 depicts the already existing good A and the good-to-be C. Will good C be introduced in the economy? The answer depends on two factors. First of all, the inventor has to be able to appropriate the resulting benefits from the invention in order to recuperate the fixed costs made. This means that under perfect competition, where supernormal profits are competed away instantly through entry by new firms, the initial investment cannot be earned back resulting in the failure to introduce new goods. Figure 2.2 illustrates this situation. If (a_1-a_2) cannot be recuperated, a firm under perfect competition prefers point a_1 to point E.

Figure 2.2: Production and consumption equilibrium with fixed costs



Secondly, the utility for the producer from introducing a variety has to be greater than the utility derived from not introducing the variety. If the first condition is met, the answer whether good C will be introduced is 'yes' in the case of figure 2.3, because $U_1>U_0$, but 'it depends' in general. Recall that in figure 2.1 the problem was to decide between different quantities of existing goods. Figure 2.3 poses a far more important and far more common problem to economic theory: the decision whether each potential good (represented by good C in this example) is worth the cost it takes to bring it into existence. In figure 2.3 good C will be introduced because the expected worth of good C is larger than the expected inventory costs shown by an increase in utility for the representative agent in this economy from U_0 to U_1 (and assuming the fixed costs can be recuperated by the inventing firm). However, if for another good D very large expenses have to be made, the expected costs may very well exceed the expected future benefits, resulting in a decrease in utility for the representative agent in this economy. The latter example is shown in figure 2.4.

Figure 2.3: Costs of introducing goods are lower than expected profits

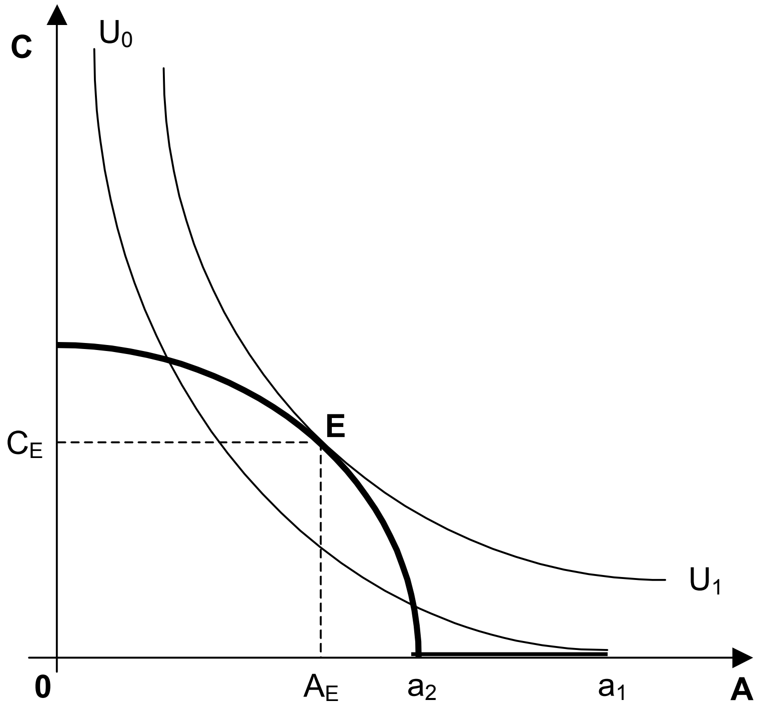
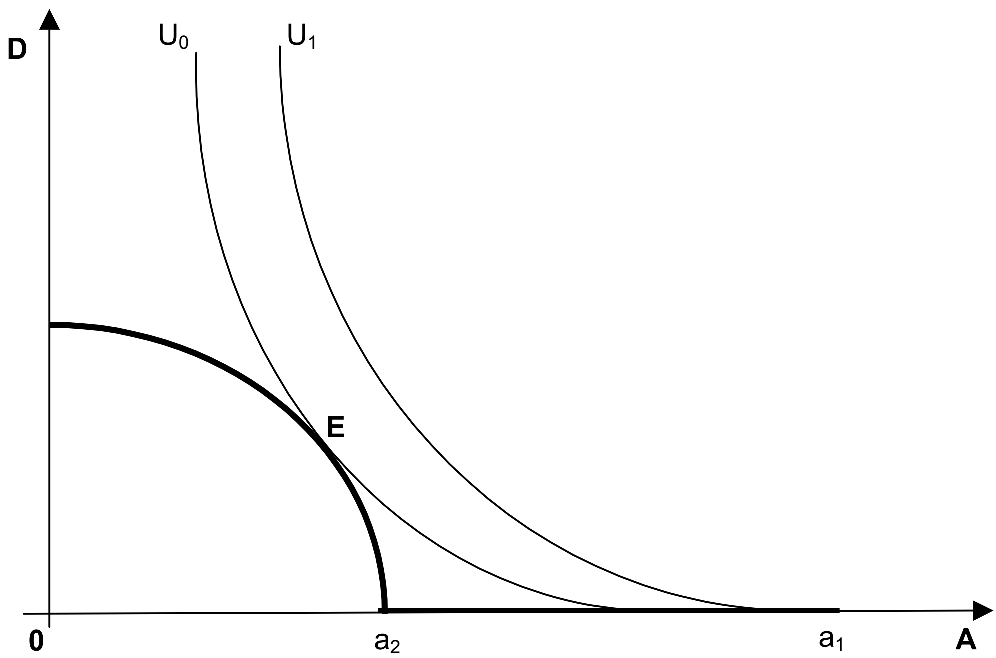


Figure 2.4: Costs of introducing goods are higher than expected profits



Romer (1994) gives a lengthy presentation on the so-called principle of plenitude (Lovejoy, 1933; Warsh, 1984) and argues that it does not hold.[7] To put it in Romer's words: *'To an economist, it [the principle of plenitude] means that we can always assume that we are in the interior of goods space. […] When it is applied in a specific scientific context … it is now obvious that the principle of plenitude is not just false; it is wildly misleading. […] Scientifically, a far better guiding principle would [be] that of sparsity: only a vanishingly small fraction of all conceivable entities can actually exist in the physical world.'*

If we acknowledge that we live in a world in which not every good has yet been invented, the problem we face consists of deciding whether each potential new good is worth the cost it takes to bring it into existence rather than the mere problem of deciding between different quantities of existing goods as basic micro-economics tells us. Thus we will have to look at the introduction of new goods. More specifically – like Grossman and Helpman (1991) have done – we will look at the introduction of new varieties in an economy.

2.2.2. The Poisson process and the exponential distribution

When looking at the introduction of potentially valuable varieties, one of the main problems becomes that the costs of invention are not known for certain *ex ante*. It can, for example, take a few weeks to invent a variety F in which case the costs *ex post* will be likely to be a lot lower than when the inventory process takes two years in order to invent variety G. As a consequence the product development costs of variety F might be lower than F's worth resulting in an introduction in the economy while the costs of variety G might exceed G's worth, making this specific type of variety unprofitable to introduce. But again: this knowledge is not available *ex ante*.

The process of product development takes place within every individual firm independently from other competing firms.[8] At the aggregate level, we can say that the longer resources are allocated to research, the greater the number of new inventions is likely to be. At the individual firm level, because of uncertainty, some

[7] The principle of plenitude states that every possible entity already exists or every conceptual possibility already has a realisation in the real world today.
[8] That is given certain specifications to be developed in the following two sections.

inventions might take weeks, others years, independently from the time that has passed since the previous invention.[9]

If we look at the Poisson postulates and compare them to the aspects of the product development process mentioned above, we notice several similarities.

1. First of all, the events – being inventions – that take place in intervals that do not overlap are independent of each other because independent firms cause them.
2. The probability an invention occurs in a small time interval is proportional to the size of this interval. This means that the larger the time interval, the larger the probability one or more inventions take place.
3. The probability is independent of the position of the interval mentioned under point 2 on the time axis. The time that has elapsed since the previous invention has no influence on the time until the next invention is to take place. This postulate is to be modified in a later stadium.
4. The probability two or more inventions take place in a very small interval is negligible compared to the probability one invention occurs.

The Poisson distribution seems to be the distribution that best suits the problem we would like to solve. The Poisson distribution is the probability distribution of the number of successes that occur in the chosen interval. The inventions take place incidentally but randomly within a certain time interval which is exactly what happens under a Poisson process that belongs to the Poisson distribution.

The Poisson distribution has the following form:

$$P(r) = \frac{\lambda^r}{r!} e^{-\lambda} \qquad \text{For r = 1, 2, 3, ...} \qquad (2.1)$$

[9] It can be argued here that the time it takes to invent a new variety is dependent on the time research has already been going on for. If knowledge is partly a public good, the larger the number of new varieties, the larger the pool of knowledge that is generally available and thus only the specific research has to be done.

Special properties of the Poisson distribution are that the expected value and variance are equal to each other and that the additivity property holds for this distribution.[10]

The stochastic variable, r, can theoretically, but also practically, take many possible values. We introduce a real stochastic variable, x, and a continuous function, f(x). The function f(x) does not represent a probability but merely a *'start to a probability'*.

Upon integrating the probability density function, f(x), we get the probability distribution function, F(x). This integral shows the *'probability of a specific event'* within a certain interval.

In order to be able to model waiting times, the exponential distribution, a special case of the family of gamma distributions will be used.[11] The probability density function of the exponential distribution looks as follows:

$$f(x) = \frac{1}{\beta} e^{-x/\beta} \qquad \text{With } x > 0 \,;\, \beta > 0 \qquad (2.2)$$

When we integrate, we get the probability distribution function F(x):

$$F(x) = \int_0^x \frac{1}{\beta} e^{-w/\beta} dw = \left[- e^{-w/\beta} \right]_0^x = 1 - e^{-x/\beta} \qquad (2.3)$$

The expectation of f(x) is E(x) = β and the variance V(x) = β². The waiting time is a continuous stochastic variable with the property of being memory-less. This property can be written as follows:

$$P\{X > s+t \mid X > t\} = P\{X > s\} \qquad \forall\, s, t \geq 0 \qquad (2.4)$$

That means that the time until the next event does not depend on how much time has already elapsed since the last one. In this case the time until a new invention is

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[10] See Pindyck and Rubinfeld (1998)

[11] The exponential distribution sets the value of α below equal to zero which simplifies the gamma distribution considerably. The general form (gamma distribution) then becomes the more specific form (exponential distribution):

$$f(x) = \frac{1}{\alpha!\,\beta^{\alpha+1}} x^{\alpha} e^{-x/\beta} \rightarrow f(x) = \frac{1}{\beta} e^{-x/\beta}$$

independent from how much time has passed since the last one. This meaning is exactly what is of vital importance for the exponential distribution: it can be seen as the probability distribution of the waiting time between two events under a Poisson process. To show this take a Poisson process in which within one hour, on average λ events occur. Then in a time interval *h*, on average *h*λ events take place. We take *h* sufficiently small in order to satisfy the fourth Poisson postulate. According to the Poisson distribution, the following probabilities can be calculated:

the probability 0 events occur in *h* is: $P(0) = e^{-\lambda h}$

the probability 1 event occurs in *h* is: $P(1) = \lambda e^{-\lambda h}$

The probability of waiting *r* time intervals of length *h* between the occurrance of two subsequent events is equal to the probability that in the r^{th} interval an event takes place and in the preceding (*r-1*) events no event has taken place.

This can be written down as follows:

$$P(r) = \left(e^{-\lambda h}\right)^{r-1} \lambda h e^{-\lambda h} = \lambda h e^{-\lambda h r} \qquad (2.5)$$

But this is the probability belonging to a waiting time of *r* time intervals of length *h*. Strictly speaking we now have a discrete probability distribution with a large number of possible values for *r*. By going to a continuous probability density function, we replace the discrete variable *r* by the continuous stochastic variable *w*. We can write (2.5) as:

$$f(w) = \lambda h e^{-\lambda h w} \qquad w>0 \qquad (2.6)$$

In order to return to the original time interval-size, i.e. the time interval in which on average λ events based on the Poisson process take place instead of the used size *h*, we apply a scale transformation. We get the continuous stochastic variable *x* in the following probability density function:

$$f(x) = \lambda e^{-\lambda x} \qquad (2.7)$$

by taking $x = hw$ and $dx = h\ dw$.

In this section, first we have established that the inventory process can best be characterised by a Poisson process with accompanying distribution. Second, the exponential distribution is shown to be the continuous probability distribution of the waiting time between two events under the aforementioned Poisson process.

2.3. The product-specific information model with uncertainty

We live in an economy in which producers direct resources into Research & Development in order to invent new varieties and spend money on producing the already discovered varieties. Consumers aim at maximising utility and consume all of the products produced in the economy.

A component of uncertainty is incorporated in the R&D process as producers do not *a priori* know the efforts and time necessary to invent a new variety of an existing product. The way knowledge capital is being treated has large implications for the model. In this section, non-rivalry and in most cases non-excludability – two distinct features of technology – will be ignored. In section 2.4 the specifications will be altered in order to incorporate these characteristics of knowledge capital.

2.3.1. The Model

Consumer behaviour

Consumer households aim at maximising utility over a given horizon with preferences as given by (2.8):

$$U(\underline{x}) = \left[\sum_{i=1}^{N} x(i)^{\alpha} \right]^{\frac{1}{\alpha}} \qquad \textit{with } 0 < \alpha < 1 \qquad (2.8)$$

$$\sum_{i=1}^{N} p(i)x(i) = I \qquad (2.9)$$

The index vector $U(\underline{x})$ in (2.8) shows the household's taste for diversity in consumption and $x(i)$ denotes the consumption of brand i. From the used specifications a liking for an increasing diversity in consumption follows because new goods are not perfect substitutes for old goods. The elasticity of substitution between two products is $\varepsilon = \frac{1}{1-\alpha} > 1$. The parameter α characterises the different tastes for variety. Equation (2.9) represents the consumer's budget constraint. Using (2.8) and (2.9) and Lagrange optimization, we calculate the demand for *x(i)*:

$$\text{Max L} = \left[\sum_{i=1}^{N} x(i)^{\alpha}\right]^{\frac{1}{\alpha}} + \lambda\left[I - \sum_{i=1}^{N} p(i)x(i)\right]$$

$$x(i) = \frac{Ip(i)^{-\varepsilon}}{\sum_{j=1}^{N} p(j)^{1-\varepsilon}} \tag{2.10}$$

An important consequence of the used specifications in (2.8) is that – if we view equation (2.8) as a production function as suggested by Ethier (1982a), productivity rises with the number of varieties or in other words: total factor productivity rises with the number of varieties. $U(\underline{x})$ can be viewed as a quantity of the same type of final goods and $x(i)$ represents the input of intermediate good or service i into the final good. If we assume a symmetric equilibrium $x(i) = x$ and all inputs have the same price. The summation can be simplified as follows:

$$U(\underline{x}) = \left[\sum_{i=1}^{N} x(i)^{\alpha}\right]^{\frac{1}{\alpha}} = \left[Nx^{\alpha}\right]^{\frac{1}{\alpha}} = N^{\left(\frac{1}{\alpha}\right)}x \tag{2.11}$$

For all inputs x of the same size the same quantity of resources is needed. $X = Nx$ therefore measures the total amount of resources used in final goods. Total factor productivity (the final output per unit of input) becomes:

$$\frac{U(\underline{x})}{X} = \frac{N^{\left(\frac{1}{\alpha}\right)}x}{X} = \frac{N^{\left(\frac{1}{\alpha}\right)}x}{Nx} = N^{\frac{(1-\alpha)}{\alpha}} \tag{2.12}$$

With $0 < \alpha < 1$ (necessary because of the mark-up pricing due to monopoly power) the first derivative of $\frac{U(\underline{x})}{X}$ turns out to be positive:

$$\frac{d\left(\frac{U(\underline{x})}{X}\right)}{dN} = \frac{d(N^{\frac{(1-\alpha)}{\alpha}})}{dN} = \frac{(1-\alpha)}{\alpha} N^{\frac{(1-2\alpha)}{\alpha}} > 0 \tag{2.13}$$

This means that the productivity of a given amount of resources increases with the number of available varieties.

Producer behaviour

As indicated above, producers take part in two activities. First, they manufacture the products and varieties that have been developed in the past. Second, producers spend resources on R&D in order to invent new types of varieties. We assume that each variety is produced by a single atomistic firm.[12] For simplicity, we assume labour to be the single factor of production. This means we have a total amount of labour, L, part of which is used in R&D (L_R) and part of which is used to produce the previously developed varieties (L_P):

$$L = L_P + L_R \tag{2.14}$$

- *Manufacturing the existing varieties*

We assume that all known differentiated products are manufactured subject to a common constant-returns-to-scale technology. It takes L_P labour to produce 1 unit of good *x(i)*. The profit and price made by the supplier of variety *i* equals:

[12] This assumption can be justified in two ways. First, one could argue that inventions are protected by infinitely lived patents given out by the government. Second, if imitation costs money and firms engage in ex post price competition, the imitator would earn no profits in Bertrand competition and consequently would be unable to recuperate the costs made, therefore making imitation financially unattractive.

$$\pi(i) = p(i)x(i) - wx(i) \tag{2.15}$$

We have already calculated the elasticity of substitution to be equal to $\varepsilon = \frac{1}{1-\alpha}$. For each variety we are dealing with a monopolistic firm that under constant returns to scale with *L* as the single factor of production sets the price as follows:

$$p(i)\left(1 - \frac{1}{\varepsilon}\right) = MC \tag{2.16}$$

When we set *MC*=*w*, *p(i)* simplifies to[13]:

$$p(i) = \frac{w}{\alpha} \tag{2.17}$$

Aggregate production depends on the part of the labour force devoted to production, L_P. Total production of all existing varieties is:

$$L_P = Nx = I \tag{2.18}$$

In the momentary equilibrium, all varieties are priced the same at p. We will use the normalisation p=1:

$$p = \frac{w}{\alpha} = 1 \tag{2.19}$$

From the above equations it follows that the share α of total income goes to the workers as a reward while the share *(1-α)* goes to the shareholders as profit. The result in total profit π (equation 2.20) and reward to the workers (equation 2.21) is:

[13] This can be shown straightforwardly as follows:

$$P\left[1 - \left(\frac{1}{\varepsilon}\right)\right] = MC \Leftrightarrow P\left[1 - \frac{1}{\left(\frac{1}{1-\alpha}\right)}\right] = w \Leftrightarrow P(1-(1-\alpha)) = w \Leftrightarrow \alpha P = w \Leftrightarrow P = \frac{w}{\alpha}$$

$$\pi = \frac{(1-\alpha)L_P}{N} \tag{2.20}$$

The reward to the workers can be calculated as follows:

$$Reward\ workers = wx = \frac{wx\alpha}{\alpha} = \alpha\frac{L_P}{N} = \alpha\frac{I}{N}$$

$$Reward\ workers = \frac{\alpha L_P}{N} \tag{2.21}$$

Equation (2.20) can identically be shown by substituting (2.10) into (2.15).[14]

As mentioned above, the profits from equation (2.20) go to the shareholders of a firm (for example in the form of dividends) as competition among manufacturers ensures that the rental rate for capital matches the value marginal product of a machine. Together with possible capital gains or losses the discounted stream of profits constitutes the value of the firm. Consumers will be willing to hold claims to the existing units of capital only if the return of these units is at least equal to the return to a perfectly substitutable asset, like a consumption loan. In a perfect-foresight equilibrium the sum of the profit plus the capital gains/losses must equal the yield on a riskless loan. Thus equilibrium in the capital market requires:

$$\pi + \dot{v} = rv \tag{2.22}$$

This equation represents a 'no-arbitrage condition' on the capital market. If the stock markets correctly price the firms, that is, if the stock market value of a firm equals the present discounted value of its profit stream, we can write the value of any firm as follows:

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14 $$\pi = p(i)x(i) - wx(i) = \frac{p(i)Ip(i)^{-\varepsilon}}{\sum_{i=1}^{N} p(i)^{1-\varepsilon}} - \frac{wIp(i)^{-\varepsilon}}{\sum_{i=1}^{N} p(i)^{1-\varepsilon}} = Ip^{-\varepsilon}N^{-1}p^{\varepsilon-1} - wIp^{-\varepsilon}N^{-1}p^{\varepsilon-1} =$$

$$\pi = IN^{-1} - wIN^{-1}p^{-1} = IN^{-1} - wIN^{-1}\frac{\alpha}{w} = \frac{(1-\alpha)I}{N}$$

$$v(t) = \int_t^{\infty} e^{-\rho(\tau - t)} \pi(\tau) d\tau \qquad (2.23)$$

When we combine equations (2.23) and (2.20) we get (2.24) with $N(\tau) = N(t)e^{-gt}$.

$$v(t) = \int_t^{\infty} e^{-\rho(\tau - t)} \frac{(1-\alpha)L_P}{N(\tau)} d\tau = \frac{1}{\rho + g} \frac{(1-\alpha)L_P}{N(t)} \qquad (2.24)$$

Here *g* stands for the rate of innovation in the economy which we assume constant for the moment:

$$g \equiv \frac{\dot{N}}{N} \geq 0 \qquad \textit{with g being a constant} \qquad (2.25)$$

Equation (2.25) shows the value *v(t)* of a firm given success in the research sector. It is important to note that this firm value is conditional upon having success. The value of the firm is inversely proportional to *N(t),* indicating that the larger *N(t)*, the lower the firms expected value *v(t)*. Furthermore from (2.25) also follows that the larger the share of the labour force working in the manufacturing sector of the representative firm, the higher the expected firm value which can be expected with (2.19) in mind.

- *Inventing new varieties*

Every individual firm spends money and resources on research and development in order to invent new varieties that thereafter start to generate a continuous profit stream. We assume that a firm spends resources on R&D with the possibility of stopping instantly if necessary. Also we take the resource of product development to be 'large' in the order of magnitude to the value of the stream of profits that the entrepreneur appropriates. L_R is the amount of labour available for the R&D sector. Intuitively, we expect the number of varieties to go up faster, the larger L_R. If λ is the probability for successfully inventing a new variety (we see in a moment), using the law of large numbers, we can write L_R as follows:

$E(\dot{N})=$ probability of success x the resources in the R&D sector $\Leftrightarrow$

$$E(\dot{N})=\lambda\cdot L_R \qquad \Leftrightarrow$$

$$L_R=\frac{\dot{N}}{\lambda}=\frac{gN}{\lambda} \tag{2.26}$$

As shown in section 2.2, if the invention costs exceed the future discounted revenues, a good-to-be will not be introduced. This means that for every individual firm the expected revenues should equal the costs and thereabove be fully appropriable. If a firm can stop the inventory process at all times, it will stop researching a certain variety as soon as the costs exceed the future expected revenues:

Expected revenues < *Costs of invention*

The expected revenues can be found by multiplying the conditional value of the firm by the chance of success, P(success). The probability for success, λ, is given by the exponential distribution discussed in section 2.2.

The probability λ is independent from the number of varieties that already exist, because in this section we still ignore the public character of knowledge. This means that spillovers to other firms do not occur because all generated knowledge is appropriated by the inventing firm.

In order to invent a new variety a firm has to direct labour to the R&D sector, L_R. For a time interval of length dt a firm has an expected production $dn=\lambda L_R dt$ new products where λ is the probability a new variety will be invented. The total costs of this research amount to $wdt=\alpha dt$ with total value for the firm amounting to $v(\lambda L_R)dt$.[15]

$$Cost=w=\alpha \tag{2.27}$$

[15] From w=α following from (2.19).

To maximise the value of the firm, L_R will be chosen as large as possible if $\lambda v > w$ and equal to zero if $\lambda v < w$. In general equilibrium the expected value cannot be greater than the wage rate since that implies an infinite demand for labour by the research sector. The other case, in which $\lambda v < w$, is an equilibrium in which no R&D takes place at all. The combination of free entry and the constant returns to scale production function prevents the research sector from earning excess returns. Therefore we get the following equilibrium condition:

$$w \geq v\lambda \qquad \textit{with equality when } \dot{N} > 0 \tag{2.28}$$

Once we know that λ is the probability the research and development sector will successfully invent a new variety, we can calculate the expected revenues from the equations (2.24) and (2.28):

$$\textit{Expected revenue} = \frac{\lambda}{\rho + g} \frac{(1-\alpha)L_P}{N(t)} \tag{2.29}$$

If in equilibrium expected revenues equal the costs of invention, with (2.27), (2.28) and (2.29) we get the following equation:

$$\frac{(1-\alpha)\lambda L_P}{(\rho + g)N(t)} = \alpha \tag{2.30}$$

Finally, the labour market has to be in equilibrium. The total population provides the factor of production labour, *L*. According to (2.14), labour will be directed toward both the manufacturing and research sectors. If the flow of new varieties is $\dot{N}$, total employment in the R&D sector is equal to $L_R = \frac{\dot{N}}{\lambda}$ (see equation (2.26)). Concerning the manufacturing sector, we know that the price of a representative variety is p from (2.17). An aggregate spending level, *I*, implies that each firm sells I / Np units. Aggregate sales by N manufacturers therefore demand I / p units of labour. Thus labour market equilibrium requires:

$$L = \frac{\dot{N}}{\lambda} + \frac{I}{p} \tag{2.31}$$

Finally, since employment in any activity cannot possibly be negative, the equilibrium price, p, must satisfy:

$$p \geq \frac{I}{L} \tag{2.32}$$

2.3.2. Dynamic analysis

The inverse relationship between profits and the number of varieties (see (2.20)) shows that profits are lower the greater the number of varieties. If this number is very large, profits might be so low that product development might not occur at all. In other words, depending on the starting point, it could be possible that there will be no R&D taking place at all.

These two intuitive propositions can be verified. If *N(t)* is very large, intuition tells us that no R&D takes place. We know that the change in *N* over time equals the probability of success times the amount of labour directed into the R&D sector. This was shown in equation (2.26). Using (2.14), (2.28), (2.30) and (2.26), we get the following expression for *g*:

$$g = \frac{(1-\alpha)\lambda L}{N(t)} - \alpha\rho \tag{2.33}$$

First of all, (2.33) shows that the assumption made in (2.25), namely g has a constant growth rate, is violated for all but one value of g. The only value for g satisfying (2.28) irrespective of any value for *N(t)* is when *g=0*. For all the other values, *g* changes as soon as *N(t)* changes and is therefore not constant which makes it impossible to integrate the way it was done in (2.28).

Secondly (2.33) shows that *g* decreases with increases in *N(t)*. Therefore if *N(t)* grows very large, growth eventually comes to a halt.

If we equate (2.33) to zero, that means $g \equiv \frac{\dot{N}}{N} = 0$, the assumption made in (2.28) is not violated. The rate of innovation is equal to zero only if no resources are devoted to R&D which means that the entire labour force must be employed in producing the already existing varieties. Therefore, the value of $N(t)$ with $g = 0$ in (2.33) is consistent with the free-entry condition (2.28) if and only if $N(t) \geq \overline{N}$. We calculate $\overline{N}$ as follows:

$$g = \frac{(1-\alpha)\lambda L}{N(t)} - \alpha\rho = 0 \Leftrightarrow N(t) = \overline{N}$$

$$\overline{N} = \frac{(1-\alpha)\lambda L}{\alpha\rho} \tag{2.34}$$

So if the initial number of varieties exceeds $\overline{N}$, there exists an equilibrium with no product development: the resources spent on R&D are equal to zero, the flow of new varieties is equal to zero and the growth rate of innovation in the economy is zero. From (2.35) it also follows that the greater the probability of successfully inventing a new variety, the greater $\overline{N}$.

With total L fixed, the introduction of new varieties causes firms to compete ever fiercer for labour. Because equilibrium mark-ups do not vary with the number of varieties (see equation (2.19), sales per variety must decline. Because of this decline, profits also decline over time. Eventually, inventions drive the profit rate down to the level of the discount rate at which point it is no longer attractive for individual firms to engage in research and development. In other words: for R&D to be profitable the reward for successful research must be sufficiently high; that is for $\dot{N} > 0$, $v > \overline{v}$. The value of $\overline{v}$ can be derived mathematically from the free-entry condition (2.28), the pricing equation (2.19) and the constraint (2.32) that employment in R&D be non-negative:

$$\left.\begin{array}{l} \left.\begin{array}{l} w = v\lambda \\ p = \dfrac{w}{\alpha} \end{array}\right\} \alpha p = v\lambda \\ p \geq \dfrac{I}{L} \end{array}\right\} \alpha \frac{I}{L} = \bar{v}\lambda \Leftrightarrow \bar{v} = \frac{\alpha I}{\lambda L} \tag{2.35}$$

So if $v \leq \bar{v}$, there will be no R&D and therefore no increase in the number of varieties over time ($\dot{N} = 0$). If $v > \bar{v}$, resources will be allocated to the R&D sector in order to invent new varieties and therefore the number of varieties will increase over time ($\dot{N} > 0$). From the free-entry equation (2.28), the pricing equation (2.19) and the resource constraint (2.31) we can calculate the path of $\dot{N}$ when $v > \bar{v}$:

$$\left.\begin{array}{l} \left.\begin{array}{l} \dfrac{\dot{N}}{\lambda} + \dfrac{I}{p} = L \\ p = \dfrac{w}{\alpha} \end{array}\right\} \dot{N} = \lambda L - \dfrac{\alpha I \lambda}{w} \\ w = v\lambda \end{array}\right\} \dot{N} = \lambda L - \frac{\alpha I}{v} \tag{2.36}$$

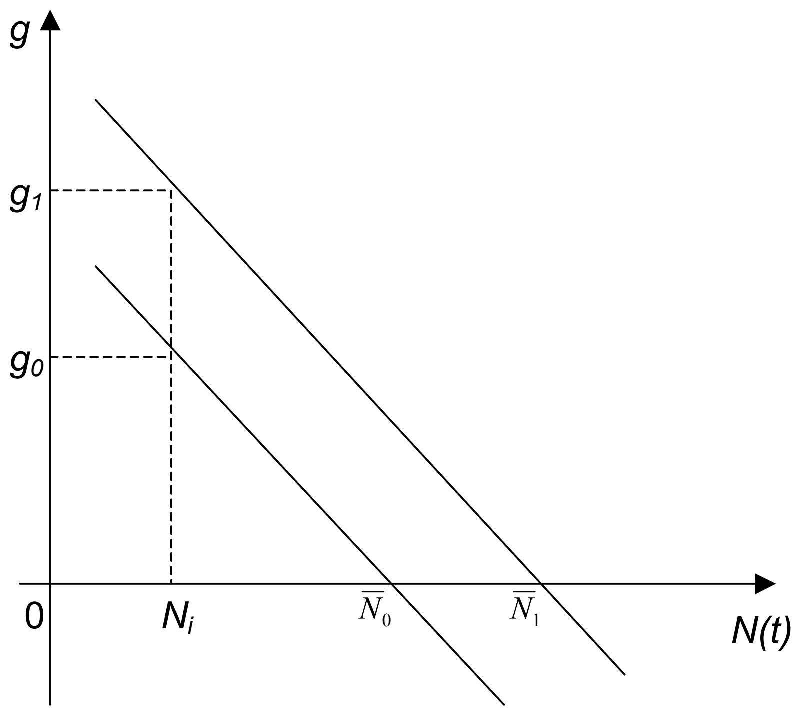
Depending on the value for v with respect to $\bar{v}$, we can now write an expression for the way $\dot{N}$ evolves over time:

$$\dot{N} = \begin{cases} \lambda L - \dfrac{\alpha I}{v} & for : v > \bar{v} \\ 0 & for : v \leq \bar{v} \end{cases} \tag{2.37}$$

The incorporated uncertainty in this model has the effect of shifting the $v = \bar{v}$ line down. We have seen from (2.35) that if λ increases, $\bar{v}$ will decrease. This can be understood intuitively because the greater λ, the greater the expected value of the representative firm. With costs remaining the same, the higher initial value of the firm has to decrease more in order to break even.

An increase in λ has a proportional effect in the same direction on $\overline{N}$ (see equation (2.34)). This effect can be understood in two ways. First, if λ increases, the probability a new variety will be invented increases. If the probability of inventing new varieties increases at the micro-level, there will be a higher initial rate of innovation at macro-level. Therefore growth rate, *g*, will be higher initially (g_1 instead of g_0 at N_i) and consequently take longer to diminish to zero resulting in a larger value for $\overline{N}$ ($\overline{N}_1$ instead of $\overline{N}_0$).[16] Figure 2.5 shows the situation with the initial $\lambda=\lambda_0$ and the new $\lambda=\lambda_1$ where $\lambda_1>\lambda_0$.

Figure 2.5: The model with two values for λ, with $\lambda_1>\lambda_0$.



In this model the effects of uncertainty boil down to shifts in the $v=\overline{v}$ and $N=\overline{N}$ curves thereby shifting any stationary equilibrium. With lim λ→1, the model turns out to be a model set in a deterministic environment as developed similarly by Grossman and Helpman (1991). An increase in λ might prolong growth for a short while, but the important thing to notice from the product-specific model used in this section is that for all stationary solutions of the model, the innovation rates are equal to zero. So the important conclusion that can be drawn from the section 2.3 model is that the growth

[16] The implicit assumption here is that the growth diminishing process is the same regardless the initial values of *g*. In figure 2.5, for illustrative purposes, we have drawn a linear decrease in *g* toward *g=0*.

rate of innovation will eventually become zero. This happens because the costs of inventing new varieties do not decrease over time while the expected profit streams do. The costs of inventing new varieties do not decrease over time because the specification in the model that no knowledge-spillovers can occur prevents firms from inventing ever more cheaply despite the fact more and more technologies and different varieties become known. In the next section, we will alter the specification in the model in order to incorporate the public character of knowledge.

2.4. The general information model with uncertainty

In the previous section the product-specific information model leads to the conclusion that the innovation rate eventually comes to a halt. Because of the private character of knowledge capital firms are unable to benefit from the knowledge generated by competitors. Therefore, despite the increasing number of different varieties, the costs of inventing a new variety do not decrease. With a limited market and an increasing number of different varieties, profit rates go down on products that cost the same to develop. Growth is bound to stop.

In this section, an important characteristic of knowledge will be introduced: its public aspect. The assumption that knowledge is merely a private good seems too stringent in real life: patents, though intentionally there to protect knowledge from dispersing, are not perfect, competitors can analyze the newest products in order to find the innovative aspect or some uses of invented products might simply not be recognized by the original inventors.

The Model

Romer (1990) distinguishes between two types of products resulting from R&D activities. First of all, as in section 2.3, R&D boosts product development and therefore the number of new varieties. Second, each research project generates knowledge capital that cannot be appropriated by the inventors. This product of R&D contributes to a large pool of general knowledge, $K_R(t)$ and cannot be influenced by individual firms nor be excluded from public use. Every time a new product is developed, part of this knowledge flows to the general knowledge capital which increases. Intuitively, we can see that the larger the number of different varieties, the larger also the general pool of knowledge capital must be. Because this general knowledge is freely available to every individual firm, when the number of different varieties increases, more and more knowledge can be used without having to pay for it, therefore making product development less costly as time goes by. So not only the labour employed in the R&D sector determines the flow of new varieties, also the general knowledge capital, $K_R(t)$, has to be taken into account.

The incorporation of the public aspect of knowledge capital is captured by a slight alteration of the model developed in the previous section.

Equation (2.38), the section 2.4 equivalent of equation (2.28), shows the relationship between the flow of new varieties and the share of the labour force employed in the R&D sector:

$$L_R = \frac{\dot{N}}{\lambda K_R} \tag{2.38}$$

From the equation it follows that *'advancements in the fields of applied science and engineering reduce the labour requirements for designing new products'* (Grossman and Helpman, 1991, p. 58).

The probability of successfully inventing a new variety is not only dependent on λ anymore, but also on $K_R(t)$ because of the general knowledge capital accumulation. Now that we have identified a second – and public - component to the process of knowledge creation, it is important to specify a link between this process and the accumulation of general knowledge capital. Mansfield (1985) and Adams (1990) use lags between the end of the research process and the dispersion of knowledge into the 'pool'. Rather than investigating this link in detail, we would like to focus on the comparison between sections 2.3 and 2.4 as we go along. We follow Grossman and Helpman (1991) by assuming, by appropriate setting of the units, that the knowledge capital is directly proportional to the cumulative R&D-level:

$$K_R = N \tag{2.39}$$

Taking this into consideration, equation (2.38) can also be derived as follows:

$E(\dot{N})$ = probability of success x the resources in the R&D sector

$E(\dot{N}) = \lambda N(t) \bullet L_R$

$$L_R = \frac{\dot{N}}{\lambda N(t)} \tag{2.40}$$

With the new specification in the R&D market given in (2.38) and the assumed proportionality from (2.39), we can write the labour market clearing condition as follows:

$$L = \frac{\dot{N}}{\lambda N} + \frac{I}{p} \tag{2.41}$$

Costs are also influenced by the existence of a pool for general knowledge capital: the greater this general knowledge, the smaller the costs. This is shown in equation (2.42) by using equation (2.41):

$$Costs = \frac{w}{N} = \frac{\alpha}{N} \tag{2.42}$$

As in the previous section, we can determine the free-entry condition (2.43):

$$\frac{w}{\lambda N} \geq v \qquad \textit{with equality whenever } \dot{N} > 0 \tag{2.43}$$

The value of the firm is not influenced by the pool of general knowledge capital as the value depends on the present discounted value of the firm's profit stream, therefore, equation (2.44) is equal to equation (2.25):

$$v(t) = \int_t^{\infty} e^{-\rho(\tau - t)} \frac{(1-\alpha)L_P}{N(\tau)} d\tau = \frac{1}{\rho + g} \frac{(1-\alpha)L_P}{N(t)} \tag{2.44}$$

Again we have made the assumption that there is a constant growth rate of innovation, *g*:

$$g \equiv \frac{\dot{N}}{N} \geq 0 \qquad \textit{with g constant} \tag{2.45}$$

Solving (2.44) with (2.43) and (2.45) yields the following expression:

$$\frac{\lambda N(t)}{\rho + g} \frac{(1-\alpha)L_P}{N(t)} = \frac{(1-\alpha)\lambda L_P}{\rho + g} = w = \alpha \tag{2.46}$$

This time, unlike with equation (2.29), we can see that *N(t)* falls out of the equation. Therefore, as we will come to see in a moment, when we solve for *g*, *N(t)* will have no effects. This is a major difference with the model in the previous section, where growth diminished because the number of varieties increased all the time, therefore lowering profits right until the cost level of research and development.

The inverse relationship between profits and the number of varieties (from equation (2.20)) shows that profits decrease with the number of varieties increasing. However, because of the existence of a pool of general knowledge, the costs of developing new varieties also fall with a greater number of varieties. The net effects on the growth rate *g* can be calculated by solving for *g* from (2.46):

$$g = (1-\alpha)\lambda L - \alpha\rho \tag{2.47}$$

From (2.47) it is straightforward to see that the number of different varieties has no effect on *g*. Equation (2.47) is similar to equation (2.34) used in Grossman and Helpman (1991, p. 61) with $\lambda = \frac{1}{\alpha}$. The rate of innovation depends on the parameters of the model only. Therefore, this time, the assumption that *g* is a constant growth rate is correct with the following specifications determining whether that be greater or smaller than zero:

$$g: \begin{cases} g > 0 & iff \quad (1-\alpha)\lambda L > \alpha\rho \\ \\ g = 0 & iff \quad (1-\alpha)\lambda L < \alpha\rho \end{cases} \qquad (2.48)$$

From the labour market clearing condition (2.41), the free-entry condition (2.43), the pricing equation, $p = \frac{w}{\alpha}$ and (2.44) we can derive the path for the rate of growth of the number of varieties:

$$\left.\begin{array}{l} \left.\begin{array}{l} \frac{\dot{N}}{\lambda N} + \frac{I}{p} = L \\ p = \frac{w}{\alpha} \end{array}\right\} \frac{\dot{N}}{N} = \lambda L - \frac{\alpha I \lambda}{w} \\ v = \frac{(1-\alpha)I}{(\rho + g)N(t)} \\ w = v\lambda N \end{array}\right\} \frac{\dot{N}}{N} = \lambda L - \frac{\alpha I}{vN} = (1-\alpha)\lambda L - \alpha\rho \qquad (2.49)$$

Equation (2.49) is equal to the derived equation (2.47) with the greater the probability for success, the greater the rate of growth of new varieties. According to (2.49) a change in the value of the firms has no effect on the rate of innovation. We can now write an expression for the growth rate (2.49) given the value of the parameters from (2.48):

$$g \equiv \frac{\dot{N}}{N} = \begin{cases} (1-\alpha)\lambda L - \alpha\rho \\ \\ 0 \end{cases} \qquad (2.50)$$

Next we substitute the profit equation into the no-arbitrage condition with $\rho = r(t)$.[17] We then get a relationship between the change in the value of a firm over time and the present value of an invention and the number of available brands as presented in equation (2.51):

$$\left.\begin{array}{l} \left.\begin{array}{l} \pi + \dot{v} = rv \\ \rho = r \end{array}\right\} \dot{v} = \rho v - \pi \\ \pi = \dfrac{(1-\alpha)L_P}{N} \end{array}\right\} \dot{v} = \rho v - \frac{(1-\alpha)L_P}{N} \tag{2.51}$$

Unlike in the previous section, because of a constant growth rate, *g*, *I* is also a constant. Dynamic equilibrium now boils down to the two equations (2.50) and (2.51).[18]

In order to simplify matters further, we can use $V = \frac{1}{Nv}$ to represent the inverse of the total equity value in the economy. This allows us to create a phase diagram. From the definition $V = \frac{1}{Nv}$ we get the following expression in relative changes:

$$\frac{\dot{V}}{V} = -g - \frac{\dot{v}}{v} \tag{2.52}$$

Combining (2.52) with (2.50) gives us one single differential equation which we can solve for $\dot{V} = 0$:

$$\frac{\dot{V}}{V} = (1-\alpha)V - g - \rho \tag{2.53}$$

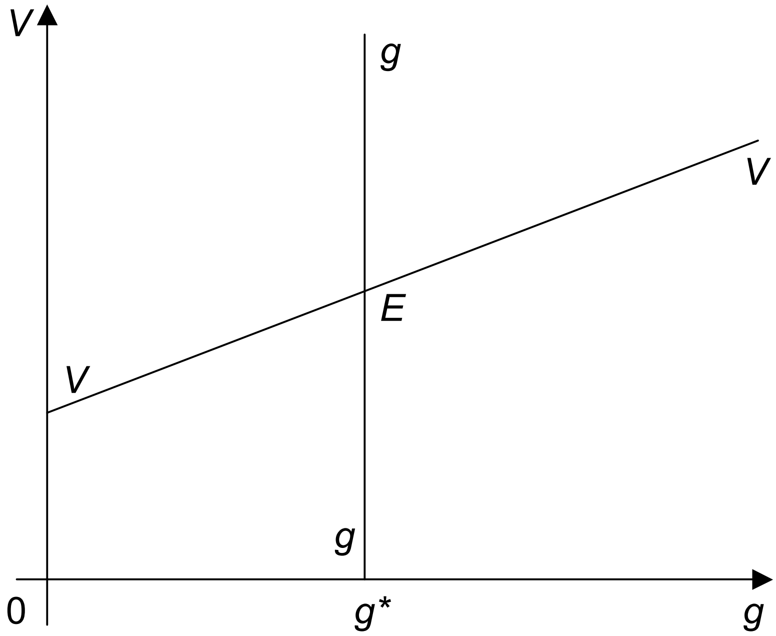
---

[17] $\rho = r(t)$ because we use the normalisation *p=1*. If the prices are fixed, expenditure can only change because of a change in the division of labour between the production sector and the R&D sector. As we find ourselves on an equilibrium path with a constant growth rate, the relative factors will not change and neither will total income, *I*. This gives: $\frac{\dot{E}}{E} = \rho - r(t) = 0 \Leftrightarrow \rho = r(t)$

[18] The only way to set *I* = constant in the previous section is to set expenditure equal to 1 (see Grossman and Helpman (1991)). Because we took *p=1*, *I* was not constant as long as the growth rate *g* was not a constant.

Now we can set up a phase diagram. Figure 2.6 shows the *VV*-line (equation (2.53)) and the *gg*-line (equation (2.50)). On the *VV*-line, $\dot{V} = 0$.

Figure 2.6: Equilibrium of VV- and gg-lines



The gg-curve:

The *gg*-curve shows the evolution of the rate of innovation in the economy. The slope of the *gg*-curve can be explained directly from equation (2.50). The rate of innovation, *g*, is dependent on the parameter values and with those constant, the growth will also be constant for any value *V*.

The VV-curve:

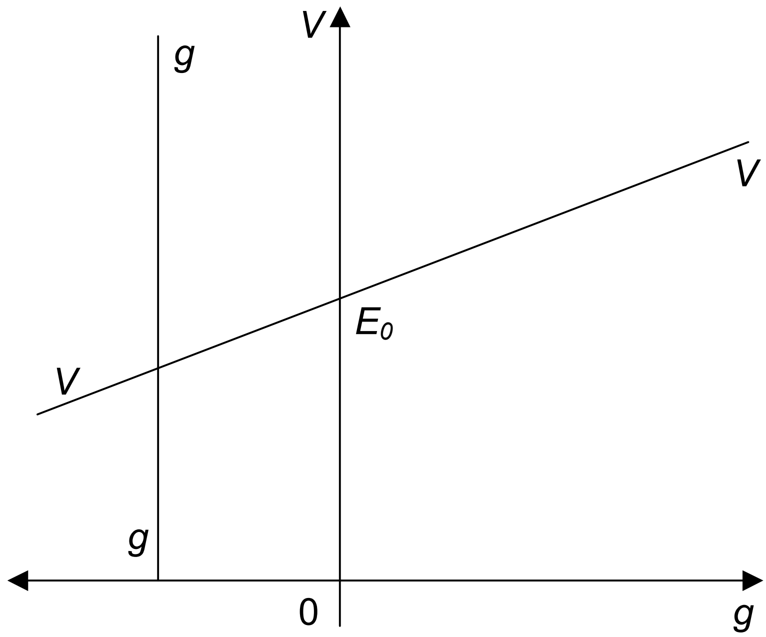
The *VV*-curve shows the loci with values for *V* and *g* implying that $\dot{V} = 0$; that is the rate of decline in the share price of the representative firm exactly matches the rate of new product development. Above the curve, the number of varieties grows less rapidly than the value of the firm and below the curve the opposite occurs.

At the equilibrium point *E*, *V* and *g* will not change anymore over time. In other words: at this point, the economy continues to grow with a constant growth rate g^* with a fixed division of labour between the production and R&D sectors.

However, the economy will only grow with g^* if point E is the immediate starting point. Any other starting point on the gg-line will lead to either an infinite or a zero value of the firm. The economy should therefore start at point E and remain there forever with a constant rate of innovation, g^* as shown by equations (2.47) and (2.49). The growth rate can be sustained because even though the returns of developing a new variety decrease, so do the costs of product development due to the general knowledge capital.

The equilibrium point E in figure 2.6 has been drawn on the condition that $(1-\alpha)\lambda L > \alpha\rho$. If this specification of the parameter values is violated, the equilibrium will generate a zero value for g in point E_0 and the intersection between the VV- and gg-curves will occur in the negative quadrant. This situation has been depicted in figure 2.7 below:

Figure 2.7: Intersection of VV- and gg-lines in the negative quadrant



Instead of a positive value for g, g^*, growth will equal zero. When we have a closer look at the parameters, we can conclude the following:

Growth will be greater than zero only if:

- the economy is sufficiently big: L is sufficiently large
- the people are patient enough: ρ is sufficiently small
- the probability for successfully inventing a new variety is sufficiently big: λ is large enough
- households sufficiently value variety in consumption: α is sufficiently small

The public character of knowledge has a lowering effect on the costs of product development. However, if the parameters explained above do not comply, this pool of general knowledge is not large enough to ensure continuous growth in the economy.
Contrary to the model in the previous section, the innovation rate can be sustained at a rate greater than zero. In this section, the public character of knowledge creates spill-over effects that prolong growth indefinitely given the correct specification of the model parameters. The introduction of uncertainty was also possible in this section like in the previous one. Despite the fact the mathematical alterations in the model developed by Grossman and Helpman (1991) were not too large, the interpretation is a new one. Instead of looking at labour productivity in a certain R&D sector, we look at the probability the R&D sector is successful in inventing a new variety thus changing the value of the firm and the growth rate depending on a value for λ. Because of the introduction of uncertainty, the model incorporates an important fact of life, thus showing a more realistic approach to every day situations concerning uncertain situations individual firms face.

2.5. Conclusions

Uncertainty has successfully been incorporated in the Grossman and Helpman (1991) endogenous growth model. The Poisson process with the exponential distribution as the waiting time between two discrete Poisson processes best fits the characteristics of the inventory process. We find that λ is the probability a firm successfully invents a new variety. In a deterministic world the problem a firm has to solve is to equate the costs of product development to the discounted revenues. If uncertainty is introduced however, the costs must equal the expected revenues, given the fact a new variety has been developed successfully, times the probability, λ, that a firm is successful.

In section 2.3, the rate of innovation in the model goes to zero in the long run, because we only look at knowledge capital as a private good. This can be seen as follows: in the production sector of the firm, workers that are paid certain wages, produce goods that are being sold. The production in the production sector goes partly to the workers in that sector in the form of wages and partly to operating profits. From these profits the wages of the workers in the R&D sector have to be paid. Only as long as the profits exceed the costs in the form of wages, the firm will continue R&D. A growth rate greater than zero cannot be sustained indefinitely. This is due to the fact that the marginal returns of a variety decrease while the costs of product development remain constant. The effect of uncertainty on the model in section 2.3 is that growth, if greater than zero initially, will come to a halt. An increase in λ might prolong growth for a short while, but the main conclusion from the section 2.3 product-specific model is that for all stationary solutions of the model, the innovation rates are equal to zero.

Section 2.4 looks at the same model but now with not one but two products resulting from R&D. The first product – with which we are familiar from section 2.3 – is the possible new invention. Second, with every invention, a part of the knowledge production is regarded as a public good. Since this part cannot be appropriated by the inventing firm, all other firms can benefit from this generated knowledge. A constant growth rate can this time be sustained because even though the returns of developing a new variety decrease (like in section 2.3), so do the costs of product development due to the existence of a pool of general knowledge capital. Whether this growth rate is greater than or equal to zero depends on certain parameter values used in the model, like the size of the economy, the discount factor and the household valuation of variety in consumption. Also λ, the probability for successfully inventing a new variety, is one of these parameters. The greater the value of λ, the greater the rate of innovation in the economy, ceteris paribus.

Chapter 3: Terms-of-trade uncertainty, Growth and the Endogeneity of Openness

"The best weapon of a dictatorship is secrecy, but the best weapon of a democracy should be the weapon of openness"

Niels Bohr, Physics Nobel Prize Laureate

3.1. Introduction

This research sheds new light on two important aspects in development economics. First, the theoretical aspects underpinning the relationship between fluctuations in (primary) commodity prices, the terms-of-trade and the lagging growth performance of many of the poorest developing countries. Second, the relationship between openness and growth.

The relationship between term-of-trade and output growth is an issue that has drawn a lot of attention, especially in empirical studies. This should not come as a surprise, since this relationship is a problem that – when answered and policy implications drawn – offers the potential to improve the welfare and quality of economic life in large parts of the world for many of the world's poorest through higher economic growth and increased levels of investment. The terms-of-trade are an important determinant of economic welfare since they determine the quantity of imports that can be bought with a given amount of domestic production (exports). Moreover, commodity price volatility is an incentive for the reallocation of resources from agriculture to industry or from the export-oriented sector to domestic production that could lead to a major redistribution of income between sectors in the economy. Finally, changes in primary commodity prices could have large consequences for the distribution of the gains from international trade between countries. In a world of uncertainty (read: in a world with terms-of-trade fluctuations) that hits the export sector disproportionately hard (like for example the fourfold increase in the price of oil in 1973-74) volatility has a negative effect on the share of exports in gross domestic product (i.e. a country is becoming 'closed'), the level of investment and economic growth.

We can make some important observations related to commodity price fluctuations, terms-of-trade developments and output growth:

- Ricardo (1817) and John Stuart Mill (1848) predicted a long-run improvement in the prices for primary products while Prebisch (1950) and Singer (1950) on the other hand argued that there is a secular deterioration in relative prices of primary products over time: the Prebisch-Singer hypothesis.[19] The Prebisch-Singer hypothesis is further supported by some empirical observations (e.g. protection of domestic primary production in industrialised countries versus the need for developing countries to import manufactures, mainly capital goods, to proceed on the road towards industrialisation) and rejected by others.
- Primary products tend to have fairly inelastic demand and supply curves, leading to relatively large price fluctuations in short time periods. This implies higher levels of volatility in the terms-of-trade which is a fact economic scholars agree to.
- Growth rates of developing countries with large shares of primary product exports have been significantly lower than developing countries that were less endowed.
- There is a positive relationship between openness of an economy to international trade and capital and economic growth performance.

This has led us – like several authors before us - to believe that terms-of-trade uncertainty is detrimental in determining output growth and explaining output volatility. Essentially, terms-of-trade fluctuations may have an effect on economic growth through a – long-debated - long-run trend in the terms-of-trade and/or through levels of short-run fluctuations in the terms-of-trade around the trend. We believe it is

[19] The classical economists believed that the combination of decreasing returns to scale in the production of primary commodities and constant to increasing returns to scale in producing manufactures would lead to increases in the terms-of-trade of primary products. This effect would even be strengthened by population growth and the fact that land and natural resources are in inelastic supply. Contrary to that, the Prebisch-Singer hypothesis was based on the fact that primary products experience a low income elasticity of demand and that material-replacing technical change takes place in manufacturing, reducing the amount of raw materials needed per unit of manufacturing output. Also productivity gains in the primary sector – especially in countries with surplus labour and lower degrees of labour market organisation – translate into lower wages rather than higher rewards for local factors of production.

the existence of price volatility with its effects on economic growth – in which investment plays a crucial role – that needs to be looked at more carefully.[20] Moreover, one of the distinguishing features of this paper is that we show that terms-of-trade volatility makes it possible to endogenously determine the level of openness of a country – to be approximated by the ratio of exports to gross domestic product – and thus infer conclusions about higher or lower levels of economic growth following the observation of a positive relationship between openness and growth. No longer do we have to treat 'openness' as an exogenous factor in growth regressions. Instead we can treat it as determined endogenously from within the model or within the system of regressions.

In this chapter, we develop a stylised theoretical representation of the effects of short-run volatility in the terms-of-trade. We show that a higher variance in the terms-of-trade leads to lower levels of openness, a lower steady-state income and thus lower transitional levels of economic growth. Using cross-country regressions, these model outcomes are tested for a longer time horizon and for various sub-periods. Section 3.2 will provide a theoretical overview of previous work on the terms-of trade literature and the openness-growth literature while in sections 3.3 and 3.4 the model is developed. In section 3.5 we analyse the significance and implications of the model while in section 3.6 the theoretical predictions are tested empirically by analysing the relationship between price volatility, openness and output growth. Section 3.7 concludes.

3.2. Theoretical considerations

After looking at economic growth over longer periods of time, Diaz-Alejandro (1984) has observed what he termed the 'commodity lottery', an observation supported by data according to Hadass and Williamson (2003) when commenting on the Grilli and Yang (1988) dataset. That is: exportable resources of a country are determined by geography and chance and differences in economic development stem from the economic, political and institutional attributes of each of those commodities. Though

[20] In section 3.2 we provide a concise literature overview among others about the debate on a secular trend in the commodity terms-of-trade. This is important since from the policy perspective effects running from the terms-of-trade to economic growth through a trend or through volatility around the mean make a large difference (Sapsford and Balasubramanyam, 1999).

institutions, geography and culture are able to explain large shares of growth differentials between countries, these fundamentals are much less volatile than the growth rates they are supposed to explain (Pritchett, 2000; Easterly, Kremer, Pritchett and Summers, 1993). It seems that an important factor for economic growth has been omitted: terms-of-trade shocks stemming from the abovementioned characteristics of primary commodities. This chapter argues that – contrary to the findings of Ramey and Ramey (1995) one important channel through which the term-of-trade shocks influence output growth and its volatility is investment. Another factor that we show to have an important impact on gross domestic product is the endogenously determined level of openness of a country.

Throughout the 19th century, the classical economists, notably Ricardo and John Stuart Mill, believed there would be an increase in the ratio of primary commodity prices relative to manufacturing prices over time. This line of thought was reversed by the Prebisch-Singer hypothesis in 1950 (Prebisch, 1950; Singer, 1950).[21] Since then many have looked at the secular deterioration in the commodity terms-of-trade. Firstly, looking at the trend in the terms-of-trade, Lewis (1952), Spraos (1980), Sapsford (1985), Thirlwall and Bergevin (1985), Sarkar (1986) and Grilli and Yang (1988) have all found evidence in support of the Prebisch-Singer hypothesis. The declining trend in the terms-of-trade was also found by Basu and McLeod (1992), Sapsford, Sarkar and Singer (1992), Barros and Amazonas (1993) and Cashin and McDermott (2001). The downward trend was however contested by Cuddington and Urzua (1989) who found support for a structural break in 1920/21, Powell (1991) whose findings support three downward jumps in real commodity prices (in 1921, 1938 and 1975) and Cuddington, Ludema and Jayasuriya (2002) who find stationarity of the terms-of-trade once structural breaks are introduced. Bleaney and Greenaway (1993) find a significant but slow downward trend in prices of primary products relative to those of manufactures of little more than 0,5% per annum (for non-fuel primary commodities) and argue that only a fraction of this decline passes through to the terms-of-trade of developing countries. Moreover, the negative trend varies across

[21] The Prebisch-Singer hypothesis is not uncontested though, especially when looking at the data available on which Prebisch based his hypothesis. For a good overview of the issues, see Spraos (1980) where he identifies four principal criticisms brought up in the fifties, sixties and seventies by economists no less than Kindleberger (1956), Haberler (1959), Lipsey (1963), Johnson (1967), Viner (1953), Baldwin (1955) and Bairoch (1975).

the 1900-1991 time span and price behaviour of different categories of primary commodities is sufficiently different to doubt the validity of a long-run downward trend for primary commodities as a whole. Gillitzer and Kearns (2005) carry out an interesting study on long-term patterns in Australia's terms-of-trade and conclude that there is an overall negative – though insignificant – trend in Australia's terms-of-trade of -0.1% per annum.[22] (Short-run) volatility in the Australian terms-of-trade was much more pronounced. Also Cuddington (1992) and more recently Newbold et. al (2005) find that in the majority of investigated cases, no significant trends were inferred. Moreover, for those trends that were found, the estimates were not always negative. Newbold et. al (2005) – like Bleaney and Greenaway (1993) before them – conclude that it is volatility that matters. Like them we conclude that – in light of the mixed evidence on a secular positive/negative trend or not there is one stylised fact that applies to commodity prices in general which is that of overall (short-run) volatility rather than predictable trend movements'.[23] Another complicating factor – when carrying out an investigative analysis of the Prebisch-Singer hypothesis – is the fact that in a world that is globalising more and more, with international production fragmentation that leads to the inclusion of developing countries into international production networks as suppliers of basic parts and components, an easy distinction at country level between primary product exporters and industrialised economies can no longer be made. A recent UNCTAD (2005) study supports this observation.

Though much research focused on the long-running debate surrounding the deterioration in the terms-of-trade of internationally traded primary commodities vis-à-vis manufactures as argued by Prebisch (1950) and Singer (1950), much less attention was initially given to the impact of terms-of-trade movements on economic growth. Instead early research has focused on the effects of exports on GDP movements. A first overview of the literature in this area is provided by Behrman (1987). Exports and export instability play an important role in explaining output growth according to Feder (1983), Ram (1987) and Gyimah-Brempong (1991). However, Fosu (1992), basing his research on Glezakos (1973) – the same study on which Gyimah-Brempong (1991) base their work – finds no relationship between

[22] Interestingly they find that Australia's commodity exports have risen faster in price than average world commodity prices and that growth in manufacturing exports had little to do with the negative trend.
[23] Newbold, P., S. Pfaffenzeller and A. Rayner (2005).

export instability and growth. More recently Dehn and Gilbert (2001) – in line with the export instability literature – fail to find evidence of commodity price variability or uncertainty on growth.

Turning away from exports alone and looking at the terms-of-trade effect on growth, it was the strand of empirical growth literature in the 1990s (Barro, 1991; Barro and Lee, 1993; Easterly and Rebelo, 1993; Fischer, 1993; Easterly et al., 1993; Razin and Yuen, 1994; Barro and Sala-i-Martin, 1995) that found that the terms-of-trade play a significant and robust role in explaining growth differentials. According to the economic growth literature there is empirical evidence for a link between the long-run terms-of-trade fluctuation and economic growth. Mendoza (1997) and Reinhart and Wickham (1994) argue indeed that the opposing trends of terms-of-trade between developing and developed countries stem from the strong (relative) decline of commodity prices much as predicted by the Prebisch-Singer hypothesis (Prebisch, 1950; Singer, 1950). Moreover, Easterly et al. (1993), Barro and Sala-i-Martin (1995) and Fischer (1993) further support the importance of the terms-of-trade for economic growth relative to other explanatory variables used to explain growth differentials, like education, human capital and political factors.[24] A positive and significant link between improvements in the terms-of-trade of internationally traded primary commodities vis-à-vis manufactures and output growth is akin to technological advances. Those lead to improved levels of productivity, more rapid capital accumulation and economic growth. According to Mendoza (1997) the mechanism runs from high terms-of-trade growth to higher expected real rates of return on savings (in units of imported goods) which in turn affect the savings rate and thus the growth rate of an economy. Bhagwati (1973) in his work on immiserizing growth contests these outcomes and shows that economic growth, leading to higher levels of production and exports of goods may lead to a disproportionately large fall in prices of those products. This deterioration in the price level may more than offset the increases in production thus leading to a loss of welfare.

Besides Bhagwati (1973), another strand of literature that contends the view of a positive relationship between improvements in the terms-of-trade and economic

[24] Raddatz (2005) however, shows that external shocks (like commodity price fluctuations) can only explain a small fraction of output variance of a developing country compared to internal factors.

growth is the ‘curse of natural resources’ or ‘Dutch disease’ literature. It states that abundance of resources leads to lower economic growth and development.[25] Sachs and Warner (1995, 1999, 2001) show repeatedly that indeed abundance of resources and not other variables that have been suggested – like omitted geographical or climate variables – explain the curse.[26] Neither do they find evidence for bias resulting from other unobserved growth deterrents. Rather they claim that resource-abundant countries were ‘high-price economies’ and as a possible consequence have missed out on export-led growth. Also Hadass and Williamson (2003) find evidence of the Dutch disease between 1870 and World War I where improvements in the terms-of-trade reduced growth in certain commodity exporting countries.[27] That is, initially, a positive terms-of-trade shock will raise GDP but over the longer run, a positive terms-of-trade shock in primary product-producing countries will strengthen comparative advantage forces, reallocating resources into primary product production which leads to de-industrialisation.[28]

Besides the ‘resource curse’ argument as previously discussed, Pritchett (2000) and Easterly, Kremer, Pritchett and Summers (1993) argue that the fundamental determinants of growth exhibit far more persistence than do the rates of output the determinants are supposed to explain. No matter whether there is an empirical trend in terms-of-trade fluctuations or not, we need to turn to the issue of volatility which we believe to be of much more significance and which is much less contested. There is a vast literature on the effects of different types of risk on output growth.[29] Early work on the effect of short-term terms-of-trade volatility on growth is performed by Basu

[25] Sachs and Warner (1995, 1999, 2001) and Gylfason et al. (1999).

[26] Sachs and Warner (1999) show that there is evidence from seven Latin-American countries that natural resource booms are sometimes accompanied by declining levels of GDP per capita.

[27] Firstly, their dataset covered only a few of the developing countries that remained poor up to World War II and neither did they look at volatility. Secondly, the causal relationship between terms-of-trade can also be seen the other way as demonstrated by Bhagwati (1973) in his work on immizerising growth.

[28] Paul Samuelson – when challenged by Stanislaw Ulam (a mathematician) to ‘name […] one proposition in all of the social sciences which is both true and non-trivial’ – answered: ‘Comparative advantage. That it is logically true need not be argued in front of a mathematician; that it is not trivial is attested by the thousands of important and intelligent men who have never been able to grasp the doctrine for themselves or to believe it after it was explained to them.’ Allowing free trade to determine national and international trade patterns leads to specialisation of countries in an immense range of products. The discussion on fluctuations in the terms-of-trade has arguably made the theory even less obvious.

[29] Aizenman and Marion (1993, 1997) Turnovsky (1993), Turnovsky and Chattopadhyay (1998), Kormendi and Meguire (1985), Devereux and Smith (1994), Obstfeld (1994), Asea and Turnovsky (1998), Imbs (2002).

and McLeod (1992) who use impulse response functions to show a negative effect of greater variance in price fluctuations on economic output; a result that is a year later supported by Edström and Singer (1993) who find a significant negative effect of the net barter terms-of-trade volatility on output growth using pooled cross-section and time-series data.[30] Cashin and McDermott (2001) add that volatility has different causes: in certain time periods the increase would come from a greater amplitude in price movements (in the early 1900s) and in other periods (the early 1970s) from increased frequency of large price movements, i.e. a fall in the duration of large price cycles. The study of Basu and McLeod (1992) also raised another issue: the problem of distinguishing between a trend and the transient components around that trend. Already in 1979, Gelb (1979) claimed to have found at least sixteen different methods of doing that. Basu and McLeod (1992), Cuddington (1992) and Reinhart and Wickham (1994) follow Beveridge and Nelson (1981) in distinguishing between a stochastic trend that allows for a random walk and a stationary cyclical component and use Cochrane (1988) to provide a convenient nonparametric estimator of the 'size' of the random walk trend component – the variance ratio. Studies by Watson (1994), Cashin, McDermott and Scott (1999) and Cashin and McDermott (2001) deal with data in levels avoiding the subjective choice as to which detrending method to use.[31] Sapsford and Balasubramanyam (1999) argue that – apart from econometric challenges – trend and volatility in the terms-of-trade are maybe not Siamese twins but at least twin pillars of the same fundamental problem of less developed countries and should not be seen separately at all. It is the heavy dependence on primary commodities (or more recently upon components and parts of manufactured goods) as a source of export revenue that is the problem.[32] Ramey and Ramey (1995) – in support of previous work – found that countries with large volatility in output growth

[30] More recently Moledina, A.A., T.L. Roe and M. Shane (2001) show that a large share in commodity price volatility is predictable, leaving only a small share for unpredictable components – thus suggesting lower levels of terms-of-trade volatility than expected.

[31] This means price slumps (booms) are seen as periods of absolute declines (increases) in the series, not as a period of below-trend (above-trend) growth in the series.

[32] Arguably, the parts and components the less developed countries provide as inputs for manufactured goods are the ones at the labour intensive and technology extensive range of intermediate inputs. This implies that the gains from investment will be lower in the less developed countries. Also, whether the transmission mechanism works through the trend in the terms-of-trade or volatility around that trend is a matter of great concern for policy makers. In case of the former, a country can diversify its exports away from commodities that experience a secular deterioration in their terms-of-trade into commodities and products that do not show that trend. Volatility of the terms-of-trade around a negative or positive trend do not offer such a policy solution; it just warrants measures to dampen the fluctuations to mitigate its adverse consequences for capital accumulation and output growth.

tended to have lower average growth rates. Sapsford and Balasubramanyam (1999) argue that the previous studies might even underestimate the effects of volatility on investment and growth because (government) policies may be in place to insulate the domestic economy from fluctuations in commodity prices creating the 'illusion' of no significant relationship. Those policies are not costless though because the opportunity costs are the loss of investible resources: a link between volatility, investments and growth is therefore likely to be underestimated.

Theoretically we expect a negative impact of volatility in the degree around the trend terms-of-trade on output growth as well as on the share of exports in gross domestic product (Devarajan, Lewis and Robinson, 1990; Go and Sinko, 1993).

- For output growth, firstly, the volatility effect runs through the tradable component of output (X-M). Fluctuations in the term-of-trade lead to fluctuations in X-M that lead to fluctuations in gross domestic product (GDP). This link explains output *volatility* but not how output is actually *reduced* as a consequence of uncertainty.
- For that we need to look at the behaviour of agents at the micro-level under uncertainty; that is to incorporate uncertainty into the theory of production.[33] So, secondly, uncertainty at the micro-level leads firms (micro-economic agents) that are risk-averse to reduce production compared to a situation with full certainty – an outcome that follows from including uncertainty in the theory of expected utility.[34] Uncertainty may reveal itself here through prices – i.e. here the price of exports with normalised import prices – or technology. The larger the level of uncertainty, that is the larger the mean-preserving spread (a 'Sandmo' increase in risk), the lower output growth (as supported by Basu and McLeod, 1992; and Ramey and Ramey, 1995). In an industry with perfect competition, this leads to lower levels of production for a given level of resources because firms operate at a sub-optimal level with average costs above the Pareto-optimal minimum. Looking at different sectors in the economy, we also argue that the export sector experiences larger volatility in the terms-of-trade (like Devarajan, Lewis and Robinson (1990) and Go and Sinko (1993)) which means that increased volatility will lead to a disproportionately larger decrease in production for exports when

[33] An analysis of industry-level uncertainty can be found in Shesinsky and Dreze (1976).
[34] See Sandmo (1971), Hey (1984) and Gravelle and Rees (1992) for outcomes in terms of including uncertainty in expected utility theory.

compared to sectors producing for domestic consumption. It means that we expect countries with higher levels of volatility to be more closed, i.e. to have a lower share of exports in gross domestic product, than countries with lower levels of volatility.

- Thirdly, an increase in volatility/uncertainty – modelled as a mean-preserving spread in the terms of trade – may lead to a lower expected growth rate of output (Basu and McLeod, 1992) because of the effect uncertainty has on financial decisions of producers, governments and households.
    - Uncertainty changes producer's incentives to invest, since in the presence of (capital) restrictions that could lead to sunk costs, uncertainty may cause additional costs to investments (Pindyck, 1991; Dixit and Pindyck, 1994). That means uncertainty leads investors to place a risk premium (or an 'option value' according to Lutz (1994)) inside their net present value (NPV) or return on investment (ROI) calculations, essentially lowering the level of investments undertaken because of 'higher costs' leading to lower levels of economic growth.[35] Indeed some investigations find that temporary trade shocks show that investment can be expected to respond strongly to discrete ex post commodity price shocks (Bevan, Collier and Gunning, 1990; Collier, Gunning and Associates, 1999). Firms that are risk-averse and that operate in the export-sector will adjust their investment decisions – even without the irreversibility of investments indicated by Pindyck (1991).
    - Governments may under-invest in public goods, given revenue uncertainty, especially given the fact they may well face borrowing constraints on international capital markets. Indeed, Ramey and Ramey (1995) find that government spending and macro-economic volatility are closely related and lead to lower output growth.[36]

[35] Additionally, the risk premium of uncertainty may lead to a reallocation of investments geographically or in terms of composition (e.g. from financial investments to property investments or to investments in the non-tradable sector that is to a lesser degree affected by uncertainty in the terms-of-trade).
Also note that with the risk premium (or option value) on terms-of-trade equal to zero, there is no uncertainty in investment decisions and we operate in a certain world.

[36] Catao and Kapur (2004) have shown that for the period 1970-2001 with greater volatility comes a greater need for international borrowing by governments but less willingness from international capital markets.

- Risk-averse households save less when returns to capital are fluctuating a lot. Mendoza (1997) models the idea that terms-of-trade volatility discourages savings among households by assuming they consume imported goods and save for future consumption. That means terms-of-trade are directly related to the real returns to saving which combined with sufficient levels of risk-aversion and closed capital markets leads to the conclusion that countries with more fluctuations grow slower.

Mendoza confirms, in a sample of 40 industrial and developing countries for 1970-1991, a positive relationship between terms-of-trade trend and economic growth as well as a negative relationship between terms-of-trade volatility and growth. These empirical findings have been corroborated by Bleaney and Greenaway (2001), Turnovsky and Chattopadhyay (2003) and Blattman, Hwang and Williamson (2004). The latter study additionally emphasises an asymmetry between 'core' and 'periphery' in the world for 1870-1939. Where terms-of-trade volatility was present, it was found to have a much stronger negative impact on economic growth in the 'periphery' than in the 'core'. The 'core' benefited strongly from positive secular growth in the terms-of-trade while in the 'periphery' the effects on output growth were negligible or even negative. Moreover Blattman, Hwang and Williamson (2004) find a negative influence of terms-of-trade volatility on capital flows in the 'periphery' but not in the 'core'.[37]

In light of the observation that terms-of-trade volatility may not only have a negative impact on output growth but also on the level of openness of a country, i.e. the share of exports in gross domestic product, we investigate the literature that looks at the relationship between openness and growth in more detail. It was Baumol (1986) who started the empirical debate about economic convergence and the argument – stemming from the Solow-model (Solow, 1956) that poor countries should grow faster than richer ones due to their higher marginal products of capital. The combination of large datasets (Madisson, 1982; Summers and Heston, 1991) combined with growth empirics (for example Barro and Sala-i-Martin, 1991, 1992, 1995 and Lee, 1994) has lead to an investigation regarding the effect of openness in explaining economic growth. According to Dollar and Kraay (2004): 'Openness to

[37] For a more detailed analysis of the reasons for these observations, we refer to the original article by Blattman, Hwang and Williamson (2004).

international trade accelerates development: this is one of the most widely held beliefs in the economics profession, one of the few things on which Nobel prize winners of both the left and the right agree'. And with some notable exceptions, the majority of the economics profession agrees (Dollar, 1992; Harrison, 1995; Sachs and Warner, 1995; Edwards, 1998; Pain, 2000; Dollar and Kraay, 2002, 2004; Baldwin, 2003; Cuadros, Orts and Alguacil, 2004). Corden (1984, 1985) argues that indeed opening up the economy to international trade will produce benefits through higher productivity in terms of greater consumer choice and higher living standards[38]. Though the static effects of more openness on economic growth performance are not large, Romer (1994) and Berden and Van Marrewijk (forthcoming JDE 2007) argue that the dynamic welfare implications are much larger. Quah and Rauch (1990) use the idea of freer trade having a positive effect on growth using time series analysis while Edwards (1993, 1998) uses comparative data for 93 countries to analyse and find the robustness of the relationship between openness and total factor productivity. Also Harrison (1995) finds that overall there is a positive association between growth and various approximations to openness.[39] Srinivasan and Bhagwati (1999) – though not in favour of the shift from case studies to cross-country work – quote studies by the OECD, NBER and IBRD during the 1960s and 1970s that have plausibly shown that trade leads to higher growth, possible even for prolonged periods of time.

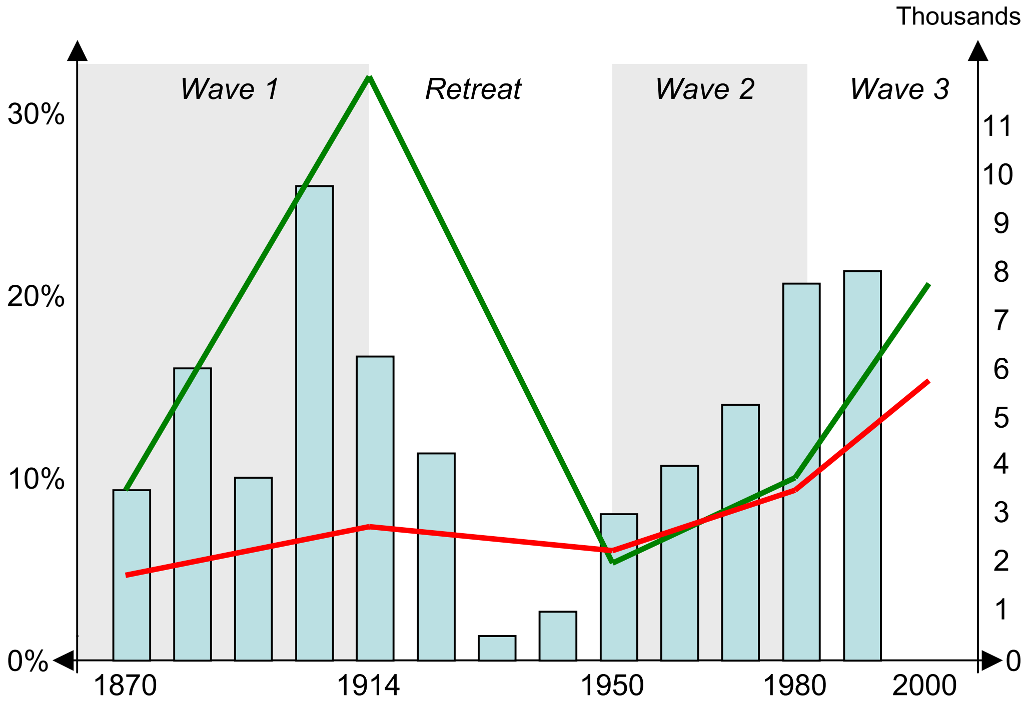
Some authors have challenged the aforementioned studies based on econometric, policy variables or omitted variables grounds. It is interesting to see that many of the critical research focuses on Latin-American examples. Cimoli and Correa (2002) find that there are other factors that are more important for determining growth. Additionally they show that a virtuous link between exports and output can only be maintained with an increasing deficit on the trade balance. Yanikkaya (2003) finds that the specific approximation for openness matters for the results found on the effect of openness on growth. Regressions using trade intensity ratios show a positive effect on growth while higher trade barriers seem to have a positive effect also. The former is in line with the existing literature, the latter clearly not. Vamvakidis (2002) checks historical evidence from 1870 to the present and finds that the positive relationship

[38] See Van Marrewijk (2002) for an overview of the underlying (trade) theories of comparative advantage and intra-industry trade.

[39] Though the strength of the association depends on the specification of the data (cross-section or panel data)

between openness and growth is there but hinges on a very strong positive correlation in the post 1970 period. In fact, the relationship is a negative one for the period 1920 – 1940. This may suggest that the third wave of globalisation has changed the parameters in the world economy in such a way that openness is more important for growth today than it was, for example in 1930. Figure 3.1 shows slight differences in foreign capital stock as share of a developing country's GDP, merchandise expoerts as share of world GDP and immigrants to the US in millions for each of the waves of globalisation.

Figure 3.1. Three waves of globalization



Source: Globalization, Growth and Poverty, World Bank (2001)

Fundamental criticism on the empirical observations regarding openness and growth comes from Rodriguez and Rodrik (2000). They challenge the outcomes of several cross-country regression analyses that openness is good for growth. They look at the outcomes of Dollar (1992), Sachs and Warner (1995) and Edwards (1998) among others, and argue that these are methodologically flawed for several reasons. First, the openness indicators used are poor measures of trade barriers and secondly they are highly correlated with other variables measuring 'bad performance'. Dollar and Kraay (2004) partially agree with this critique but argue that Levine and Renelt (1992) criticised the cross-country work before and also find that certain variables (like changes in average tariff rates) are not strongly correlated with changes in trade volumes. Moreover, Dollar and Kraay (2004) look at *changes* in trade policy and *changes* in growth, thus eliminating other factors that may blur the relationship in standard cross-country growth regressions.

Pain (2000), Baldwin (2003) and Cuadros, Orts and Alguacil (2004) find that openness is to include more than just trade liberalisation in order to have a positive impact on output growth. According to Pain (2000), openness is part of a development strategy, no a goal in itself, and needs to be complemented by a solid institutional and legal framework. Cuadros, Orts and Alguacil (2004) argue that international capital flows with a focus on Foreign Direct Investment (FDI) matter while Baldwin (2003) looks at measures like stable exchange rates, prudent monetary and fiscal policy and a corruption-free administration to support the positive relationship. Berg and Krueger (2003) ask themselves how important trade policy is for poverty reduction. They find that openness has a positive effect but only through the general effect on overall economic growth. Lee, Ricci and Rigobon (2004) take the lessons from the Rodriguez-Rodrik paper and apply a heteroskedasticity methodology to measure the effect of openness on growth while controlling for the effect of growth on openness. Though small, the outcomes show that openness has an unequivocally positive effect on growth.

When summarising the openness-growth literature we conclude that most evidence points in favour of a positive relationship between openness and growth despite the dissenting view by Rodriguez and Rodrik (2000). There are means to mitigate the critiques raised and after doing so (Dollar and Kraay, 2004; Lee, Ricci and Rigobon, 2004) the evidence is decisive. It is interesting to note that openness is seen as an exogenous policy variable in its effects on output growth with only a rare exception (Aizenman, 2004). In this paper we will show that in addition to financial openness mentioned by Aizenman (2004), terms-of-trade volatility can also endogenously explain the level of openness and thus indirectly as well as directly the rate of growth in an economy. In order to do that, we now turn to the model in section 3.3.

3.3. Uncertainty in a general framework

In order to work out the relationship between volatility, openness and economic growth, let's assume a Ramsey economy with a national budget constraint that holds each time period. Assuming a steady-state with certainty, that leads to the following general system of equations for the steady-state structure of a small open economy:

$$e(p,q) - g(p,k:v) - m(p - p^*) = B \quad (3.1)$$

$$m = e_p - g_p \quad (3.2)$$

$$p = p^* \cdot T' \qquad \text{(with } T = 1 + t\text{)} \quad (3.3)$$

$$r(T,k) = \frac{g_k}{e_q} \quad (3.4)$$

$$\bar{r} = (\delta + \rho) \quad (3.5)$$

$$r(T,k) = \bar{r} \quad (3.6)$$

In equation (3.1) the term $e(\cdot)$ is the expenditure function for the composite good *q* depending on the vector of domestic prices, *p*. The composite good can either be consumed or directly invested. $g(\cdot)$ is the GDP function that depends on the domestic price vector, capital, *k*, and other factors of production, *v*. *B* is the trade balance which we will assume to be equal to zero down below while $m(\cdot)$ represents the vector of imports that – according to equation (3.2) – is the difference between domestic supply and demand. Equation (3.3) shows the difference between domestic and world prices, whereby the difference arises from *T'* our variable – made explicit here but essentially 'inside' p^* - to model price volatility. Equation (3.4) relates real investment expenditure – as a function of *T* and capital – to the expenditure function and revenue function. The equilibrium real rate of return in steady state is determined by the rate of time discount, ρ, and the rate of depreciation, δ. The long run equilibrium supply and demand in investments is given by equation (3.6).

We can introduce uncertainty, like trade volatility in the terms-of-trade, by characterising variable *T* with the probability density function $f(T)$[40]:

[40] It is possible to introduce different types of uncertainty besides the volatility in the terms-of-trade. We refer to Francois (1997), Baldwin et al (1997), Rodrik (1986, 1994) and Nelson (1994).

$$\mu_T = \int_{-\infty}^{\infty} f(T) \cdot dt \tag{3.7}$$

We can then express the real return to investment by combining equations (3.6) and (3.7) into:

$$\mu_r = \int_{-\infty}^{\infty} r(T,k) \cdot f(T) \cdot dt \tag{3.8}$$

In order to relate the uncertainty of investment returns to savings – since the two are related and an assumption regarding behaviour under uncertainty lies underneath – we need to model exponential temporal utility functions of consumers whereby they maximise the present value of utility streams. Equation (3.9) models this utility function:

$$u = c - e^{-b \cdot q_c} \tag{3.9}$$

In equation (3.9), u stands for temporal utility which depends on a constant, c, the measure for risk aversion, b, and the consumption of q, q_c. For reasons of mathematical rigour, note that we employ the CARA (constant absolute risk aversion) specification of risk in this model.[41] We can now combine equations (3.6) and (3.9) in order to get the certainty equivalent rate of return to investment. 'Certainty equivalence' is the return needed under complete certainty to provide the same expected utility as a particular return with mean μ and variance σ_r^2. If we assume a normal or gamma distribution for T, we get the following certainty equivalents (CE) respectively:

Normal: $$CE = \mu_r - \frac{b}{2}\sigma_r^2 \tag{3.10a}$$

[41] Using a different type of risk aversion, like Constant Relative Risk Aversion (CRRA), makes the calculations more complex but does not yield much different results.

Gamma: $$CE = \frac{\mu_r^2}{b \cdot \sigma_r^2} \ln\left(\frac{b \cdot \sigma_r^2}{\mu_r}\right) \quad (3.10b)$$

Combining equations (3.6) and (3.10a/3.10b) to equation (3.11), we find the certainty equivalent expression, characterised by μ and σ for the long-run equilibrium on the savings-investment market. Equation (3.11) states that, at the margin, savers/investors will allocate their spending between current and future consumption so that the certainty equivalent return is exactly enough to offset the discounting of future consumption.

$$CE(\mu_r, \sigma_r^2) = \bar{r} \quad (3.11)$$

3.4. An example with an Armington model

Having discussed the specifications and model structure in general form in section 3.3, let's now turn to a specific example using a stylised model based on Armington-type trade, following De Melo and Robinson (1989) and Francois and Reinert (1997). A neat feature of the model is that it exactly addresses the nature of external shocks that we investigate: terms-of-trade shocks and the mechanisms by which these shocks pass through the economy of a country.

We assume a small open economy (i.e. facing fixed world prices for exports and imports) with two sectors: a tradable and non-tradable sector and three goods, which we call the 1-2-3 model. This allows us on the one hand to look at the relationship between the external sector and the rest of the economy (e.g. in terms of relative prices allowing a country to affect its international competitiveness) and on the other hand makes the country part of the world because it is not immune to shocks that occur elsewhere affecting the global economy. For our purpose, within the category of tradable goods, we also distinguish between export goods and importables since it enables us to analyse the effects of terms-of-trade shocks.

The 1-2-3 model is different from the standard trade models in that it allows for non-tradable goods as well as imperfect substitution between import goods and goods that are produced domestically. Also it specifies imperfect transformability on the export side.[42] Following early work by Taylor (1975), Salter (1959) and Swan (1960) this allows us to look more realistically at the empirical observation that changes in world prices are only partially transmitted into the domestic economy (with the level of openness dictating the strength of these effects). The aforementioned specifications in the 1-2-3 model actually extend and generalise the Salter-Swan model, rendering it empirically relevant.

The demand-side is modelled as a CES composite good that can be used for consumption or savings/investment. The composite good, *Q*, is defined by two components: domestic good, *D,* and imported good, *M,* as shown in equation (3.12).[43]

$$Q = A_1 \cdot \left[\beta \cdot M^{\rho} + (1-\beta) \cdot D^{\rho}\right]^{\frac{1}{\rho}} \tag{3.12}$$

The supply side of the economy is defined as a composite, *X*, over the domestic good, *D*, and export good, *E*. A certain level of technology is used on the domestic and export goods. The total GDP (size) of the economy, indexed below by X, is determined by the aggregate CET production function based on capital and labour combined in a Cobb-Douglas form. Equation (3.13) shows us the substitution possibilities while (3.14) represents the resource constraint.

$$X = A_2 \cdot \left[\alpha \cdot E^{h} + (1-\alpha) \cdot D^{h}\right]^{\frac{1}{h}} \tag{3.13}$$

$$X = A_3 \cdot K^{a} L^{1-a} \tag{3.14}$$

In order to simplify the calculus we normalise quantities so that world prices for *X* and *M* are unity. From optimisation on the product transformation surface we can relate relative supply to the price of domestic good P_D.

---

[42] This is important since without this assumption, the law-of-one-price would still hold for all sectors that have shares in exports.

[43] In multi-sector models the composite commodity idea is extended, assuming that imports and domestically produced goods are imperfect substitutes (Armington, 1969).

$$E = D \cdot P_D^{-\Omega} \cdot \left(\frac{1-\alpha}{\alpha}\right)^{\Omega} \quad (3.15)$$

In equation (3.15), Ω is the elasticity of transformation of production (supply-side) and in equation (3.16), s is the elasticity of transformation of demand (demand-side).[44]

Also, from First Order Conditions (FOC) for utility maximisation, we can relate relative quantities demanded to the price of domestic good P_D.

$$M = D \cdot P_D^{s} \cdot T^{-s} \cdot \left(\frac{1-\beta}{\beta}\right)^{-s} \quad (3.16)$$

The price of utility (identical to e_q in (3.4)) can be related to relative prices through the CES price index for Q as presented in equation (3.17). This relationship shows the internal price of imports by the power of the tariff (recall that world prices are unity):

$$P_Q = e_q \cdot \left[\beta^{s} \cdot T^{1-s} + (1-\beta)^{s} \cdot P_D^{1-s}\right]^{\frac{1}{1-s}} \quad (3.17)$$

As already indicated above, we assume balanced trade (*B=0*). Balanced trade combined with unity of world prices means that imports, M, must equal exports, X, in equilibrium. Combining equations (3.15) and (3.16) satisfies this condition as is presented in equation (3.18) below:

$$E = M \quad (3.18)$$

$$D \cdot P_D^{-\Omega} \cdot \left(\frac{1-\alpha}{\alpha}\right)^{\Omega} = D \cdot P_D^{s} \cdot T^{-s} \cdot \left(\frac{1-\beta}{\beta}\right)^{s}$$

From equation (3.18) we can deduce the price level P_D:

---

[44] The elasticities Ω and s are defined as follows: $\Omega = \frac{1}{h-1} \quad h > 1$; $\quad s = \frac{1}{1-\rho} \quad -\infty < \rho < 1$

$$P_D = T^{\frac{s}{s+\Omega}} \cdot \left(\frac{1-\alpha}{\alpha}\right)^{\frac{\Omega}{s+\Omega}} \cdot \left(\frac{1-\beta}{\beta}\right)^{\frac{s}{s+\Omega}} \qquad (3.19)$$

Now that we have P_D, we can solve for equilibrium quantities D and E and prices P_X and P_Q:

$$D = X \cdot A_2^{-1} \cdot (1-\alpha)^{\frac{-1}{h}} \cdot \left[\left(\frac{1-\alpha}{\alpha}\right)^{\frac{\Omega hs}{s+\Omega}-1} \cdot \left(\frac{\beta}{1-\beta}\right)^{\frac{\Omega hs}{s+\Omega}} \cdot T^{\frac{-\Omega hs}{s+\Omega}} + 1\right]^{\frac{-1}{h}} \qquad (3.20)$$

$$E = X \cdot A_2^{-1} \cdot \alpha^{\frac{-1}{h}} \cdot \left[\left(\frac{1-\alpha}{\alpha}\right)^{1-\frac{\Omega hs}{s+\Omega}} \cdot \left(\frac{\beta}{1-\beta}\right)^{\frac{-\Omega hs}{s+\Omega}} \cdot T^{\frac{\Omega hs}{s+\Omega}} + 1\right]^{\frac{-1}{h}} \qquad (3.21)$$

$$P_X = \frac{E + P_D \cdot D}{X} \qquad (3.22)$$

$$P_Q = \left[\beta^s \cdot T^{1-s} + (1-\beta)^s \cdot T^{\frac{s(1-s)}{s+\Omega}} \cdot \left(\frac{1-\alpha}{\alpha}\right)^{\frac{\Omega(1-s)}{s+\Omega}} \cdot \left(\frac{1-\beta}{\beta}\right)^{\frac{s(1-s)}{s+\Omega}}\right]^{\frac{1}{1-s}} \qquad (3.23)$$

From the FOC associated to equation (3.14) we can show that the equilibrium real return on capital is:

$$r(T,K) = a \cdot A_3 \cdot \left(\frac{K}{L}\right)^{a-1} \cdot \frac{P_X}{P_Q} \qquad (3.24)$$

Combining (3.24) with equations (3.22) and (3.23) yields (3.25) where the real rate of return is expressed in endogenous variables *T* and *K* only:

$$r(T,K) = a \cdot A_3 \cdot \left(\frac{K}{L}\right)^{a-1} \cdot \left[A_6 \cdot \left(1 + A_7 \cdot T^{\phi\Omega h}\right)^{\frac{-1}{h}} + T^{\phi} \cdot A_8 \cdot \left(1 + A_9 \cdot T^{-\phi\Omega h}\right)^{\frac{-1}{h}}\right] \cdot \left[\left(\beta^{s} + (1-\beta)^{s} \cdot A_5^{1-s} \cdot T^{\phi}\right)^{\frac{1}{s-1}}\right] \quad (3.25)$$

$$r(T,K) = a \cdot A_3 \cdot \left(\frac{K}{L}\right)^{a-1} \cdot j(T)$$

A nice property of (3.25) is that the marginal returns effect due to changes in *K* and the relative price effect due to changes in *T* are separable.

Equation (3.26) shows the steady-state capital stock under certainty. The coefficients A_j (with *j* ranging from one to eight) used in equations (3.20) to (3.26) represent reduced form constants.[45]

$$K = L \cdot \frac{P_X}{P_Q} \cdot a^{\frac{1}{1-a}} \cdot \bar{r}^{\frac{1}{a-1}}$$
$$K = A_4 \cdot \left(j(T)\right)^{\frac{1}{1-a}} \quad (3.26)$$

Equations (3.19) to (3.26) provide us with the entire system needed to determine the equilibrium values. The (non-linear) relationship between real returns, *r*, and volatility in world prices is represented by the $j(T)$ function. The overall impact of uncertainty on real returns in the economy depends on the characteristics of the function $j(\cdot)$. The characteristics are specified in equation (3.27):

$$\mu_r = a \cdot \left(\frac{K}{L}\right)^{a-1} \cdot \mu_j$$
$$\sigma_r^2 = a^2 \cdot \left(\frac{K}{L}\right)^{2(a-1)} \sigma_j^2 \quad (3.27)$$

From (3.25), (3.26) and (3.27) it becomes clear that a higher level of volatility leads overall to a lower real expected return to capital (3.25 and 3.27) and a lower level of

[45] See Appendix 1 for the exact specification of those constants. The parameter $\phi = \frac{s}{s+\Omega}$.

capital (3.26 and 3.27) – which means the economy is less efficient when subject to uncertainty. These are important implications of the model and the $j(T)$ function.

But there is more to this model than only the overall economy-wide effects represented by the $j(T)$ function. Next to those, the model also shows implicitly that sectoral re-allocation of resources takes place because we need certainty equivalence to be equalised. At a risk-neutral production equilibrium equations, (3.28) and (3.29) show that the expected rates of return must be equal in the overall economy:

$$\bar{r} = a\frac{P_E \cdot E}{K_E} = a\frac{P_D \cdot D}{K_D} \tag{3.28}$$

$$\bar{r} = \frac{a}{P_Q}\frac{P_E \cdot E}{K_E} = \frac{a}{P_Q}\frac{P_D \cdot D}{K_D} \tag{3.29}$$

Writing (3.28) and (3.29) in natural logarithms, we get (3.30) and (3.31). Note that we use lower case p_Q, p_E and p_D because now they are the variation in proportional changes in the rate of return.

$$\ln \bar{r}_E = \ln a - \ln p_Q + \ln p_E + \ln E - \ln K_E = G_E \tag{3.30}$$

$$\ln \bar{r}_D = \ln a - \ln p_Q + \ln p_D + \ln D - \ln K_D = G_D \tag{3.31}$$

Turning to the zero-arbitrage condition for capital in a risk-averse CARA world, with help of (3.9), we calculate the expected *real* rate of return to capital in the two sectors where the risk/variance comes from volatility in export prices:

$$\ln \bar{r}_E^{CE} = \ln a - \ln p_Q + \ln p_E + \ln E - \ln K_E + \omega \cdot \mathrm{var}(r_E) \tag{3.32}$$

$$\ln \bar{r}_D^{CE} = \ln a - \ln p_Q + \ln p_D + \ln D - \ln K_D + \omega \cdot \mathrm{var}(r_D) \tag{3.33}$$

Looking carefully at (3.32) and (3.33) we see that volatility in $\bar{r}^{CE}$ for both D and E comes from volatility in p_Q and p_E and not from volatility in p_D nor in the other variables on the right-hand-side.[46] And since p_Q shows up equally in both (3.32) and (3.33) the *difference* between the two equations comes from var(p_E). However, for certainty equivalence returns to be equal, this difference must be zero. Rewriting (3.32) and (3.33) shows this as follows:

$$\ln \bar{r}_E^{CE} = G_E + \omega \cdot \text{var}(r_E) \quad (3.34)$$

$$\ln \bar{r}_D^{CE} = G_D + \omega \cdot \text{var}(r_D) \quad (3.35)$$

where from (3.28) to (3.31) it follows that $G_E = E[r_E]$ and $G_D = E[r_D]$, at the risk neutral production point $G_E = G_D$. Therefore, for certainty equivalence arbitrage to hold economy-wide we would need $\omega \cdot \text{var}(r_E) = \omega \cdot \text{var}(r_D)$.[47] But because $\text{var}(r_D) = 0$ and $\text{var}(r_E) \neq 0$ this cannot hold at the risk neutral equilibrium.

The only way to achieve equal certainty equivalent returns economy-wide is through reducing the number of exports because a reduction leads to a higher marginal product to the composite good *(X* - the tradable sector) which is needed to offset the reduction in mean returns as a consequence of volatility in the terms-of-trade. In the optimum, the tradable sector will shrink exactly enough to raise the expected rate of return in that sector to equal the marginal product of capital under certainty plus the certainty equivalent (CE). We note here that the entire surplus from the tradable sector is allocated to capital for risk compensation which leads to a lower marginal product of labour and thus lower wages. Fully in line with the finance literature, this result implies that through diversification away from the risky sector, investors decrease the variance at the expense of lower mean returns.

[46] Note that p_D does not change. The relative price p_D / p_M changes but that is due to changes in p_M.

[47] The parameter ω is negative, implying that a higher variance (i.e. higher volatility) leads to lower returns, which needs to be compensated for by reducing production in the export sector.

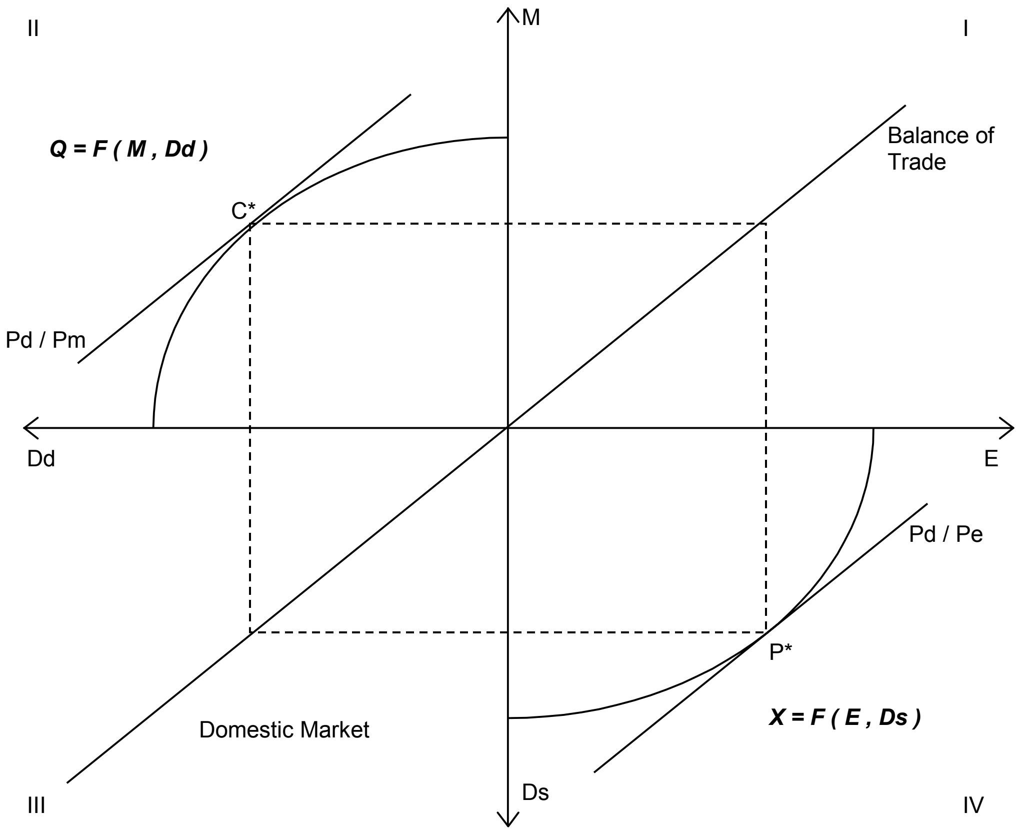
3.5. Analysis and transition dynamics

Section 3.2. provides an extensive literature overview on terms-of-trade, economic growth, investment and openness. In sections 3.3 and 3.4, the 1-2-3 model has been developed and explained. From the final set of equations (3.19 to 3.35) we can draw conclusions on the theoretical predictions regarding the effects of volatility in the terms-of-trade. This leads us to present the following stylised observations:

- **Observation 1:** When the variance in the terms-of-trade increases, according to (3.34) there is a decrease in the level of openness of a country.
- **Observation 2:** When the variance in the terms-of-trade increases, steady-state income levels will be lower as real returns to investors and the equilibrium capital stock will be lower according to (3.25) and (3.26).
- **Observation 3:** When the variance in the terms-of-trade increases, transitional economic growth will be lower. This follows from observation two and the transition dynamics of this section.
- **Observation 4:** When there is terms-of-trade uncertainty, the expected GDP-function, responding efficiently to uncertainty, has a lower mean value at any point in time compared to a deterministic situation.
- **Observation 5:** Given the starting level of real per capita GDP, countries that are on low-income trajectories because of terms-of-trade volatility tend to be more closed.

Analytically, these observations can be explained with support of figure 3.2. and figure 3.3. below (from: Devarajan et al. in Francois and Reinert, 1997). Figure 3.2. depicts the situation with full certainty and figure 3.3. shows the situation with terms-of-trade volatility (uncertainty).

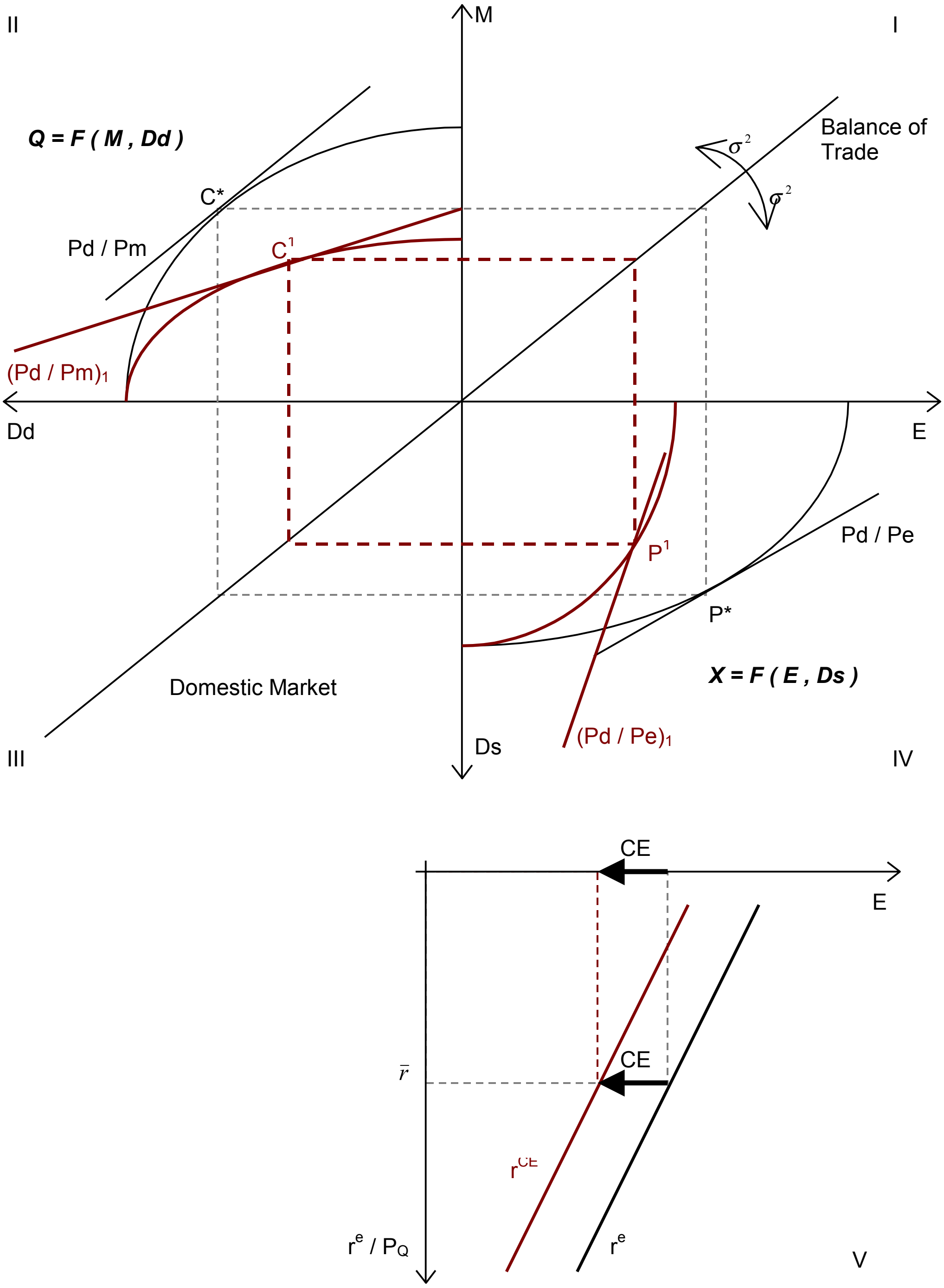
Figure 3.2. The 1-2-3 model under certainty (Pareto-optimal).



Starting from the IVth quadrant in Figure 3.2. the supply side of the economy is in steady-state equilibrium (under full certainty) where the tangency of the price ratio P^D / P^E with the domestic production possibility frontier – assumed to be concave and specified as a CET function – determines the amounts of domestic (*D*) and export (*E*) goods produced (equation 3.13). We assume Cobb-Douglas technology in producing the goods and show that the share α goes to capital and (1-α) to labour (equation 3.14). The returns to labour and capital in the export sector and domestic production sector are the same; that is: $w_E = w_D$ and $r_E = r_D$. If we assume that the trade balance (*B*) is zero (i.e. there are no capital inflows or outflows) and we normalise world prices to one, it is simply a 45° line through the origin as depicted in quadrant I. It is important for the analysis to realise that with *B=0*, the only source of foreign capital needed to pay for imports must come from exporting goods. Quadrant II shows the optimal consumption situation where the consumers can choose between goods that are produced domestically and imports. In the optimum the consumption possibility frontier is the image of the production possibility frontier and the tangent between prices of domestic goods over imports (P^D / P^M) to the frontier determines how many imports and how many domestic goods are being consumed. Thus in equilibrium, the economy would produce in $P*$ and consume in $C*$.

If we then turn to terms-of-trade volatility, essentially introducing uncertainty into the model, we start from the trade balance in quadrant II of figure 3.3. (the link between exports and imports!). Imagine lots of volatility around the mean of the terms-of-trade all the time. Sometimes the volatility is high, sometimes lower but it is always there in an unpredictable fashion. The direct effect of those terms-of-trade shocks is to shift the trade balance in quadrant I erratically left and right all the time. At some points in time the country can buy fewer imports with the foreign currency earned by exports and at other points in time the opposite is true.

Figure 3.3. The 1-2-3 model with terms-of trade-volatility.



Also with uncertainty, prices P^D and P^E are a function of the production of the ratio of goods produced domestically and good that are exported. With respect to the workers in both sectors, again $w_E = w_D$ holds. For investors that make investment decisions, the picture is now different. Investors in the domestic industry would want the marginal product of capital, *a*, like before.

However, risk-averse investors want a compensation above marginal product to capital, a* > a to offset the volatility risk in world prices in the exporting sector. [48] That is: a* needs to be equal to the marginal product of capital under certainty plus the certainty equivalent. The only way to do this is to reduce the output of exports, *E*, as a share of gross domestic product which leads to a fall in the 'price of exports' (*Observation 1*). This fall is a 'fall' in producer price at cost terms which means that we could also look at this reduction in exports as a reduction in 'costs' and thus the appearance of a wedge between revenues and costs: profits.[49] It is these profits that are the compensation for higher risk for firms in the exporting sector. So relative supplies depend on the volatility in the terms-of-trade, shifting demand toward the domestic sector and reducing trade as a share of gross domestic product *(Observation 1)*. The real return to capital is inversely related to the supply of capital – representing diminishing marginal returns in the GDP-function – and to volatility in the terms-of-trade leading to lower steady-state levels of output *(equation 3.26 – Observation 2)*. Both the real return to investors ($\bar{r}$) and the equilibrium capital stock (*K*) will be negatively affected by terms-of-trade volatility (equations 3.25 and 3.26). If the steady-state output level is lower because of a lower equilibrium capital stock, then the transitional growth levels towards that lower equilibrium must be lower also *(Observation 3)* and the GDP-function is less efficient at any point in time compared to a situation characterised by full certainty *(Observation 4)*. Combining *Observations 1, 2 and 3*, we derive *Observation 5*: countries that are on low-income trajectories because of terms-of-trade volatility tend to be more closed. So the level of openness is endogenously determined through terms-of-trade fluctuations. This means economic growth is directly and indirectly (through openness) affected by terms-of-trade volatility. The level of openness is endogenous.

Transition dynamics

Before turning to the empirical part of this paper one important issue needs to be addressed. The 1-2-3 model assumes economies to be in steady-state before shocks occur (see equations (3.6) and (3.11)). Looking again at the model observations,

[48] The assumption of constant absolute risk aversion.

[49] This 'wedge' and implicitly the fact that the economy is no longer under Pareto-optimality conditions can be seen from the fact that the price line is no longer tangent to the production possibility frontier but actually intersects with it.

however, we see that the economy is less efficient because of terms-of-trade volatility. Lower efficiency shows through the GDP-function that generates lower income levels than without risk.[50] This is due to the fact that risk-averse investors demand a premium, a higher real rate of return (as if it were a greater rate of time discount – compare equation (11) in Chapter two of Blanchard and Fischer, 1989) to compensate for the higher risk which leads to lower steady state levels of capital per capita and income levels per capita. That also implies the transition growth rate must be lower than in a world of certainty. On top of that, the collected data in section 3.6 are not steady-state data but rather annual measurements. This means we need to look briefly at the transition paths of economies towards their steady states – rather than assuming they *are* in a steady state.

In this we follow Blanchard and Fischer (1989) to describe the dynamic system and dynamic behaviour of the economy assuming constant absolute risk aversion. The change of capital per person over time can be linearised in the neighbourhood of the steady state to give an idea about the dynamic behaviour of the economy:

$$\begin{aligned} \frac{dk}{dt} &= \dot{k} = [f'(k^*) - \delta](k - k^*) - (c - c^*) \\ \frac{dk}{dt} &= \dot{k} = \rho(k - k^*) - (c - c^*) \end{aligned} \qquad (3.36)$$

According to equation (3.36), on a transition path towards the steady state, there are two effects at work.[51] Due to terms-of-trade volatility there is a risk premium (essentially a deadweight tax) which leads to a lower level of (ultimate) steady-state capital, k^* and a lower $f'(k^*)$. With the CARA assumption and uncertainty, $f'(k^*)$ leads to a lower rate of change of capital over time: dk/dt is lower. On the other hand, due to higher marginal products in countries with lower starting levels of capital, k, far from the steady-state (k - k^*) is large and may offset the lower level of $f'(k^*)$ resulting in a higher level of capital accumulation over time. Noting, however, that we have applied linearization of the dynamic system in the vicinity of the steady state, it

[50] Even though this lower mean is the most efficient way to react to uncertainty.

[51] Alternatively, the dynamic adjustment may also be modelled as an economy with full capital mobility with adjustment costs (Blanchard and Fischer, 1989).

is safe to argue that the former argument dominates the latter and the overall effect on capital accumulation is negative. With a negative overall impact on capital accumulation over time, also economic growth on the transition path towards steady-state – though still growing towards the equilibrium values in the economy – will be lower.

3.6. Cross-country regression analysis

The model makes some interesting theoretical predictions about the relationship between terms-of-trade volatility, openness and economic growth. Before we turn to methodology and results, let's look at the data first.

Data

Our analysis covers the period of 1970 – 2000 from the breakdown of the Bretton Woods System of exchange rates and the oil crises to the eighties and nineties when countries continued to open up and integrate their economies more and more into international production networks. We chose this period because there have been clear developments in the terms-of-trade volatility (e.g. the oil price shocks in the seventies) as well as clear differentiated developments in the level of openness of countries. Some – notably the Asian economies – have relied on export orientation as a road to development and been successful at it while others – notably many African countries – applying import substitution policies have not been so open. Other periods have also been looked at by others, for example Blattman, Hwang and Williamson (2004).

We have collected data for 53 countries as listed in Appendix 2. Because we are looking for overall effects of terms-of-trade volatility we did not split the sample into various subcategories. The key variables that we used are the following:

- **GDP per capita (at constant 1995 US$).** We have used the World Development Indicators 2005 of the World Bank for time series on GDP per capita and from there calculated the growth rates in GDP per capita per country. Given the time span of 1970 – 2000 the data were available for 53 countries (see Appendix 2).

- **Openness measured as the share of exports of goods and services in GDP (X/GDP).** Using the World Development Indicators 2005 of the World Bank we obtained the time series for 1970 – 2000 for 53 countries. It is the effect of openness on economic growth per capita that we are looking for as well as the effect on terms-of-trade volatility on the level of openness.

- **Terms-of-Trade volatility.** Since we are interested in volatility in the terms-of-trade and not any kind of trend, we first calculated the net barter terms-of-trade from the unit price of exports and imports (IMF International Financial Statistics) and then regressed the terms-of-trade on time and the square of time:

  $$ToT = \alpha_1 + \alpha_2 t + \alpha_3 t^2 + \varepsilon_t \qquad (3.37)$$

  Thus eliminating a possible trend or cyclical component, the part that was not explained, i.e. the short-run volatility around the mean is captured by the variable ε_t as standard error of the regression. This SE is used as the measure for terms-of-trade volatility in the subsequent regressions.

- **Secondary school enrolment (gross %).** In standard growth regressions, human capital is an important explanatory variable. Secondary school enrolment is a proxy for the level of human capital in the country. The data were obtained from the World Development Indicators 2005 of the World Bank.

- **Personal freedom and liberties** are approximated with the Gastil index that we obtained from Freedom House. The index ranges from 1 to 7 where 1 is the higher degree of freedom and 7 the lowest.

Empirical strategy

There are two model predictions that we want to test empirically in this section of chapter three: first of all the effect of terms-of-trade volatility on the level of openness of a country and secondly the effect of terms-of-trade volatility directly on the per capita economic growth rate. The basic empirical specifications look as follows:

$$GRPCGDP_t = \beta_1 + \beta_2 \ln PCGDP_{1970} + \beta_3 R\_\ln XGDP_t + \beta_4 \ln SE + \beta_5 \ln TOTV_t + \beta_6 \ln PF_t + \varepsilon_t \qquad (3.38)$$

$$\ln XGDP_t = \gamma_1 + \gamma_2 \ln GDP_{1970} + \gamma_3 \ln TOTV_t + \varepsilon_t \qquad (3.39)$$

Because the log-level of openness as well as the log-level of terms-of-trade volatility are present in both equations there is interdependence of the two equations. The terms-of-trade volatility has an effect on openness and thus on growth and we also expect terms-of-trade volatility to have a direct impact on output growth. In order to avoid multicollinearity between openness and volatility, we first carry out regression (3.39) and use the residuals from openness regression (3.39) (denoted as $R\_\ln XGDP_t$) in growth regression (3.38). This way we split the two effects and we can look at the coefficients separately: γ_3 measures the effect of volatility on openness and β_5 measures the direct effect of terms-of-trade volatility on output growth corrected for the indirect effect of volatility on openness.

In order to avoid a problem with possible heteroskedastic properties and misspecification because of OLS regression, we also carry out the growth regression with robust standard errors.[52]

Given our model outcomes, *ex ante* we expect the following results:

- A negative relation between initial GDP p.c. and GDP growth p.c. because we expect poor countries to grow faster than rich ones (based on the conditional convergence literature).
- A positive relation between openness and GDP growth p.c. because trade is good for growth and it allows the imports of new technologies and inventions done elsewhere in the world.
- A positive relation between % of secondary education enrolment and GDP growth p.c. because investments in human capital make an economy more productive.

[52] Ordinary Least Squares estimation leads to overestimation of the error-term in case of heteroskedasticity which leads to t-values that are too low. This can be corrected for by using robust standard errors.

- A negative relation between terms-of-trade volatility and GDP growth p.c. because volatility leads to uncertainty and higher ‘costs’ of investment.
- A positive relation between personal freedom and GDP growth p.c. because more freedom means individual thinking and creativity are valued more which is good for innovative behaviour.
- A negative relation between terms-of-trade volatility and openness because we expect the tradable sector to suffer more from volatility than the non-tradable sector reallocating resources in the economy away from the tradable sector, leaving it more closed.

Results

The results of the regression analyses are shown in table 3.1 and in table 3.2. Specifications 3.1.B and 3.2.B are the openness regressions using robust standard errors correcting for heteroskedasticity.

*Table 3.1. Regression results ‘Growth Regression’**

Variable	3.1.A.	3.1.B.
Constant	5.16**	5.16
	(0.077)	*(0.106)*
Ln p.c. GDP_{1970}	-0.78**	-0.78**
	(0.009)	*(0.019)*
R_Ln XGDP	0.77	0.77
	(0.143)	*(0.144)*
Ln SE	1.32**	1.32**
	(0.016)	*(0.009)*
Ln TOTV	-0.73	-0.73*
	(0.117)	*(0.093)*
Ln PF	-0.58	-0.58
	(0.387)	*(0.426)*

*P-values in parenthesis; $R^2 = 0.30$; ** = significant at 5% level; * = significant at 10% level*

From table 3.1, column 3.1.B. it becomes clear that initial level of per capita GDP has a negative impact on economic growth per capita at the 5%-level (P-value of 0.017).

There is a positive effect of openness on growth even though it is not significant. Secondary education has a strong positive and significant effect on per capita growth in GDP. Terms-of-trade volatility has the expected sign and is statistically significant at the 10% level. When running the growth regression again, this time without TOTV, the difference is about 4% in the variation in growth rates. This is not a huge direct effect of TOTV on GDP growth, but it is significant. 30% of the variation in growth rates is accounted for by the explanatory variables.

Table 3.2. Regression results 'Openness Regression'

Variable	3.2.A.	3.2.B.
Constant	4.32**	4.32**
	(0.000)	*(0.000)*
Ln GDP_{1970}	-0.17**	-0.17**
	(0.000)	*(0.000)*
Ln TOTV	-0.34**	-0.34**
	(0.001)	*(0.005)*

*P-values in parenthesis; $R^2 = 0.36$; ** = significant at 5% level; * = significant at 10% level*

Our results in table 3.2 column 3.2.B. show that there is a negative and significant relation between initial levels of GDP and openness and that there is a negative and significant relation between volatility in the terms-of-trade and openness (a P-value of 0.000). This is evidence that terms-of-trade volatility is a significant determinant for openness. Overall we find that 36% of openness is related to the size of the economy and terms-of-trade volatility. Only about 5% of this is related to volatility itself. This means the volatility – openness – growth mechanism is weak. The direct link between volatility and growth is significant at the 10% level with volatility explaining about 4% of the variation in economic growth rates.

3.7. Conclusions

Looking at the effect of uncertainty on economic growth, an important factor that emerges from the literature is the terms-of-trade. Whether or not there is a trend in the terms-of-trade is still a matter of debate while there is widespread agreement about the fact that terms-of-trade volatility has a negative impact.

We show that in a theoretical setting with an Armington model, we expect terms-of-trade volatility to have a negative effect on economic growth and on the level of openness of a country. A higher variance in prices leads to lower steady-state income levels because real returns to investors will drop and so will the equilibrium capital stock. This means that countries that experience high levels of volatility are expected to be on lower transitional growth paths. Given the starting level of real per capita GDP, we then find that countries on lower transitional growth paths tend to be more closed.

Empirically, we find evidence for a weak indirect effect of volatility on economic growth per capita through the level of openness. However, the direct effect matters as it can explain around 4% of the variation in growth rates which is not large but significant nonetheless. Also our evidence suggests that growth does depend on openness and openness does indeed depend on variance in prices.

Chapter 4: The static and dynamic costs of trade restrictions

"I think there is a world market for maybe five computers"

Thomas Watson, Chairman IBM, 1943

4.1 Introduction

Empirically, developing countries are largely dependent on R&D efforts undertaken in the industrial countries for access to newly developed products and services and the availability of quality improvements for existing goods and services (see Coe, Helpman, and Hoffmaister, 1997). A few years earlier, Romer (1994) already incorporated this aspect of a developing economy in a static model, where he argued that the costs of unexpected increases in trade restrictions (estimated using Harberger triangles) are smaller than the costs of expected increases in trade restrictions (estimated using Harberger and Dupuit triangles), because the latter affects the range of goods available in the developing economy.

We provide a dynamic extension of this framework in an endogenous growth setting, see Romer (1986, 1990), Grossman and Helpman (1991), and Aghion and Howitt (1992).[53] We analyze a small developing economy which depends on R&D undertaken in the rest of the world and introduced on its market for an extension of the available range of (intermediate) capital goods. Using the variety approach, the introduction of new capital goods is associated with a positive production externality. The providers of the capital goods have market power and are therefore able to charge a mark-up over marginal costs, allowing them to enjoy positive operating profits *if* they introduce their capital good on the market in the developing economy. They will only do so if the discounted operating profits are larger than the introduction costs for their particular variety. In general, therefore, only a fraction of all newly invented goods in the rest of the world will actually be introduced on the market in the developing economy. We analyze how changes in trade policy and various parameters affect the share of actually introduced capital goods. This set up enables us to explain the level of economic development in a dynamic setting and analyze the static and

[53] See van Marrewijk (1999) for an overview.

dynamic costs of trade restrictions (Berden and Van Marrewijk, forthcoming JDE 2007).

Two implications of our model are worth emphasizing from the start. First, the estimated static costs of trade restrictions are smaller than the dynamic costs of trade restrictions if, and only if, the increase in trade restrictions reduces the *share* of invented capital goods introduced on the market. In this dynamic setting it is therefore not the fact that we ignore the Dupuit triangles of newly invented goods in estimating the effects of an increase in trade restrictions, as it is in the Romer (1994) model, but the fact that an increase in the trade restrictions affects the share of newly invented goods not introduced on the market. Second, as a result of the sunk-cost nature of the introduction costs, there is an asymmetric adjustment path of the developing economy after a change in trade restrictions. An increase in the level of trade restrictions will slow-down economic growth and put the economy on a transition path to a new balanced growth rate. If the new level of trade restrictions exceeds a critical value, the new growth rate will be zero and stagnation occurs. If trade restrictions fall, the developing economy may embark on a rapid catch-up process of economic growth by benefiting from the backlog of previously-invented-but-not-yet-introduced capital goods which may now, as a result of the increase in operating profits resulting from the decrease in trade restrictions, be introduced on the market in the developing economy.

We believe that the second implication of our model, that a decline in prosperity following increases in trade restrictions is more gradual than the potential increase in prosperity following reductions in trade restrictions, is in accordance with empirical observations. In the period 1973-1991, for example, Maddison (2003) estimates per capita GDP in the North Korean economy to be stagnant at $2,841 (in 1990 international Geary-Khamis dollars). Arguably, this stagnation is caused by the high level of trade restrictions, which makes it unprofitable to introduce newly invented goods and services on the North Korean market. Since the rest of the world continues to grow in this same time period (by investing in capital, schooling, and R&D to develop new goods and varieties or discover quality improvements for existing goods), North Korea's level of income per capita relative to the world average gradually declines from 69 percent in 1973 to 55 percent in 1991. The South Korean economy, in contrast, continues to rapidly open up to the world economy in this period and experiences an impressive increase in GDP per capita relative to the world average, namely from 69 percent in 1973 to 184 percent in 1991. In the absence of extreme terms of trade effects and catastrophes, such as wars, floods, and famines, it appears that a relative decline in production occurs more gradually than seems to be possible in the catch-up process of a relative increase in production. For example, seven countries (mostly the 'Asian Tigers') have experienced an increase of more than 100 percent in per capita income relative to the world average within a 20 year period at least once in the last decade of the 20th century.[54] Although a similar decrease also occurred seven times, this is never due to the size of the contraction of economic production, but always the result of a large negative terms of trade effect, namely in the price of oil.[55]

Section 4.2 provides the basic structure of the model. Section 4.3 determines the range of invented capital goods actually introduced on the market in the developing economy. Sections 4.4 and 4.5 focus on the balanced growth path and the long-run implications of changes in trade restrictions. Sections 4.6-4.8 analyze the asymmetric transition dynamics and the static and dynamic costs of trade restrictions, followed by a brief discussion in section 4.9 and a general summary and conclusions in section 4.10.

4.2 The model

Our analysis focuses on a small developing economy which at time t uses labor $L(t)$ and a range (indexed by i) of different types of capital goods $x(i,t)$ to produce a final good $Y(t)$. The set of available capital goods at time t is denoted by $A(t)$. We use the term capital goods in a broad sense to refer to intermediate goods and services used in the production of final goods, that is we employ the Ethier (1982) interpretation of a continuous representation of the Dixit-Stiglitz (1977) constant elasticity of substitution variety function (a generalization of Romer, 1994). It is well-known that, given the claim on real resources, an increase in the number of varieties

[54] The countries are: Norway, Ireland, Japan, South Korea, Taiwan, Hong Kong, and Singapore.
[55] The countries are: Venezuela, Iraq, Kuwait, Qatar, Saudi Arabia, United Arab Emirates, and Gabon

available in the economy will lead to higher productivity through a positive externality effect, see van Marrewijk (2002, chs 10, 16). Since our focus is on the introduction of new capital goods, we keep the level of employment constant, that is $L(t) = L$. It is, however, straightforward to allow for changes in employment. This brings us to the following aggregate production function:[56]

$$Y(t|.) = L^{1-\alpha} \int_{i \in A(t)} x(i,t)^{\alpha}\, di\,; \quad \alpha \in (0,1) \tag{4.1}$$

The ultimate objective is to explain the level of economic development in a dynamic setting and illustrate various types of welfare costs of imposing trade restrictions or other impediments to economic interaction with the rest of the world. To do this, we have in mind a Romer (1990) or Grossman and Helpman (1991) type endogenous growth model giving rise to an ever expanding variety of capital goods in the rest of the world. Since the economy we are analyzing is only a small developing economy, we make two simplifying assumptions, namely (i) this economy cannot influence the economic growth rate in the rest of the world and (ii) this economy does not engage in any R&D activity to develop new types of capital goods. As mentioned in the introduction to this dissertation, these are exactly the assumptions we generally make with respect to developing economies.

Assumption (ii) implies that the small developing economy depends on R&D activity in the rest of the world for introducing new types of capital goods, which is in accordance with the empirical results of Coe, Helpman, and Hoffmaister (1997). Assumption (i), in combination with the assumption that the rest of the world is on a positive balanced growth path, implies that the world's growth rate of knowledge (measured by the total range of invented capital goods $N(t)$) is equal to a constant $g > 0$, that is:

$$N(t) = N(0)e^{gt} \equiv N_0 e^{gt}\,; \quad \dot{N}(t)/N(t) = g > 0\,; \quad where\ \dot{x} \equiv dx/dt$$

$$N(t) = N(0)e^{gt} \equiv N_0 e^{gt} \tag{4.2}$$

[56] The notation $t|.$ signals that the income level may depend on historical developments, see the sequel. See Berden and van Marrewijk (2001) for a similar structure to determine active and non-active firms.

In general, the range of invented capital goods available to producers in the *developing* country is a *subset* of the total range of invented goods (assumed to be a measurable set), see equation (4.3). The objective of this chapter is to determine the size of this subset as a function of trade restrictions and the costs of introducing the capital good on the market of the developing country in a small general equilibrium model.

$$A(t) \subseteq [0, N(t)] \tag{4.3}$$

Given the range of available capital goods $A(t)$, the production function exhibits constant returns to scale in L and $x(i,t)$. This allows us to model the production of final goods in the developing economy as perfectly competitive, where the producers face wage rate $w(t)$ for the use of labor and prices $p(i,t)$ for the use of capital goods $x(i,t)$. In equilibrium, profits by the final goods producers are zero, labor's share of income will be equal to $1-\alpha$, and in the aggregate the share of income paid for the use of all capital goods will be equal to α, see equation (4.4). Moreover, the price elasticity of demand for individual capital goods by final goods producers is equal to a constant $\varepsilon > 1$, see equation (4.5).

$$w(t)L = (1-\alpha)Y(t); \quad \int_{i \in A(t)} p(i,t)x(i,t)\,di = \alpha Y(t) \tag{4.4}$$

$$x(i,t) = \alpha^{\varepsilon} L\, p(i,t)^{-\varepsilon}; \quad \varepsilon \equiv 1/(1-\alpha) > 1 \tag{4.5}$$

To determine the range of invented capital goods actually introduced on the market of the developing economy, we have to confront the costs and benefits of doing this to the inventor of a particular capital good. Starting with the latter, we will assume that the monopolistic producer of a capital good (who has the sole property rights to selling this good) can produce a unit of the capital good at a constant marginal cost of 1. To enable us to investigate the dynamic effects of trade restrictions, we will assume that the government of the developing country requires a payment of tariff T for the imports of foreign goods.[57] The foreign producers of capital goods take this tariff rate as given and assume that it will be applied indefinitely. As a result of the additively separable structure of the production function, the demand for a particular capital good *if* it is introduced on the market in the developing economy is stable over time, see equation (4.5) and Romer (1994). Since the price elasticity of demand is constant, the price of introduced capital goods is a constant mark-up over marginal costs and does not change over time, see equation (4.6). Obviously, an increase in the tariff rate leads to a higher price charged for the use of capital goods and thus a lower quantity demanded. The equilibrium quantity demanded for actually introduced varieties can be easily determined by substituting the optimal price (eq. 4.6) into market demand (eq. 4.5), see equation (4.7).

$$p(i,t) = (1+T)/\alpha \equiv p(T); \quad p'(T) = 1/\alpha > 0 \tag{4.6}$$

$$x(i,t) = \alpha^{2\varepsilon} L(1+T)^{-\varepsilon} \equiv x(T); \quad x'(T) = -\varepsilon\, x(T)/(1+T) < 0 \tag{4.7}$$

As a result of the above, instantaneous operating profits π for the providers of capital goods actually introduced on the market are constant over time, see equation (4.8). This means that the present value of operating profits of a capital good introduced at time t and discounted at the interest rate $\rho > 0$ is equal to the instantaneous operating profits divided by the interest rate, see equation (4.9).

$$\pi(T) \equiv p(T)x(T) - (1+T)x(T) = (1-\alpha)\alpha^{2\varepsilon-1} L(1+T)^{1-\varepsilon} \tag{4.8}$$

$$\pi'(T) = -(\varepsilon - 1)\pi(T)/(1+T) < 0$$

$$\int_t^\infty e^{-\rho(\tau-t)}\pi(T)\, d\tau = \pi(T)/\rho \tag{4.9}$$

Before the owner of capital good i invented at time t can reap the benefits of discounted operating profits from the market of the developing economy she has to

[57] Equivalently, the domestic government could impose a tax on goods produced by foreign companies.

introduce this good to the market at a fixed introduction cost $c(i,t)$. This can be the cost of setting up a service and parts supply network or the costs of setting up a local branch consulting office, etc. We assume these introduction costs may vary for the various producers of intermediate goods varieties from a minimum of a to a maximum of b. More specifically, we will assume that these costs are drawn independently from a cumulative distribution function F, without mass points and with support $[a,b]$ (where $0 < a < b$), see equation (4.10).

The decision on whether or not to introduce the newly invented capital good on the market in the developing economy is now simple. The answer is yes if the discounted value of operating profits is larger than the costs of introduction. Otherwise, the answer is no. This decision process is summarized by the indicator function $I(i,t)$ defined in equation (4.11), see also (4.3').

$$c(i,t)\ \textit{iid with cdf}\ F(x)\,; \quad x \in X = \left[a,b\right],\ F(a)=0,\ F(b)=1, \tag{4.10}$$

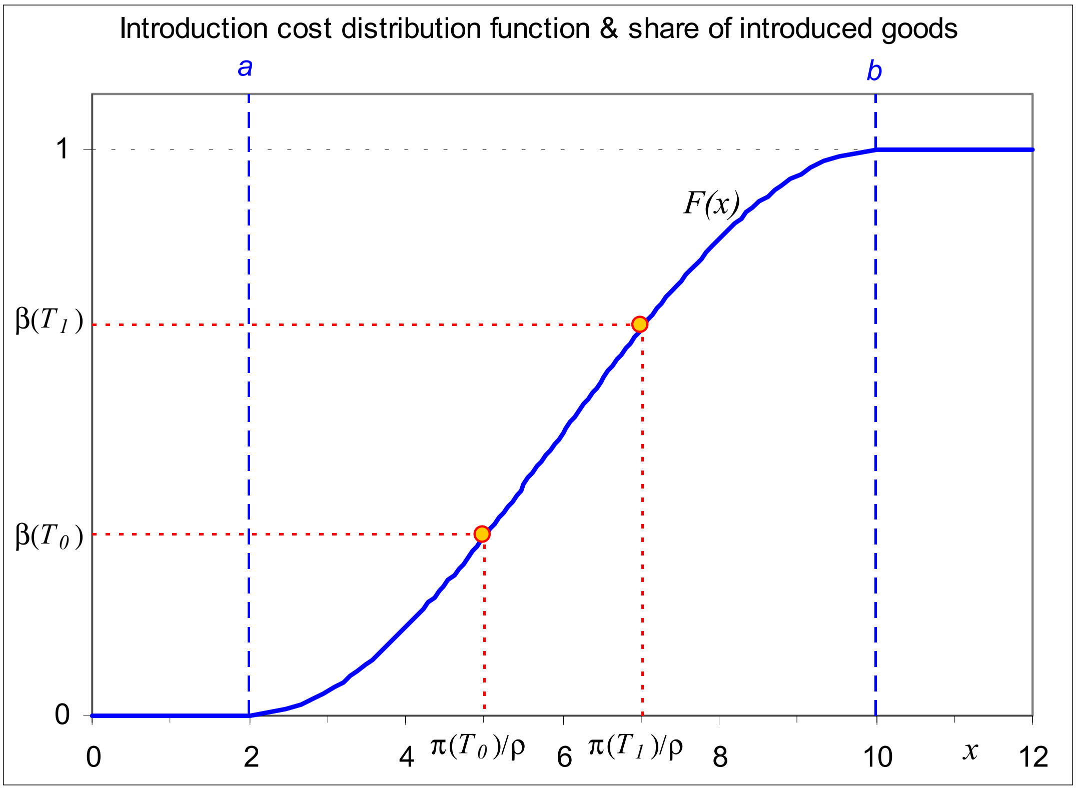
$$I(i,t) = \begin{cases} 1, & \textit{if}\ \pi(T)/\rho > c(i,t) \\ 0, & \textit{otherwise} \end{cases} \tag{4.11}$$

$$A(t) = \left\{ i \in [0, N(t)] \,\middle|\, I(i,.) = 1 \right\} \tag{4.3'}$$

4.3. The range of introduced capital goods

We are now in a position to determine the range of capital goods introduced on the market in the developing economy relative to the total range of invented goods in the rest of the world as a function of the trade restrictions T, as summarized by the introduction decision of equation (4.11). At each point in time, the growth rate of new capital goods invented in the rest of the world is g, implying that $gN(t)$ new goods become available for introduction on the market in the developing economy. Clearly, if the discounted value of operating profits $\pi(T)/\rho$ is smaller than the minimum introduction costs a *none* of the new capital goods will be introduced on the market in the developing economy. Similarly, if the discounted value of operating profits is higher than the maximum introduction costs b *all* of the new capital goods will be introduced on the market. The more interesting case occurs, therefore, if the discounted value of operating profits is in between these two extremes, that is $\pi(T)/\rho \in X$. Since the introduction costs are drawn independently from the same distribution function, the law of large numbers, which holds in this continuous specification over the number of capital goods and time, ensures that a stable *fraction*, β say, of the newly invented capital goods will actually be introduced on the market in the developing economy. At each point in time, therefore, $\beta gN(t)$ new capital goods will be available in the developing economy.

Figure 4.1. Distribution function F and share of introduced goods β



The illustrated cdf is a beta distribution with support [2,10] and parameters equal to 2.

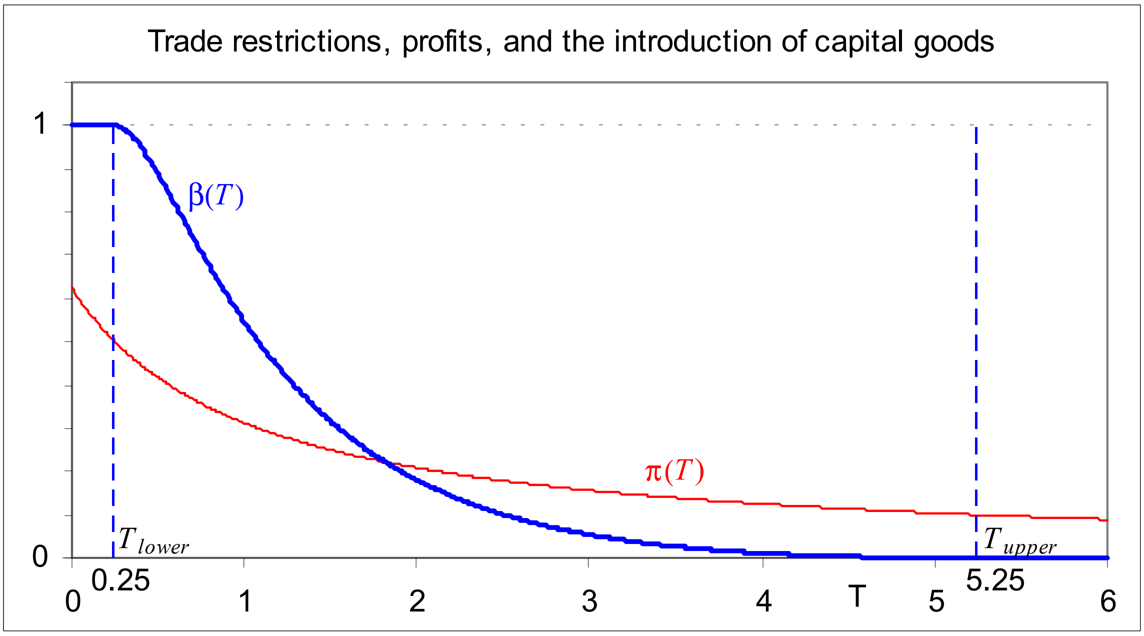
Figure 4.1 illustrates how the fraction of introduced capital goods β depends on the trade restrictions T as a function of the operating profits π, the rate of discount ρ, and the distribution function F. Suppose the import tax is initially T_0, leading to discounted operating profits $\pi(T_0)/\rho$. Given enough observations, a fraction

$F(\pi(T_0)/\rho)$ of the randomly drawn introduction costs will be below the discounted operating profit threshold $\pi(T_0)/\rho$. All these capital goods will be introduced on the market. Similarly, a fraction $1-F(\pi(T_0)/\rho)$ will be above the discounted operating profit threshold $\pi(T_0)/\rho$. All these capital goods will not be introduced on the market. If the trade restriction falls, say to $T_1 < T_0$, the discounted operating profit threshold will rise to $\pi(T_1)/\rho$ and a larger share of newly invented capital goods $F(\pi(T_1)/\rho)$ will actually be introduced on the market, see figure 4.1. To summarize, the share of capital goods actually introduced on the market in the small developing economy is equal to:

$$\beta(T) \equiv \begin{cases} 0, & \text{if } 0 < \pi(T)/\rho < a; \quad \beta' = 0 \\ F(\pi(T)/\rho), & \text{if } a \leq \pi(T)/\rho \leq b; \quad \beta' = F'\pi'/\rho < 0 \\ 1, & \text{if } b < \pi(T)/\rho < \infty; \quad \beta' = 0 \end{cases} \tag{4.12}$$

The crucial point is, of course, that the range of introduced new capital goods depends negatively on the trade restrictions T, which allows us to investigate both dynamic and static welfare costs in the analysis below. This is illustrated in figure 4.2, where it is assumed that in the absence of trade restrictions ($T = 0$) all newly invented capital goods will actually be introduced on the market in the developing economy.

Figure 4.2 Trade restrictions, profits, and the introduction of new capital goods



Note: $\alpha = 0.5, L = 10, \rho = 0.05$, *for the distribution function see figure 4.1.*

An increase in the level of trade restrictions immediately implies a higher price charged for the use of capital goods (eq. 4.6), a lower quantity of capital goods used (eq. 4.7), and lower profits for the producers of capital goods (eq. 4.8 and figure 4.2). Despite the lower profit level, however, the inventors of new capital goods will still introduce all of them on the market, provided the trade restrictions are not too high. Beyond a critical value of trade restrictions, equal to 25 per cent ($T = 0.25$) in figure 4.2, some inventors of new capital goods will decide that the costs of introducing the capital goods on the market in the developing economy are higher than the discounted value of operating profits. The share of actually introduced capital goods then starts to decline gradually until a second critical value is reached, equal to 525 per cent ($T = 5.25$) in figure 4.2, beyond which no newly invented capital goods will be introduced on the market. These critical values are, of course, determined by the support limits a and b of the distribution function in conjunction with discounted profits, see equation (4.12). For ease of reference we will call these critical values T_{upper} and T_{lower}, defined as follows:

- $T_{upper} \equiv \pi^{-1}(\rho a); \quad T \geq T_{upper} \Rightarrow \beta(T) = 0$
- $T_{lower} = \begin{cases} 0, & if\ \pi(0)/\rho < 1 \\ \pi^{-1}(\rho b), & otherwise \end{cases}; \quad 0 \leq T \leq T_{lower} \Rightarrow \beta(T) = 1$

4.4. Government revenue and welfare

This section focuses on government revenue and welfare as a function of trade restrictions under the assumption that the same policy has been operative indefinitely. We therefore assume that the same fraction of capital goods as dictated by the function $\beta(T)$ of equation (4.12) has also been introduced at time 0. The next section analyzes transitory dynamics if government policy is changed. Under the simplifying assumption above, the share of actually introduced capital goods is constant over time. More specifically, if $M(.)$ is the Lebesgue measure, it follows that:

$$M(A(t)) = \beta(T)N(t); \quad \beta(T) > 0 \Rightarrow \dot{M}(A(t))/M(A(t)) = \dot{N}(t)/N(t) = g \qquad (4.13)$$

The growth rate of newly available capital goods in the developing economy is therefore equal to the growth rate g in the rest of the world for all time periods. This allows us to explicitly determine the level of output at any point in time as a function of the level of trade restrictions by using equations (4.7), (4.12), and (4.13), see equation (4.1'). Since both the use of capital goods x is a declining function of T and the share of new capital goods introduced on the market is a non-increasing function of T, the output level is a decreasing function of the level of trade restrictions.

$$Y(t|T) = L^{1-\alpha}M(A(t))\,x(T)^{\alpha} = L^{1-\alpha}x(T)^{\alpha}\,\beta(T)N_0\,e^{gt} \equiv Y(T)\,e^{gt} \qquad (4.1')$$

$$Y'(T) = \left[(\beta'/\beta) - \alpha\varepsilon/(1+T)\right]\,Y(T) < 0$$

In the absence of an efficient tax collecting system, which requires detailed information on the inhabitants of a country, their income level, etc., as well as public servants gathering and processing information, the governments of many developing nations are tempted to collect tax revenue by imposing trade restrictions on the import of goods and services.[58] Total government revenue G is equal to the tariff T multiplied by the import of capital goods x and the measure of active firms $M(A(t))$. As with the income level given in equation (4.1'), this implies that government

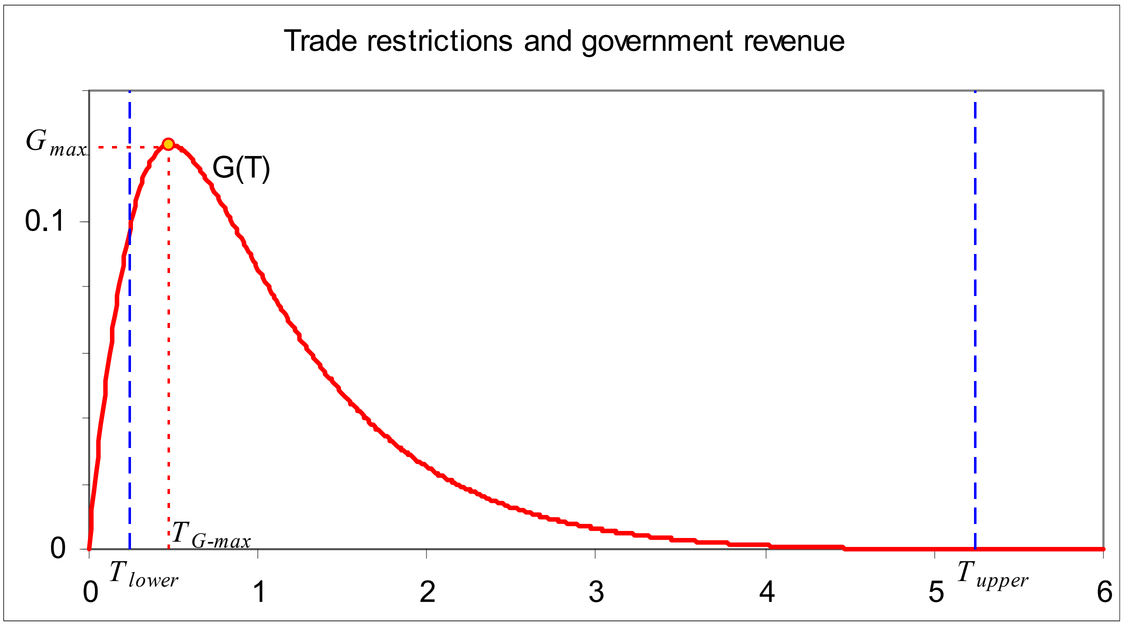
[58] The government of Swaziland, for example, relied on import duties to collect 55 per cent of total tax revenue in 2000 (World Bank Development Indicators CD-Rom 2003).

revenue increases exponentially and depends on the level of trade restrictions as follows:

$$G(t|T) = M(A(t))\,T\,x(T) = \beta(T)\,T\,x(T)\,N_0\,e^{gt} \equiv G(T)\,e^{gt} \qquad (4.14)$$

$$G'(T) = \beta\,x\,N_0 + \left[(\beta'/\beta) - \varepsilon/(1+T)\right]\,G(T); \quad G(0) = G(T_{upper}) = 0; \quad G'(0) > 0$$

Figure 4.3 Trade restrictions and government revenue



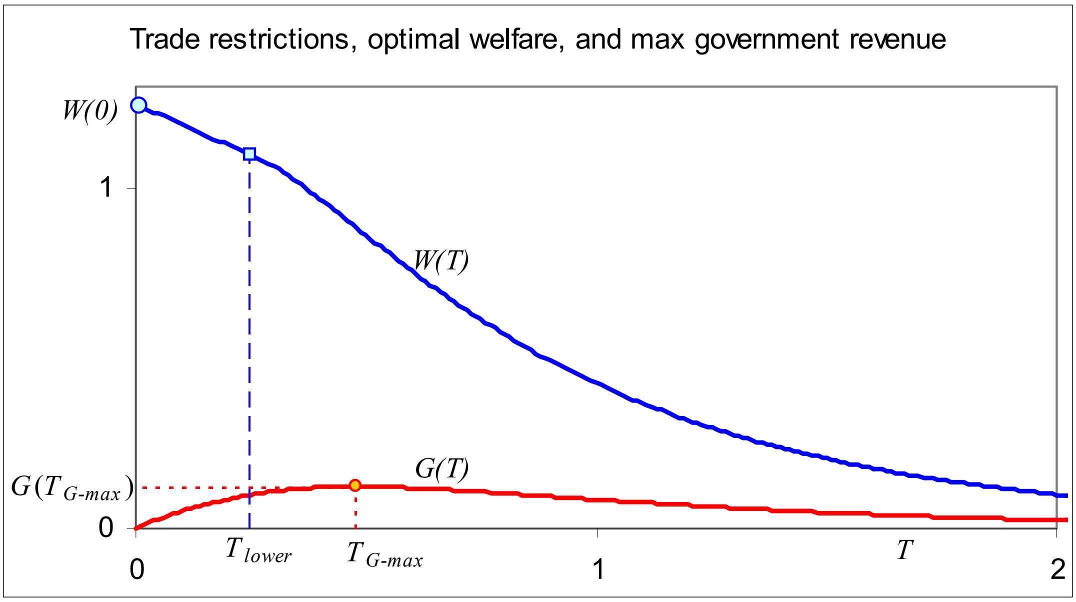
Note: $N_0 = 1$, *for the other parameter values see figure 4.2.*

From the properties of the government revenue function, it follows that there exists a strictly positive level of trade restrictions, $T_{G-\max} \in (0, T_{upper})$ say, which maximizes the present discounted value of government revenue.[59] This is illustrated in figure 4.3. Note that for the parameter setting used in figure 4.2 the level of government revenue maximizing trade restrictions $T_{G-\max}$ is higher than the level for which the share of introduced capital goods starts to decline ($T_{lower} > 0$). In general, this depends on the specific parameters and $0 < T_{G-\max} < T_{lower}$ is also possible. This finding is in line with

[59] Alternatively, myopic government revenue maximization (which takes the measure of active firms as given) leads to $T_{myopic} = 1/(\varepsilon - 1)$, which in general is larger than $T_{G-\max}$ due to the term β'/β in (4.14).

Rodrik (1994) who emphasises the importance of tariffs as a source of government revenue.

Figure 4.4 Trade restrictions, optimal welfare, and maximum government revenue



Same parameter values as used in figure 4.3.

Instantaneous welfare W for the small developing economy is the sum of government revenue (eq. 4.14) and labor income (eq. 4.4), see equation (4.15). As explained below the equation, given t instantaneous welfare is a declining function of trade restrictions T, where the first inequality follows from ignoring some negative terms, after which we use sequentially $(1-\alpha)\varepsilon = 1$, the fact that βN_0 is equal to the Lebesgue measure of active firms at time 0 in conjunction with the second part of equation (4.4) while simultaneously using equations (4.6) and (4.7), and again the optimal pricing rule given in equation (4.6), leading eventually to the conclusion that $W'(T) < 0$.

$$W(t|T) = G(t|T) + (1-\alpha)\,Y(t|T) = \left[G(T) + (1-\alpha)Y(T)\right]\, e^{gt} \equiv W(T)\,e^{gt} \qquad (4.15)$$

$$\begin{aligned} W'(T) &= \beta x N_0 + (\beta'/\beta)W(T) - \varepsilon G(T)/(1+T) - \alpha\varepsilon(1-\alpha)Y(T)/(1+T) < \\ &< \beta x N_0 - \alpha\varepsilon(1-\alpha)Y(T)/(1+T) = \beta x N_0 - \alpha Y(T)/(1+T) = \\ &= x M(A(0)) - p\, x M(A(0))/(1+T) = x M(A(0))\left[1 - 1/\alpha\right] < 0 \end{aligned}$$

Since total welfare is just the discounted value of instantaneous welfare, the optimal policy is to impose no trade restrictions at all, leading to total welfare $W(0)/(\rho - g)$. As follows from equation (4.14) and is illustrated in figure 4.4, however, a government maximizing the discounted value of government revenue would choose the level of trade restrictions $T_{G-\max} > 0$, leading to a sub-optimal outcome in terms of welfare. In general, therefore, any government assigning a disproportionate weight to the importance of obtaining government revenue from trade restrictions will impose a too high level of trade restrictions. In the thought experiment of this section, which ignores transition dynamics, the increase in the number of new goods, which is equal to the growth rate of the economy, is dictated by progress in the rest of the world and equal to g for all time periods. The next section briefly discusses the long-run implications of policy changes along this balanced growth path. Sections 4.6-4.8 demonstrate not only that the economy will indeed evolve over time towards the balanced growth path, but also that the deviation in economic growth rate and the level of income can be substantial if we allow for changes in government policy and incorporate transition dynamics. Proposition 4.I summarizes the main analytic results derived so far.

Proposition 4.I. The balanced growth path of the economy regarding income, government revenue, and welfare is given in equations (4.1'), (4.14), and (4.15), respectively. Income, welfare, and the share of capital goods introduced on the market in the developing economy increase if the level of trade restrictions falls.

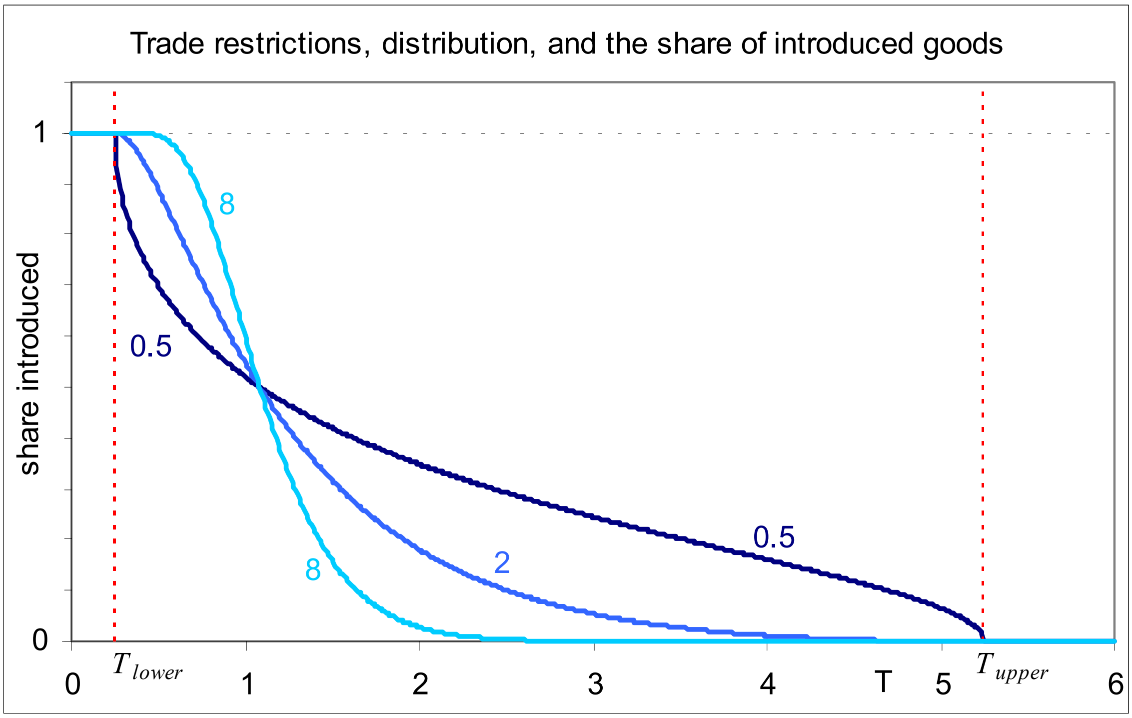
4.5. Long-run implications of policy changes[60]

As discussed in sections 4.6-4.8 below, the economy will adjust from one balanced growth path to another after a change in government policy, where the speed of adjustment depends on the size of the policy change as well as its direction. The long-run implications of the policy change are, however, determined by the new balanced growth path, which was characterized in sections 4.3 and 4.4, see equations (4.1') and (4.12)-(4.15). The discussion and exposition in section 4.4 emphasizes the implications of a change in the level of trade restrictions. An increase in trade

[60] The terms 'increases' and 'decreases' as used in this section indicate 'non-decreasing' and 'non-increasing', respectively.

restrictions (i) increases the price of capital goods, (ii) decreases the quantity demanded, (iii) decreases the profit level, (iv) decreases the share of capital goods introduced on the market in the developing economy, (v) reduces the income level, and (vi) reduces the welfare level. The effect of an increase in trade restrictions on government revenue is ambivalent. We now briefly review the impact of other parameter changes.

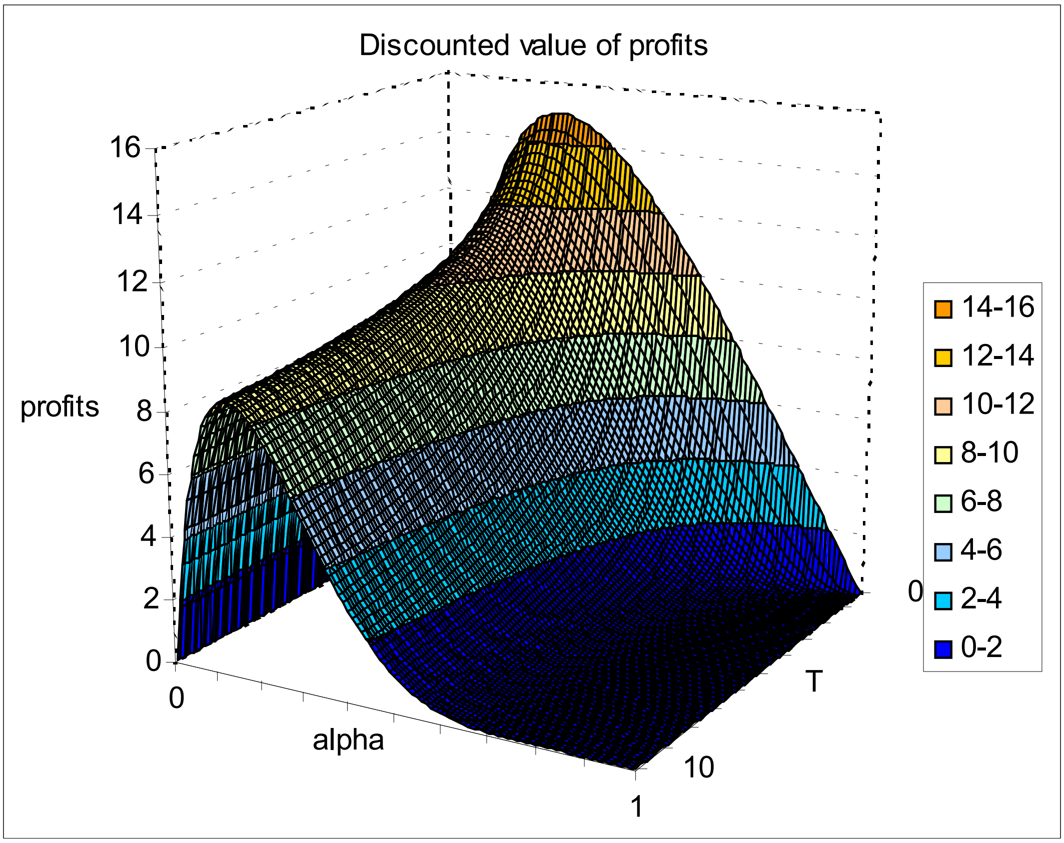
Figure 4.5 Effect of changes in the shape of distribution function on β



Beta distribution function parameters are 0.5, 2, and 8; for other parameters see figure 4.3.

The effect of a change in the discount rate ρ is straightforward. A decrease in the discount rate increases discounted profits and therefore the share of introduced capital goods. This, in turn, increases the income level, government revenue, and welfare. The effect of a change in the distribution function F is quite similar to a change in ρ, as it also only affects the equilibrium through the share of introduced goods. Other things equal, a decrease in the lower limit of introduction costs a or the upper limit of introduction costs b tends to increase the share of introduced goods, which is similar to a decrease in ρ. Changes of the distribution function itself (but not its limits) will affect the speed with which the share of introduced goods changes as the level of trade restrictions changes, but not the critical values T_{upper} and T_{lower}, see figure 4.5. The share of introduced goods curve in figure 4.5 could therefore have any smooth downward sloping shape, as long as it connects the points $(T_{lower},1)$ and $(T_{upper},0)$. In contrast to changes in the discount rate and the distribution function, changes in the labor force L affect the equilibrium not only through changes in the share of introduced goods but also through other economic variables. Since an increase in the labor force increases the demand for capital goods and hence instantaneous and discounted profits, this implies an increase in the share of introduced capital goods, the income level, government revenue, and welfare.

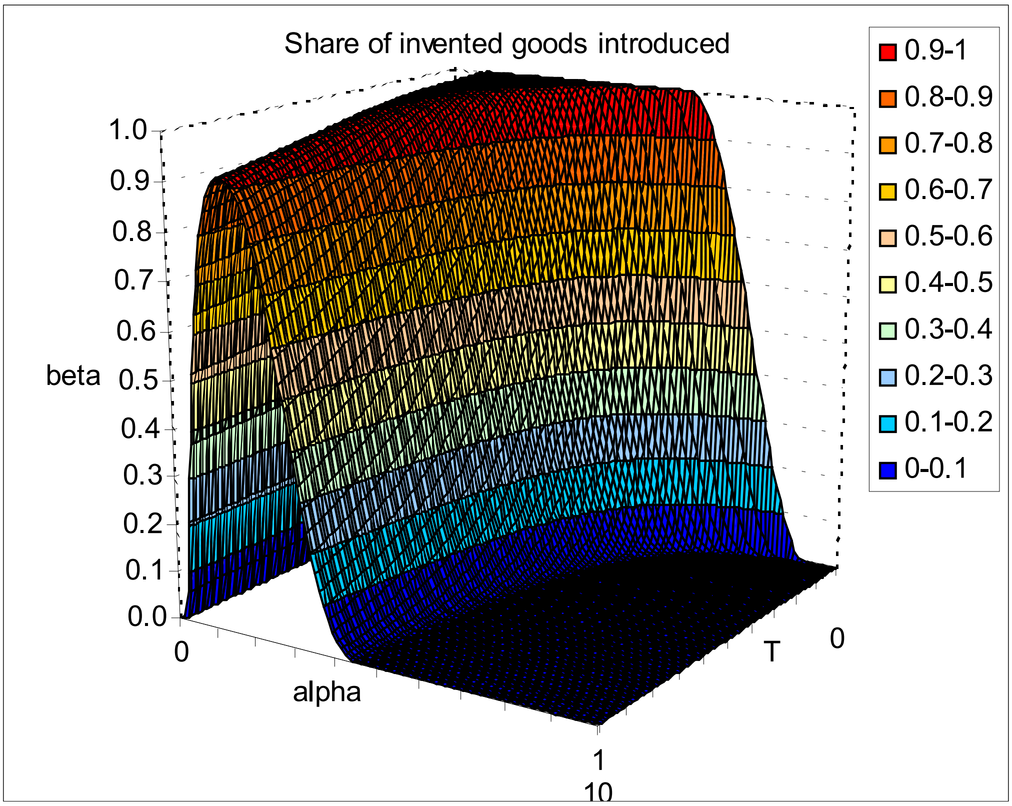
Figure 4.6 Effect of a change in α and T on profitability



Parameter values: $L = 10; \rho = 0.05$.

The effect of a change in α is a little more involved than the effect of a change in the other parameters. On the one hand, an increase in α increases the importance of capital goods in total production and raises the share of income spent on capital goods, thus raising profitability for the capital goods suppliers. On the other hand, an increase in α reduces the firm's market power, leading to a reduction in the mark-up of price over marginal cost and hence profitability. As illustrated in figure 4.6, the first effect (increased importance of capital goods) dominates for low values of α, such that profits initially rise as α increases, while the second effect (reduced market power) dominates for higher values of α. In short, given T, there exists a critical value of α, say $\bar{\alpha}(T)$, such that a rise in α implies increasing profits as long as α is below $\bar{\alpha}(T)$ and falling profits thereafter. Calculations show that $\bar{\alpha}(0) \approx 0.28$, $\bar{\alpha}'(T) < 0$, and $\lim_{T \to \infty} \bar{\alpha}(T) = 0$. The effect of a change in α on the share of goods introduced on the market is basically a truncated translation of the level of discounted profitability, see figure 4.7.

Figure 4.7 Effect of a change in α and T on the share of introduced goods



Parameter values: see figure 4.1 and figure 4.6

4.6. Policy changes and transition dynamics

A crucial aspect of this model is the sunk cost nature of the costs of introducing a capital good on the market of the developing economy, implying that once such a good is actually introduced it will continue to be supplied on the market independently of subsequent changes in the level of trade restrictions. This implies not only that the income level is path-dependent (hysteresis) but also that the response of changes in government policy is asymmetric. We will start our discussion of policy changes and transition dynamics with a simple thought experiment. Section 4.7 relates this to the static and dynamic costs of an increase in trade restrictions, section 4.8 analyzes a decrease in trade restrictions, followed by a brief discussion in section 4.9.

Policy change experiment

Suppose the government of the developing country imposes a tariff level T_0 from time 0 to time t_1. We assume that (i) within this time frame it is *expected* that this tariff level will be maintained indefinitely, (ii) initially a positive fraction of newly invented goods in the rest of the world is actually introduced in the developing country ($0 \leq T_0 < T_{upper}$), and (iii) the economy is initially on a balanced growth path ($M(A(0)) = \beta(T_0) N_0 \equiv M_0$). At time period t_1, however, as the measure of active firms has increased to $M(A(t_1)) \equiv M_1$, the government unexpectedly changes its policy by imposing a tariff level T_1. We furthermore assume that (iv) the government henceforth actually maintains tariff level T_1 indefinitely and (v) it is (perhaps surprisingly) *immediately* expected from time period t_1 onwards that the new tariff level will be maintained indefinitely. Obviously, the new level of trade restrictions may be either higher or lower than the old level. To analyze the impact of policy changes in this thought experiment, the notation $\left| t_1^+ \right.$ will be used to indicate a rise in the level of trade restrictions ($T_1 > T_0$) and the notation $\left| t_1^- \right.$ will be used to indicate a fall in the level of trade restrictions ($T_1 < T_0$).

Section 4.8 will focus on a decrease in trade restrictions. This section analyzes the impact of an *increase* in the level of trade restrictions. Initially, that is in between periods 0 and t_1, the economy is on a balanced growth path. The government levies tariff T_0, the active capital goods providers charge price $p(T_0)$, and the final goods producers demand quantity $x(T_0)$ of each capital good. This implies that the capital goods producers receive operating profits $\pi(T_0)$, which they expect to enjoy forever. Consequently, of the $gN(t)$ new capital goods that are invented each period in the rest of the world, a constant fraction $\beta(T_0)$ will be actually introduced in the developing economy, such that the income level and government revenue evolve according to (4.1') and (4.14), respectively.

Figure 4.8 Impact of an increase in trade restrictions on the rate of economic growth

Parameter values: $\alpha = 0.8; L = 60; \rho = 0.05; g = 0.02; t_1 = 10; T_0 = 0.5; T_1 = 0.6$, *combined with a beta distribution function with support [2,10] and parameters equal to 2.*

From time period t_1 onwards, the government levies tariff $T_1 > T_0$, the active capital goods providers charge price $p(T_1) > p(T_0)$, and the final goods producers demand quantity $x(T_1) < x(T_0)$ of each capital good. The capital goods producers therefore receive operating profits $\pi(T_1) < \pi(T_0)$, which we assumed they expect to enjoy forever. Regarding the range of active capital goods producers we have to distinguish between two groups of producers.

- The first group consists of all capital goods producers who entered the market of the developing economy *before* the policy change at time period t_1. Since the costs of introducing the capital good on the market are sunk costs, they will remain active despite the policy change which reduces the discounted value of operating profits. Consequently, some of these producers will *ex post* conclude that they have made the wrong decision by introducing the capital good on the market as the discounted value of operating profits turns out to be actually lower than the introduction costs.

- The second group consists of all capital goods producers who may enter the market of the developing economy *after* the policy change at time period t_1. They know their instantaneous profits are $\pi(T_1)$ and will enter the market if the discounted profits are higher than the introduction costs, as given in equation (4.12). Since at each point in time $g\,N(t)$ new capital goods are invented in the rest of the world, a fraction $\beta(T_1)$ of these will enter the market of the developing economy from time period t_1 onwards. This allows us to explicitly determine the range of active firms after the policy change:

$$M(A(t))\big|_{t\geq t_1} = M_1 + \int_{t_1}^{t} \beta(T_1)\, g\, N(\tau)\, d\tau = M_1 + \int_{t_1}^{t} \beta(T_1)\, g\, e^{g\tau}\, N_0\, d\tau =$$
$$= \beta(T_1)\, e^{gt} N_0 + \left[\beta(T_0) - \beta(T_1)\right] e^{gt_1} N_0$$

To summarize, we can now determine the range of active capital goods producers on the market of the developing economy, the income level, and the government revenue as a function of time if the government increases trade restrictions at time t_1:

$$M(A(t)|t_1^+) = \begin{cases} M_0 e^{gt}, & \text{if } t\in[0,t_1) \\ \beta(T_1)\, e^{gt} N_0 + \left[\beta(T_0)-\beta(T_1)\right] e^{gt_1} N_0, & \text{if } t\in[t_1,\infty) \end{cases} \tag{4.16}$$

$$Y(t|t_1^+) = \begin{cases} Y(T_0) e^{gt}, & \text{if } t\in[0,t_1) \\ L^{1-\alpha}\, x(T_1)^{\alpha}\, M(A(t)|t_1^+), & \text{if } t\in[t_1,\infty) \end{cases} \tag{4.17}$$

$$G(t|t_1^+) = \begin{cases} G(T_0) e^{gt}, & \text{if } t\in[0,t_1) \\ T_1\, x(T_1)\, M(A(t)|t_1^+), & \text{if } t\in[t_1,\infty) \end{cases} \tag{4.18}$$

Note that, because of the sunk cost nature of the introduction costs, the measure of active firms does not jump at time period t_1. This does not mean that the number of active firms cannot jump, see section 4.8. After the policy change, the economy adjusts over time to a new asymptotic balanced growth path dictated by the new level of trade restrictions T_1. This implies an immediate fall in the economic growth rate, which then gradually rises back to its pre-policy change level, see figure 4.8. The next section discusses the static and dynamic costs of trade restrictions based on the adjustment path given in equations (4.16)-(4.18). Proposition 4.II summarizes the results of this section.

Proposition 4.II. After an increase in the level of trade restrictions in accordance with the policy change experiment, the economy adjusts over time to a new balanced growth path. The transition dynamics regarding the number of active capital goods producers, the income level, and government revenue after an increase in trade restrictions are given in equations (4.16)-(4.18), respectively.

4.7. Static and dynamic costs of an increase in trade restrictions

The main economic implications of the increase in trade restrictions are illustrated for the income level (a perfect measure of the real wage rate in our model) in figure 4.9 using a logarithmic graph. At the time of the policy change there is an immediate reduction in the income level (indicated by the arrow in the figure), not because the number of capital goods firms active in the developing economy changes instantaneously, but because they all charge a higher price for the use of their goods (thus reducing demand and the income level). We will label this the *static* costs of increasing trade restrictions and we will measure it by calculating the reduction in income at time period t_1 as a percentage of income before the policy change. (This is, of course, the same as calculating the fall in discounted income under the *assumption* that the measure of active capital goods firms grows at the constant rate g after the policy change.) The static costs are equal to:

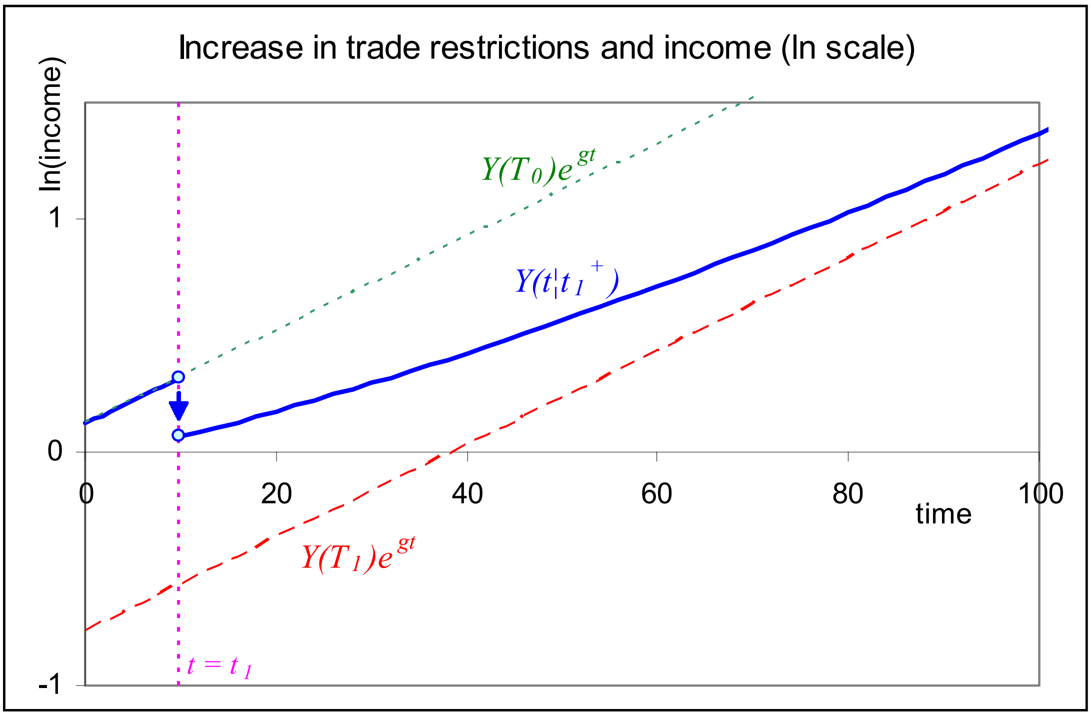
$$Y_{static}^{costs}(t_1^+) \equiv 1 - \frac{Y(t_1|t_1^+)}{\lim_{t \uparrow t_1} Y(t_1|t_1^+)} = 1 - \left[\frac{1+T_0}{1+T_1}\right]^{\alpha\varepsilon} \tag{4.19}$$

After the policy change, the economy adjusts over time to a new asymptotic balanced growth path dictated by the new level of trade restrictions T_1, as illustrated in figure 4.9. This implies that the economic growth rate falls instantaneously (to half its previous level in this case) at time period t_1 and increases gradually thereafter until the old growth rate g is reached asymptotically, see figure 4.8. We will label the decrease of income in all time periods after the policy change the *dynamic* costs of increasing trade restrictions. We will measure these dynamic costs as the discounted value of the reduction in income after time period t_1 as a percentage of the discounted value of income from t_1 onwards without the policy change. With the use of the above equations the dynamic costs are:

(4.20)

$$Y^{costs}_{dynamic}(t_1^+) \equiv 1 - \frac{\int_{t_1}^{\infty} Y(t|t_1^+)e^{-\rho(t-t_1)}\,dt}{\int_{t_1}^{\infty} Y(T_0)e^{-(\rho-g)(t-t_1)}\,dt} = 1 - \frac{Y(T_1)}{Y(T_0)} - \frac{(\rho-g)[\beta(T_0)-\beta(T_1)]L^{1-\alpha}x(T_1)^{\alpha}N_0}{\rho Y(T_0)}$$

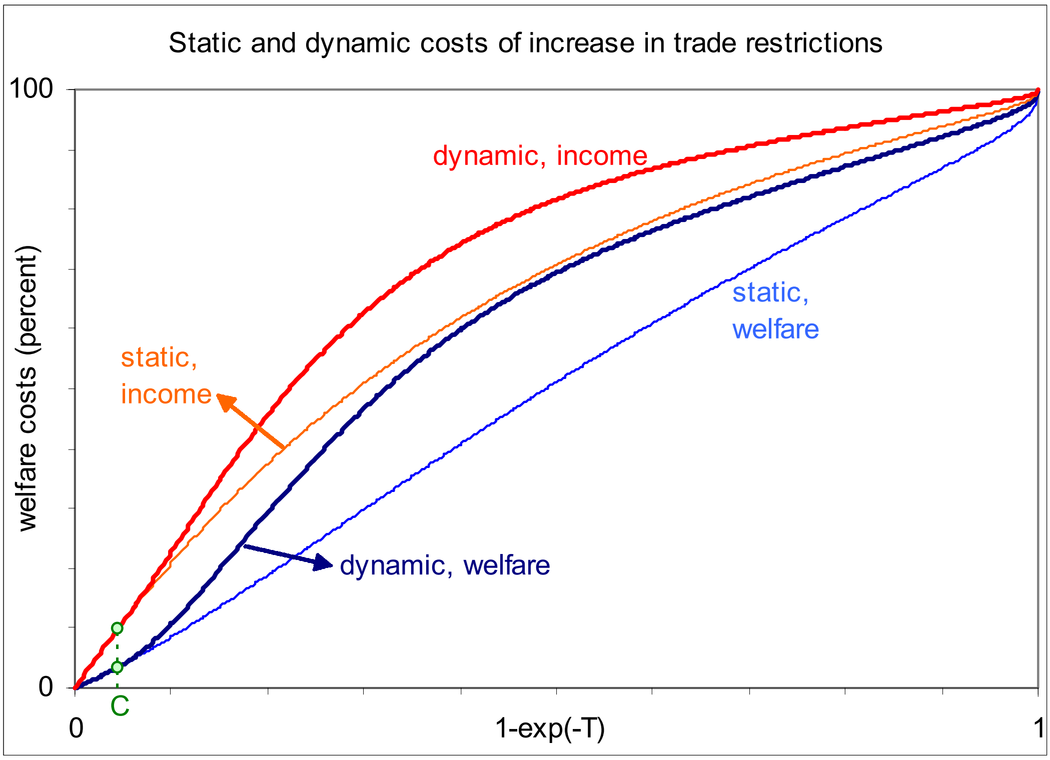
Figure 4.9 Dynamic effects of an increase in trade restrictions



Parameter values: see figure 4.8.

Measuring the static or dynamic loss of an increase in trade restrictions in terms of income is equivalent to measuring the static or dynamic loss in terms of the real wage rate, see equation (4.4). However, these measures tend to overestimate the welfare loss to the small developing economy since the latter should take into consideration the change in government revenue from increasing the trade restrictions. Appendix 3 therefore derives analogous static and dynamic welfare costs in terms of welfare.

Figure 4.10 Static and dynamic welfare and income costs; increase in trade restrictions



Parameter values: $\alpha = 0.7; L = 14; \rho = 0.05; g = 0.02; T_0 = 0$, *combined with a beta distribution function with support [2,10] and parameters equal to 2.*

Figure 4.10 illustrates the static and dynamic welfare costs, both in terms of income and in terms of welfare, starting from an initial position of no trade restrictions ($T_0 = 0$). A few things are worth noting. First, to illustrate these losses in a compact space, the horizontal axis depicts $1 - e^{-T}$, which ranges from 0 to 1; it is 0 if $T = 0$ and rises monotonically with increases in T to approach 1 as $T \to \infty$. Second, as already noted above, the static welfare costs are lower than the static income costs and the dynamic welfare costs are lower than the dynamic income costs. Third, there *may* be an initial range in which the static costs are equal to the dynamic costs, as is the case for the parameter setting illustrated in figure 4.10 for $1-e^{-T} \in [0,C]$. It should be noted that this is not necessarily true for all parameter settings. In particular, it holds only if $0 \leq T_0 < T_{lower}$, in which case $\beta'(T)=0$ and all newly invented goods in the rest of the world are introduced on the market in the developing economy for all T within that range. Fourth, and most importantly, the dynamic costs of an increase in trade restrictions are larger than the static costs as soon as $T > T_{lower}$. This implies that the static costs of imposing trade restrictions, measured by estimating the size of Harberger triangles of actually introduced goods on the market, underestimate the actual (dynamic) costs of imposing trade restrictions as soon as an increase in these costs decreases the *share* of newly invented goods introduced on the market. In this dynamic setting it is therefore not the fact that we ignore the Dupuit triangles of newly invented goods in estimating the effects of an increase in trade restrictions, as it is in the Romer (1994) model, but the fact that an increase in the trade restrictions affects the share of newly invented goods not introduced on the market. As long as this share of introduced goods is not affected, as is the case for $1-e^{-T} \in [0,C]$ in figure 4.10, the usually estimated static costs of an increase in trade restrictions are a perfect measure for the actual dynamic cost of an increase in trade restrictions.

Proposition 4.III. After an increase in the level of trade restrictions in accordance with the policy change experiment, the estimated static costs of trade restrictions are smaller than the dynamic costs of trade restrictions if, and only if, the increase in trade restrictions reduces the share of invented capital goods introduced on the market.

4.8. Reducing trade restrictions: asymmetry in adjustment

The results discussed in sections 4.6 and 4.7 on the effects of an increase in trade restrictions would hold in *reverse* for a decrease in trade restrictions, that is lead to an increase in income and welfare gains mimicking the discussion in section 4.7, *if* we assume that capital goods producers can only enter the market of the developing economy at the moment the new capital good is invented, in which case equations

(4.16)-(4.18) also hold for a decrease in trade restrictions. This, however, seems to be a too restrictive assumption. The crucial difference between an increase and a decrease in the level of trade restrictions is that capital goods producers will not decide to exit the market once they have entered it if restrictions increase (as operating profits are always positive), but may decide to enter the market if they earlier opted not to do so if restrictions decrease. This asymmetry has implications for the adjustment path of the economy.

Suppose that initially a strict fraction of newly invented goods is actually introduced on the market in the developing economy, that is $0 < \beta(T_0) < 1$. A decrease in trade restrictions $T_1 < T_0$ at time t_1 will ensure that from then on a larger fraction $\beta(T_1) > \beta(T_0)$ of all newly invented capital goods in the rest of the world will be introduced on the market in the developing economy. However, at time t_1 there is also a positive mass of capital goods owners who have decided not to introduce the good on the market because the introduction costs were too high compared to the discounted value of operating profits $\pi(T_0)/\rho$. Since at time t_1 the range of invented capital goods in the rest of the world is equal to $N_0 e^{gt_1}$, we know that $(1-\beta(T_0))N_0 e^{gt_1}$ of these goods are not available in the developing economy. At the moment of the policy change (at time t_1), a fraction $\beta(T_1)-\beta(T_0)$ of the total available capital goods (so $(\beta(T_1)-\beta(T_0))N_0 e^{gt_1}$ varieties) would decide to enter the market if they believed the new trade policy to be operative from then on, as we have assumed in section 4.6. This implies that the economy immediately jumps to a new balanced growth path if trade restrictions are decreased, see equations (4.16')-(4.18'). This asymmetry in adjustment is further discussed in section 4.9.

$$M(A(t)|t_1^-) = \begin{cases} \beta(T_0) N_0 e^{gt}, & if\ t \in [0, t_1) \\ \beta(T_1) N_0 e^{gt}, & if\ t \in [t_1, \infty) \end{cases} \tag{4.16'}$$

$$Y(t|t_1^-) = \begin{cases} Y(T_0) e^{gt}, & if\ t \in [0, t_1) \\ Y(T_1) e^{gt}, & if\ t \in [t_1, \infty) \end{cases} \tag{4.17'}$$

$$G(t|t_1^-) = \begin{cases} G(T_0) e^{gt}, & if\ t \in [0, t_1) \\ G(T_1) e^{gt}, & if\ t \in [t_1, \infty) \end{cases} \tag{4.18'}$$

Proposition 4.IV. After a decrease in the level of trade restrictions in accordance with the policy change experiment, the economy immediately jumps to a new balanced growth path, as summarized by equations (4.16')-(4.18').

4.9. Discussion

Although a policy thought experiment like that introduced in section 4.6 and analyzed thereafter is quite commonly used in economic analysis to better understand the structure and main implications of a model, it is clear that we should allow for some flexibility in interpreting the results. First, policy changes are usually not quite as abrupt as analyzed here but changed more gradually, leading to a more gradual transformation from one growth path to the other. Second, the assumption that the owners of capital goods are initially convinced that the imposed policy will be equal to T_0 indefinitely, at time t_1 are taken completely by surprise regarding the change in policy to T_1, and from then on are immediately convinced that it will remain T_1 indefinitely, is questionable. We should, of course, expect the owners of capital goods to form expectations regarding all future trade policies before introducing the good on the market in the developing economy. A significant change in trade restrictions will then only gradually shift their expectations regarding commitment of the government to the policy change. As this process takes time, we should again expect a more gradual transition process than depicted in figure 4.9 and implied by equations (4.16)-(4.18) and (4.16')-(4.18').

It is relatively straightforward to incorporate expectations into the model. The crucial variable is, of course, the expected level at time t of all future trade restrictions, $T_e(\tau,t)$ say, for $\tau \geq t$. Using equation (4.8), we can then derive the expected instantaneous profits at time τ conditional on information available at time t, denoted $\pi_e(\tau,t)$:

$$\pi_e(\tau,t) = (1-\alpha)\alpha^{2\varepsilon-1}L(1+T_e(\tau,t))^{1-\varepsilon} = \theta(1+T_e(\tau,t))^{1-\varepsilon}\,; \quad where\ \theta \equiv (1-\alpha)\alpha^{2\varepsilon-1}L$$

(4.21)

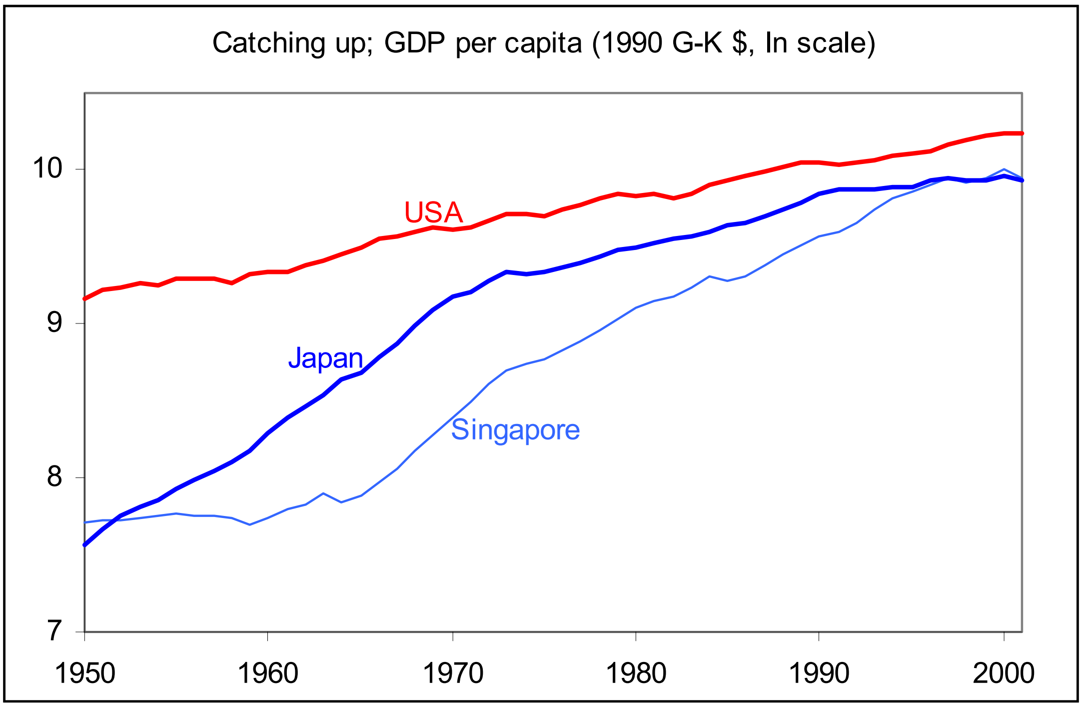
This allows us to calculate the expected discounted value of future profits, $\Pi_e(t)$ say, at time t, given the available information at that time. By differentiating with respect to t we can determine how this value evolves over time, as indicated below.

$$\Pi_e(t) \equiv \int_t^{\infty} e^{-\rho(\tau-t)} \pi_e(\tau,t)\, d\tau = \int_t^{\infty} e^{-\rho(\tau-t)} \theta (1+T_e(\tau,t))^{1-\varepsilon}\, d\tau \qquad (4.22)$$

$$\dot{\Pi}_e(t) = \int_t^{\infty} \rho\, e^{-\rho(\tau-t)} \theta (1+T_e(\tau,t))^{1-\varepsilon}\, d\tau + \int_t^{\infty} e^{-\rho(\tau-t)} \theta (1-\varepsilon)(1+T_e(\tau,t))^{1-\varepsilon}\, T_{et}'(\tau,t)\, d\tau +$$
$$-\theta(1+T_e(t,t))^{1-\varepsilon} = \rho\Pi(t) - \pi(t,t) - (\varepsilon-1)\theta \int_t^{\infty} e^{-\rho(\tau-t)}\, (1+T_e(\tau,t))^{1-\varepsilon}\, T_{et}'(\tau,t)\, d\tau ,$$

where $T_{et}'(\tau,t)$ is the derivative of $T_e(\tau,t)$ with respect to t. If the level of trade restrictions is stationary, we get $\Pi(t) = \pi(t|t)/\rho$, see equation (4.9).

Figure 4.11: Catching up in economic prosperity



Data source: Maddison (2003)

The limitations above notwithstanding, some crucial implications will continue to hold in a flexible interpretation of the model. First, a permanent change in policy will imply a transition from one balanced growth path to another. The long-run implications of the policy change can therefore be deduced from changes in the balanced growth path, see section 4.5. Second, as long as the share of capital goods introduced on the market is affected by the policy change, the static welfare costs underestimate the actual (dynamic) welfare costs of an increase in trade restrictions. Third, an increase in trade restrictions leads to a welfare loss and a decrease to a welfare gain. Fourth, there is an asymmetry in adjustment with respect to increases and decreases in trade restrictions. An increase leads to a slow-down in economic growth during a prolonged period of time due to the sunk-cost nature of the introduction costs. In the most extreme case, no new capital goods are introduced on the market, the growth rate reduces to 0 and per capita income is stagnant. Arguably, this is what happened in North Korea in the 1970s and 1980s.[61] A decrease in trade restrictions may result in rapid increases in economic growth rates if the reduction is deemed structural and reliable. The primary reason is the availability of a pool of capital goods producers (owning $\left(\beta(T_1)-\beta(T_0)\right)N(t_1)$ varieties) who previously deemed it unprofitable to introduce their good on the market in the developing economy and are now standing by to do so, enabling the economy to rapidly catch-up to its new balanced growth path.

Figure 4.11 depicts the rapid catch-up processes of Japan and Singapore in the second half of the 20th century relative to the benchmark level of the United States. We do not want to argue that the model is fully applicable to these two cases as other factors not explicitly modeled here have also contributed to their impressive economic growth performance, think of capital accumulation, schooling, and the size of the labor force (demographic transition).[62] However, all these other factors feed into the attractiveness of the economy for the catch-up process modeled here: as the labor force expands, as capital accumulates, and as schooling improves, the profitability for the providers of capital goods and intermediate services rises, such that a larger share of varieties will be introduced on the market, which leads to a virtuous cycle of rapid

[61] Maddison (2003) reports stagnant per capita income in North Korea from 1973 to 1991. After 1991 income dropped sharply as a result of the collapse of the Soviet Union. No reliable data is available before 1973, although Maddison reports the South Korean estimates before this time period as a lower bound.
[62] It is also clear that both economies became increasingly active in their own R&D projects as income rose.

economic growth. We should expect that this process comes to a hold once the boundaries of the state-of-the-art knowledge are reached, as indeed it did in Japan and Singapore. In general, our model predicts that a decline in prosperity following increases in trade restrictions is more gradual than the possible increases in prosperity following reductions in trade restrictions.

Having discussed North-Korea, Singapore and Japan as case-study examples, we then combined Sachs and Warner's (1995) trade openness indicators with the Maddison (2003) per capita GDP data to test our model predictions of an asymmetric adjustment process, with a potentially more rapid increase in GDP growth after a decrease in trade restrictions than the decrease in GDP growth after an increase in trade restrictions. Sachs and Warner classify a country as closed or open based on tariff rates, non tariff barriers, a black market exchange rate, a state monopoly on major exports, and a socialist economic system. The emphasis in this work is on trade liberalization, as it is in Wacziarg and Welch's (2003) update, who conclude (p. 3): *"the effects of increased policy openness within countries through time are positive, economically large, and statistically significant."*

Using a similar, within-country-through-time analysis, we are equally interested in the opposite movement from an open to a closed trading system. Maddison (2003) provides GDP per capita data (measured in 1990 international Geary-Khamis dollars) for the period 1950-2001. We analyze the time trend of $\ln(GDP/cap)$ for the year of the policy change and the 10 years before and after the policy change separately for all developing countries going through a regime change as indicated by Sachs and Warner for which these data are available, see Table 4.1. There are 15 developing countries going from an open to a closed trade regime. The average *decrease* in the time trend of the rate of growth was 0.3 per cent per year. There are 32 developing countries going from a closed to an open trade regime. The average *increase* in the time trend of the rate of growth was 1.79 per cent per year. This increase is statistically significant at the 10 per cent level, as is the difference between the decrease following a rise in trade restrictions and the increase following a decline in trade restrictions, thus providing support for an asymmetric adjustment process.

Table 4.1. Asymmetric trade policy adjustment (time trend of ln income p.c.) 1950 - 2001

	from open to closed*	from closed to open**
Number of observations	15	32
Average time trend 10 years before policy change plus year of policy change	0.0191	0.0053
Average time trend 10 years after policy change plus year of policy change	0.0162	0.0233
Average change in time trend	-.0030	0.0179
standard error of change in time trend	0.0076	0.0036
* Sri Lanka (1957), Venezuela (1960), El Salvador (1961), Nicaragua (1961), Costa Rica (1962), Guatemala (1962), Honduras (1962), Morocco (1965), Syria (1966), Kenya (1968), Peru (1968), Jamaica (1974), Bolivia (1979), Ecuador (1984), Sri Lanka (1984)		
** Japan (1962), Taiwan (1964), South Korea (1969), Indonesia (1971), Chile (1976), Sri Lanka (1978), Botswana (1979), Morocco (1985), Bolivia (1986), Columbia (1986), Gambia (1986), Ghana (1986), Costa Rica (1987), Guinea (1987), Guinea-Bissau (1987), Mexico (1987), Uganda (1988), Guatemala (1989), Philippines (1989), Tunisia (1989), Benin (1990), El Salvador (1990), Jamaica (1990), Paraguay (1990), Turkey (1990), Venezuela (1990), Argentina (1991), Brazil (1991), Hungary (1991), Mali (1991), Poland (1991), and Uruguay (1991).		

Source: calculations based on Sachs and Warner (1995) and Maddison (2003).

In line with our theoretical approach, Klenow and Rodriguez-Clare (1997) argue that Costa Rica’s 1986 – 1991 trade liberalization was accompanied by a surge in import variety, where a one percent larger market is associated with about 0.2 percent more varieties and a 1 percent lower tariff with an increase in variety of about 0.5 percent. Similarly, Haveman, Nair-Reichert, and Thursby (2003) analyze the effect of tariffs and non-tariff barriers (NTBs) on international trade flows and argue that higher multilateral tariffs tend to shift trade towards larger exporters, which indicates that the desire to minimize on the fixed (set-up) costs of trade flows is empirically important.

In our approach the benefits of trade are reflected in increases in total factor productivity. Pavcnik (2002) analyzes the effect of trade liberalization on plant productivity in the case of Chile. Her estimates suggest the existence of increasing returns to scale in all sectors and show that productivity of plants in the import-competing sectors grew 3 to 10 percent more than in the non-traded goods sectors. In line with our asymmetry argument she also notes the importance of commitment and expectations by arguing that (p.264): [63] "plants might not instantaneously react to an implementation in a change in trade policy. ..[but only].. after they were convinced of the government's lasting commitment."

4.10 Conclusions

We analyze the static and dynamic costs of a change in trade restrictions for a small developing economy which combines labour and (intermediate) capital goods in its final goods production process. The economy depends on successful R&D projects undertaken in the rest of the world and introduced on its market for an increase in the range of available capital goods. Any newly invented capital good is only introduced on the market in the developing economy if the (expected) discounted value of operating profits is larger than the costs of introduction. Since operating profits decline as the level of trade restrictions increases, the share of capital goods introduced on the market is a declining function of the level of trade restrictions.

The developing economy evolves over time to a balanced growth path in which income, welfare, and the share of capital goods introduced on the market in the developing economy increase if the level of trade restrictions falls. The optimal level of trade restrictions is therefore zero, while a government wishing to maximize government revenue will set a strictly positive level of trade restrictions. As a result of the sunk-cost nature of the introduction costs, there is an asymmetric adjustment path of the developing economy after a change in trade restrictions. An increase in the level of trade restrictions will slow-down economic growth and put the economy on a transition path to the new balanced growth rate. If the new level of trade restrictions exceeds a critical value, the new growth rate will be zero and stagnation occurs.

[63] Berden and Van Marrewijk (forthcoming JDE 2007) provide a brief discussion of expectations in this model.

During this process the estimated static costs of trade restrictions are smaller than the dynamic costs of trade restrictions if, and only if, the increase in trade restrictions reduces the share of invented capital goods introduced on the market. If trade restrictions fall, the developing economy may embark on a rapid catch-up process of economic growth by benefiting from the backlog of previously-invented-but-not-yet-introduced capital goods which may now, as a result of the increase in operating profits, be introduced after the fall in trade restrictions.

Chapter 5: Maintenance costs, obsolescence, and endogenous growth

"Our whole economy is based on planned obsolescence"

Brooks Stevens, Industrial Designer

5.1 Introduction

An important issue for growth theory is the relationship between the resources spent worldwide on research and development (R&D) and the number of inventions and the introduction of new types of goods and services to satisfy customer and client needs. Innovation is undoubtedly very important in today's world. However, one may wonder how many of the inventions and discoveries from the time of Napoleon we still cherish today? New management techniques appear, for example, to support the organizational structure and management information processes of firms, and disappear again once they are replaced by even more up-to-date techniques.

Endogenous growth models – both the AK-type of models of Romer (1986), Lucas (1988) and Rebelo (1991), and the R&D-type models of Romer (1990), Grossman & Helpman (1991), and Aghion and Howitt (1992) – investigate the relationship between innovative behavior and economic growth. In contrast to exogenous growth models, inventions are not a function of elapsed calendar time, but the result of conscious decisions to invest in R&D, arising from people's inspiration and perspiration. Within the widely used framework of expanding product variety, the phenomenon of obsolescence is disregarded. Aghion and Howitt (1998, p.39) argue that *"in order to formalize the notion of (technical or product) obsolescence, one needs to move away from horizontal models of product development à la Dixit and Stiglitz (1977) into vertical models of quality improvements."* Also Grossman and Helpman (1991, p.46) say: *"[The] ... complete symmetry between new and old commodities eliminates any possibility of product obsolescence"*. Many authors, like Hsieh (2001), Barreto and Kobayashi (2003), Boucekkine et al (2004), have indeed followed this line of research. Although vertical models of quality improvements are constructed to deal with the obsolescence phenomenon, we disagree with Aghion and Howitt's statement as such, by analyzing the role of obsolescence if we incorporate maintenance costs in the canonical model of horizontal product differentiation (see Grossman and Helpman, 1991, ch. 3). In this aspect, our modeling of 'obsolescence' in an endogenous growth setting differs from the endogenous growth model with embodied technical change developed by Krusell (1998) and Hsieh (2001), the one-sector model of growth constructed by Aznar-Marquez and Ruiz-Tamarit (2001), and the approach of Boucekkine et al. (1997, 2004) and Greenwood et al. (1998) who view the obsolescence mechanism as related to investment-specific technical change.

Evidently, new products – that is goods, services, or production processes – become obsolete over time. The early maritime industry in New England, for example, which had nothing much useful to do in the winter time, used to cut ice from frozen rivers and lakes, store it underground, and ship it to India. It has now been replaced by refrigerators. Other examples of once useful but now obsolete items in advanced societies are buggy whips, slide rules, oil lamps, and the telegraph. We argue that the rate at which inventions become obsolete over time is influenced by the degree of maintenance costs. A line of reasoning, supporting by McGrattan and Schmitz (1999) who show that for Canada a substantial share of GDP is spent on repair and maintenance activities. Gylfason and Zoega (2001) also – from an empirical viewpoint – investigate the relationship between per capita income and the depreciation rate. The term maintenance costs should be interpreted in a broad sense and can refer to both technical and economic obsolescence.

Some examples of maintenance costs are:

- Costs of *preventive* maintenance. To prevent machinery from breaking down too frequently, preventive maintenance is carried out. The most important costs of preventive maintenance is usually not the cost of labor involved in the maintenance process, nor the parts that need to be replaced, but the fact that the machinery is not productive during the maintenance process. Over time, as the machine-park is getting older, preventive maintenance will be carried out more often. Box 5.1 confirms the presence of preventive maintenance costs and their relevance in the airline industry: Airbus developed its maintenance system AIRMAN in order to save on preventive maintenance of the airplane fleet.
- Costs of (emergency) *repair* maintenance. Despite the fact that preventive maintenance is carried out more frequently as the production process ages, every now

and then a machine will break down and has to be fixed again. The fact that the production process is stopped represents the highest costs. In most cases, non-scheduled repair maintenance is more costly than preventive maintenance. Moreover, the older the production process, the higher the breakdown frequency.

- Costs of *updating* the production process. The introduction of new production techniques or a different marketing strategy frequently requires changes or adjustments in the production process. Such changes are more likely to occur if the production process has been operative for some time, as new production techniques become available and changes in consumers' preferences and demands require an adjustment of the marketing strategy.

- Cost of *replacing* part of the production process. In many cases, only part of a production line, rather than the entire production process, is replaced. Nonetheless, this frequently means that the whole production process is stopped. The older the structure of the production process, the larger the possibility that part of the line will have to be replaced, and thus the larger the fraction of time the machinery is not productive.

- Costs of *better alternatives*. A clear example of economic maintenance costs is represented by the arrival of better alternative ways of production or organizing the production process, which makes the old production technique more expensive in terms of income foregone. The more alternatives arise, the higher the likelihood that a production process is replaced by a better one.

BOX 5.1. Airbus' AIRMAN (AIRcraft Maintenance ANalysis)

The airline industry is one in which large-scale investments are needed in order to operate a fleet of aircraft successfully. Planes are expensive to purchase but more costs soon follow: maintenance costs of various types. Firstly, aircraft are subject to preventive maintenance following IATA rules and regulations in order to keep flying the safest mode of transport. Secondly, airplanes will have to be repaired if any part does not work, does not function as intended or gets damaged during a flight. *"Aircraft maintenance costs are high and only increase over time when the aircraft gets older",* according to Mr. Darteyre of Airbus.

To address the issue of maintenance costs, Airbus has developed a new system designed to help the airline industry keep them low: the AIRcraft Maintenance ANalaysis, AIRMAN for short. And the system is popular: *"Virgin Atlantic Airways has signed agreements for two of Airbus' support software, AIRMAN and ADOC. The combined use of these two systems should optimize Virgin's aircraft maintenance and lead to considerable savings".* AIRMAN collects and structures on-board maintenance messages, helps line mechanics with trouble-shooting and provides daily lists of preventive maintenance measures. The hangar and on-flight maintenance system also feeds directly back to Airbus that can then monitor every sold aircraft worldwide. *"Overall benefits of AIRMAN are around $4,- per flight hour,"* says Mr. Darteyre, *"making sure our Airbus planes are safer and more economical for a longer period of time".*

5.2 The model

We extend the Grossman and Helpman (1991, ch. 3) model of horizontal product differentiation to incorporate maintenance costs. Labor, the only factor of production, is used for maintenance, to produce goods, and for R&D. The returns to R&D arise from monopoly rents in imperfectly competitive product markets.

Consumer behavior

The representative consumer maximizes utility U over an infinite time horizon, using preferences as given in equation (5.1). The term $D(\tau)$ represents an index of consumption at time τ, and ρ is the discount rate.

$$U(t) = \int_t^{\infty} e^{-\rho\tau} \log\big(D(\tau)\big)d\tau \tag{5.1}$$

The index D reflects a taste for diversity in consumption, based on the Dixit-Stiglitz (1977) approach of horizontal product differentiation. We take the product space to be continuous. Preferences are defined over an infinite set of products using the index j. At any moment, only a subset of these varieties is available, identified by $A(\tau)$, which indicates the set of firms active in period τ. The set of available products will expand as a result of innovation, and contract as a result of obsolescence. The households can purchase at time τ all products of active firms at time τ. Using the Dixit-Stiglitz specification, we let $x(j;\tau)$ denote the consumption of brand j at time τ and define the elasticity of substitution between two products $\varepsilon \equiv 1/(1-\alpha) > 1$, to define the index D as:[64]

$$D(\tau) = \left[\int_{A(\tau)} x(j;\tau)^{\alpha}\, dj \right]^{1/\alpha} \tag{5.2}$$

[64] An alternative interpretation, in which the index D is production and the varieties x are intermediate goods, is provided by Ethier (1982).

A household spending an amount $E(\tau)$ at time τ maximizes instantaneous utility by purchasing the number of units of brand *j* given in equation (5.3), where $p(j;\tau)$ is the price charged by firm *j* at time τ.

$$x(j;\tau) = \frac{E(\tau)p(j;\tau)^{-\varepsilon}}{\int_{A(\tau)} p(j';\tau)^{1-\varepsilon}\, dj'} \tag{5.3}$$

The demand for a variety features a constant price elasticity of demand ε and unitary expenditure elasticity. It can thus be aggregated across consumers to arrive at aggregate demand, where E represents aggregate spending. Defining an exact price index (see Appendix 5.A.), the consumer's intertemporal optimization problem given in equation (5.1), under a budget constraint that allows borrowing and lending at the interest rate $r(\tau)$, implies that the growth rate of spending is equal to the difference between the interest rate $r(\tau)$ and the discount rate ρ, that is $\dot{E}(\tau)/E(\tau) = r(\tau) - \rho$, where an overdot indicates the rate of change over time. Following Grossman and Helpman by normalizing aggregate spending to unity, that is $E(\tau) = 1$ for all τ, implies that the interest rate is equal to the discount rate, that is $r(\tau) = \rho$ for all τ.

Producer behavior

As indicated above, producers participate in three types of activities. First, they manufacture the varieties that have been developed in the past. Second, they spend resources on R&D in order to invent and introduce new varieties. Third, and most important for obsolescence, they have to maintain the production process in working condition.

Manufacturing

Each variety is produced by a single atomistic firm under constant returns to scale[65]. By choice of units, it requires one unit of labor to produce one unit of good *x*. To maintain the production process in working condition, each active firm has to incur a fixed labor cost. As explained in the introduction, the maintenance costs arise as a

[65] This assumption can be justified in two ways. First, one could argue that inventions are protected by infinitely lived patents. Second, if imitation is costly and firms engage in ex post price competition, the imitator would earn no profits and consequently would not be able to recuperate its costs made.

result of preventive maintenance, repair maintenance, updating, replacement, and the arrival of better alternatives. Following Romer (1990) and Grossman and Helpman (1991), we assume that part of the knowledge created in the economy, as measured by the range of active firms, results in non-appropriable benefits in other sectors of the economy. In particular, there are positive knowledge spill-overs for maintaining the production process at the time of invention and introduction of a new variety[66]. As a result, the fixed maintenance costs in terms of labor, which depend on a parameter b, are inversely related to the range of active firms at the time of invention of the good. If we let $w(\tau)$ be the wage rate at time τ and $m(.)$ denote the Lebesgue measure, such that $m(A(\tau))$ measures the range of active firms at time τ, then the operating profits $\pi_j(\tau;t)$ for firm j at time τ producing a variety invented at time t is given by:

$$\pi_j(\tau;t) = p(j;\tau)x(j;\tau) - w(\tau)x(j;\tau) - \frac{bw(\tau)}{m(A(t))} \tag{5.4}$$

Profit maximization and obsolescence

The monopolistic producer maximizes the operating profits, given the demand for its variety as derived in equation (5.3). Since the price elasticity of demand ε is constant, this results in the well-known constant mark-up over marginal cost:

$$(1-1/\varepsilon)p(j;\tau) = w(\tau), \qquad or \quad p(j;\tau) = w(\tau)/\alpha \equiv p(\tau) \tag{5.5}$$

Note that the optimal pricing rule is the same for all active firms at time τ, and independent of the time t of invention of the variety. All firms active at time τ will therefore sell an equal quantity of goods, and receive the same revenue. In view of the normalization of expenditure, we can therefore calculate the operating profits for all firms active at time τ with a variety invented at time t:

$$\pi(\tau,t) = \frac{1-\alpha}{m(A(\tau))} - \frac{bw(\tau)}{m(A(t))} \tag{5.6}$$

---

66 We hereby do not go into recent literature on the downside effects of knowledge spillovers (Alsleben, 2005) or the inter-firm R&D types of cooperation (Hinloopen, 2003).

Naturally, the firm will only produce its variety invented at time t if the operating profits at time τ are positive. Equivalently, the firm will stop production if the operating profits become negative. Using the terminology of Dixit and Pindyck (1994) and Pindyck (2004), the maintenance costs are therefore fixed costs, whereas the costs of inventing the variety are sunk costs. This allows us to determine the range of active firms at time τ using the indicator function $I_A(\tau,s)$, defined to be equal to 1 if a firm producing a variety invented at time $\tau - s$ is still active at time τ, and 0 otherwise.[67]

$$I_A(\tau,s) = \begin{cases} 1, & if \quad \dfrac{1-\alpha}{m(A(\tau))} - \dfrac{bw(\tau)}{m(A(\tau - s))} > 0 \\ 0, & otherwise \end{cases} \tag{5.7}$$

Note that a firm with a variety invented at time t seizes to be active if the measure of active firms relative to the time of its invention exceeds a threshold level. If the range of active firms is non-decreasing and the wage rate is constant, as will be the case below, then the flow of firms from active to obsolete is on a first-in-first-out basis (FIFO). Equation (5.7) is called the *obsolescence criterion*.

The capital market

The profits generated in equation (5.6) go to the shareholders of a firm (for example in the form of dividends). If the stock markets correctly price the firms, the stock value $v(t,s)$ at time t of a firm producing a variety invented at time s equals the present discounted value of its future stream of profits.[68] In view of our normalization, which implies $r(\tau) = \rho$, it is equal to:

$$v(t,s) = \int_t^{\infty} e^{-\rho(\tau - t)} \pi(\tau,s)\, d\tau \tag{5.8}$$

[67] Obviously, operating profits $\pi(\tau,s)$ in equation (5.6) are defined to be 0 if the firm is not active.

[68] As Grossman and Helpman (1991, p. 50) note, this is not an assumption but an equilibrium condition in a perfect foresight model with infinite lived households maximizing lifetime utility, since speculative bubbles cannot arise. The presentation in the text is somewhat simpler.

Recall that an overdot indicates the rate of change over time of a variable. If there are two time indices, as occurs frequently in the presentation since we have to distinguish between the time at which a firm is active and the time of invention of the variety, we let a sub-index denote the time index. Differentiating equation (5.8) with respect to time *t* gives:

$$\dot{v}_t(t,s) = \rho v(t,s) - \pi(t,s) \tag{5.9}$$

This represents a 'no-arbitrage condition' on the capital market, since the sum of the profits plus the capital gains are equal to the yield on a riskless loan.

Research and development

An entrepreneur can add to the range of active firms by inventing a new variety, which requires a finite amount of labor invested for a brief period of time into R&D. There is free entry and exit of entrepreneurs into the R&D sector. Following, for example, Romer (1990) and Grossman and Helpman (1991), R&D generates not only new varieties, the revenues of which are appropriated by the entrepreneur through claims on the future stream of profits generated by the firm, but also positive knowledge spill-overs in the form of increases in the general stock of knowledge. In our specification, these knowledge spill-overs reduce the amount of labor required for developing new varieties and for the maintenance of new varieties. It is well-known that the growth rate of the economy would stop without such beneficial knowledge spill-overs. See Van Marrewijk (1999) and Funke and Strulik (2000) for a general discussion of the literature. If we let $N(t)$ denote the range of all varieties invented up to time *t*, we assume therefore that an entrepreneur denoting $L_n(t)$ laborers to R&D for a time period dt develops $dN = [m(A(t))L_n(t)/a]dt$ new products. The costs of a new blueprint at time *t* are therefore equal to $aw(t)/m(A(t))$. Given free entry and exit in the entrepreneurial market at time *t*, these costs must be at least as high as the value $v(t,t)$ at time *t* of developing a new variety:

$$\frac{w(t)a}{m(A(t))} \geq v(t,t), \qquad \textit{with equality if } \dot{N}(t) > 0 \tag{5.10}$$

Labor market equilibrium

Finally, we turn to the labor market equilibrium. The labor force is active in three types of activities. There is labor demand L_n to develop new varieties in the R&D sector, labor demand L_x for the production of goods, and labor demand L_m for the maintenance costs. The constant labor supply L is provided perfectly inelastic. Equilibrium in the labor market therefore requires

$$L_n + L_x + L_m = L \tag{5.11}$$

First, note that the required number of R&D laborers depends on the speed $\dot{N}/N$ with which new products are developed: $L_n = a(\dot{N}/N)(N/m(A))$. Second, note that each firm sells $1/pm(A)$ units of goods. Since *m(A)* firms are active, they need *1/p* units of production labor. Third, note that if a firm with a variety invented at time $t-\tau$ is still active at time *t*, the maintenance labor requirement for that firm equals $b/m(A(t-\tau)$. Since the number of such firms depends on the speed at which new varieties were developed at time $t-\tau$, there are $L_n(t-\tau)m(A(t-\tau))/a$ such firms. The total maintenance labor required for firms still active at time *t* with a variety invented at time $t-\tau$ is therefore $L_n(t-\tau)b/a$ units. Using the indicator function $I_A(t,\tau)$ defined in equation (5.7), it follows that the total maintenance labor requirement at time *t* is given in equation (5.12). The labor market clearing condition is therefore given in equation (5.11')

$$L_m(t) = \int_0^\infty L_n(t-\tau)(b/a)I_A(t,\tau)\,d\tau = \int_0^\infty \frac{bN(t-\tau)}{m(A(t-\tau))}\frac{\dot{N}(t-\tau)}{N(t-\tau)} I_A(t,\tau)\,d\tau \tag{5.12}$$

$$\frac{aN(t)}{m(A(t))}\frac{\dot{N}(t)}{N(t)} + \frac{1}{p(t)} + \int_0^\infty \frac{bN(t-\tau)}{m(A(t-\tau))}\frac{\dot{N}(t-\tau)}{N(t-\tau)} I_A(t,\tau)\,d\tau = L \tag{5.11'}$$

This completes the description of the model.

5.3 Derivation of balanced growth equilibrium

We want to discuss some aspects of the model by analyzing a balanced growth equilibrium in which the measure of active firms grows at a constant rate *g*, that is $m(A(t)) = m_0 e^{gt}$. The distribution of labor over the three types of activities, production, maintenance, and R&D, will be constant in the balanced growth equilibrium. This implies, as the appendix shows, that the wage rate *w* is constant over time, which implies in turn, using the mark-up pricing rule, that the price *p* charged for a variety of a good is constant as well.

Obsolescence and active production

Combining the constant growth rate *g* of the number of active firms and the constant wage rate *w* with the obsolescence criterion derived in the previous section allows us to explicitly calculate how long a variety invented at time *t* will be actively and profitably used. Recall equation (5.6) on the operating profits for all firms active at time τ with a variety invented at time *t* (using the fact that the wage rate *w* will be constant):

$$\pi(\tau,t) = \frac{1-\alpha}{m(A(\tau))} - \frac{bw}{m(A(t))} \qquad (5.6')$$

Clearly, the first part of the operating profits on the right-hand-side of equation (5.6') will decrease slowly over time as the number of active firms on the market is expanding. In contrast, the second term on the right-hand-side of equation (5.6'), representing the costs of maintenance, is constant. The value of this constant depends on the number of active firms on the market at the time of the invention of the variety. These costs are therefore lower the newer the production process. As described in the introduction, the maintenance costs are therefore higher for older production processes. As soon as the first part of the operating profits is not high enough to recuperate the maintenance costs, the firm will stop the production process. If the growth rate of the number of active firms is *g*, it is straightforward to calculate the number of time periods *f* in which the firm will actively produce a new variety using equation (5.6'), which gives

$$e^{fg} = \frac{1-\alpha}{bw} \quad \Rightarrow \quad f = \frac{\ln[(1-\alpha)/bw]}{g} \equiv f(g,w) \tag{5.13}$$

The explicit definition in equation (5.13) of the time period *f* as a function of the growth rate *g* and the wage rate *w* serves as a reminder that we still have to (endogenously) determine the value of these variables. Note also from equation (5.13) that, other things equal, the period of active production *f* is longer:

- The lower the growth rate *g*. If the growth rate *g* of the number of active firm falls, the firm's profits are less rapidly eroded, which means that the firm can stay in business for a longer period of time.
- The lower the maintenance cost parameter *b*. The firm is ultimately driven out of business because the maintenance costs become too high relative to the revenue generated by the mark-up over marginal costs. Clearly, therefore, if the maintenance cost parameter *b* falls, the firm can stay in business for a longer time period. In the limit, as *b* approaches 0, the firm can stay in business indefinitely.
- The lower the wage rate *w*. The maintenance costs are directly influenced by the wage rate. A fall in the wage rate therefore allows the firm to stay in business for a longer time period by reducing the maintenance costs.
- The lower the elasticity of substitution parameter α (equivalently, the lower the price elasticity of demand ε). If the different varieties are less perfect substitutes for one another, that is if the elasticity of substitution falls, the firm is able to charge a higher mark-up over marginal costs, which increases its operating profits. Again, this allows the firm to stay in business for a longer time period.

LE line (Labor market Equilibrium)

The labor market equilibrium is already given in equation (5.11'). We can simplify this equation considerably along a balanced growth path in which the growth rate *g* of the number of varieties *N* ever invented is equal to the growth rate of obsolete varieties and the growth rate of the number of active firms. Since $L_n = a(\dot{N}/N)(N/m(A))$, this implies that the labor input in the R&D sector is constant because $\dot{N}/N = g$ and the ratio $N/m(A)$ does not change. This ratio is of course determined by the obsolescence criterion, which, as a result of the first-in-first-out nature of the number of actively produced varieties, simplifies to:

$$I_A(t,\tau) = \begin{cases} 1, & 0 \le \tau \le f(g,w) \\ 0, & otherwise \end{cases} \quad (5.7')$$

Using equation (5.13) and (5.7'), it therefore follows that along a balanced growth path, the range of active firms is given by: $m(A(t)) = N(t) - N(t-f) = N(t)(1-e^{-gf})$. The above mentioned ratio of invented – to – active varieties is equal to $N/m(a) = 1/(1-e^{-gf})$, implying that $L_n = ag/(1-e^{-gf})$. Determining the number of production workers is trivial since the wage rate is constant, such that $L_x = 1/p = \alpha/w$. As for the demand for maintenance workers, using (5.7') in equation (5.12) and recalling that the number of workers in the research and development sector is constant, given the number of maintenance workers:

$$L_m = \int_0^\infty L_n(t-\tau)(b/a)I_A(t,\tau)\,d\tau = f(g,w)bL_n/a \quad (5.12')$$

Using the demand for L_n derived above and the definition of $f(g,w)$ given in equation (5.13), it follows that $L_m = \left(b/(1-e^{-fg})\right)\ln\left[(1-\alpha)/bw\right]$. Equating these demands for labor to the supply of labor gives the *Labor Equilibrium line*:

$$\underbrace{\frac{ag}{\left(1-e^{-fg}\right)}}_{L_n} + \underbrace{\frac{\alpha}{w}}_{L_x} + \underbrace{\frac{b}{\left(1-e^{-fg}\right)}\ln\left(\frac{1-\alpha}{bw}\right)}_{L_m} = L \quad (5.14)$$

IE line (Innovation Equilibrium)

Now that we know from equation (5.13) the time period *f* during which the firm will be able to actively produce its goods and reap positive operating profits, we can also determine the present value of the stream of future profits, which determines the value of the firm for a variety invented at time *t*:

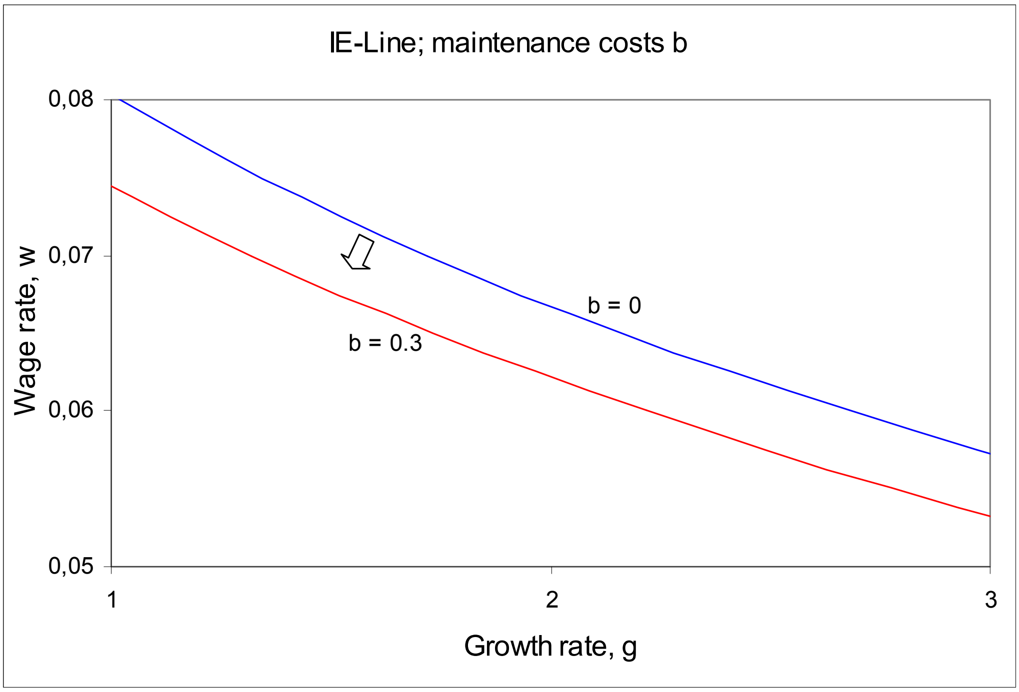
$$v(t,t) = \int_{t}^{t+f(g,w)} e^{-\rho(\tau-t)} \left[\frac{1-\alpha}{m(A(\tau))} - \frac{wb}{m(A(t))} \right] d\tau = \frac{1}{m(A(t))} \left[\frac{1-\alpha}{\rho+g} \left(1 - e^{-(\rho+g)f(g,w)}\right) - \frac{wb}{\rho}\left(1 - e^{-\rho f(g,w)}\right) \right] \tag{5.8'}$$

Note that the value of the firm at the time a new variety is invented is inversely related to the number of active firms on the market at that time. Innovation takes place at time *t* if equation (5.10) holds with equality. Since the costs $aw/m(A)$ of inventing a new variety are also inversely related to the number of active firms at time *t*, this term drops out. Substituting equation (5.8'), in equation (5.10) gives the *Innovation Equilibrium line*:

$$wa = \left[\frac{1-\alpha}{\rho+g} \right] - bw \left[\frac{1}{\rho} - \frac{g}{\rho(\rho+g)} \left(\frac{wb}{1-\alpha} \right)^{\frac{\rho}{g}} \right] \tag{5.15}$$

In figure 5.1, the IE-line is shown in (g,w)-space. Note that the innovation equilibrium line can only be written as an implicit function (except when $b = 0$, see the next section). As is clear from the first part in square brackets on the right-hand-side of equation (5.15), an increase in the growth rate *g* erodes the operating profits more quickly, and thus reduces the profitability of new inventions. To restore the innovation equilibrium, the costs of inventing a new variety, as determined by the wage rate, will have to fall. Consequently, the innovation equilibrium is a downward sloping line in (*g,w*)-space. Figure 5.1 shows two IE lines. The first line, labeled "b = 0" displays the innovation equilibrium if there are no maintenance costs. This line therefore corresponds to the Grossman and Helpman (1991, ch. 3) model. The second line, labeled "b = 0.3" shows that, other things equal, the growth rate of the economy will fall if the profitability of R&D falls as a result of the costs of maintaining the production process, as indicated by the arrow in figure 5.1.

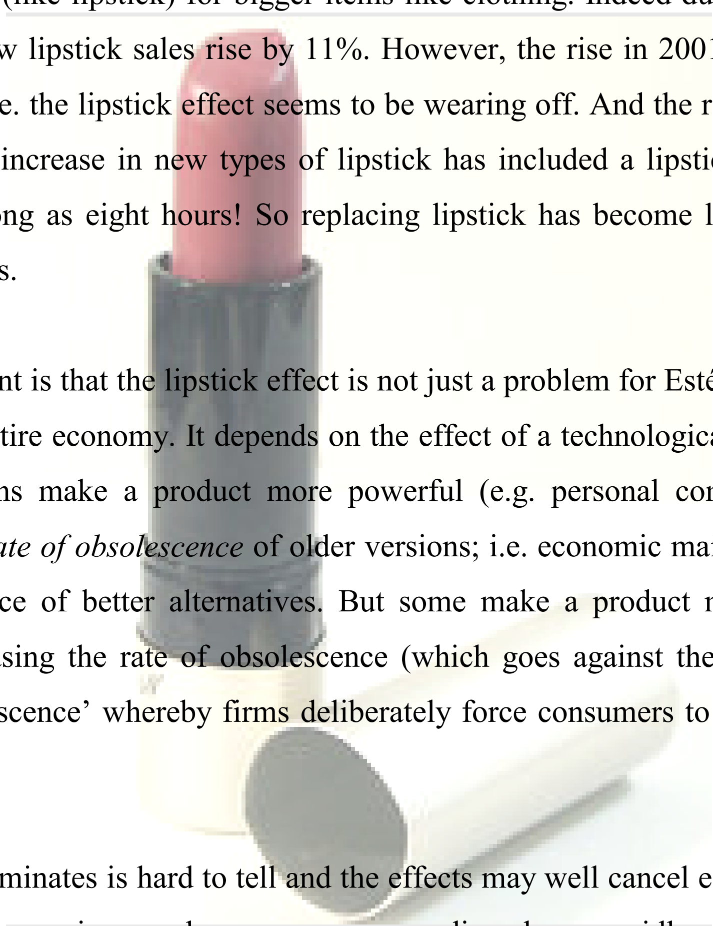
*Figure 5.1: Innovation Equilibrium (IE line)**



*Other parameters: $\alpha = 0.6$; $L = 12$; $\rho = 4$; $a = 1$

A balanced growth equilibrium exists if equations (5.14) and (5.15) hold, that is for combinations of the wage rate w and the growth rate g for which the innovation equilibrium and the labor equilibrium hold simultaneously.

Box 5.2. Replacement Killers – the Lipstick Effect



The *'lipstick effect'* refers to a theory that during a recession women substitute small, feel-good items (like lipstick) for bigger items like clothing. Indeed during the 2001 recession we saw lipstick sales rise by 11%. However, the rise in 2001 was slightly disappointing, i.e. the lipstick effect seems to be wearing off. And the reason for that is that a recent increase in new types of lipstick has included a lipstick capable of staying on as long as eight hours! So replacing lipstick has become less necessary than in the 1980s.

What is important is that the lipstick effect is not just a problem for Estée Lauder, but rather for the entire economy. It depends on the effect of a technological innovation: some innovations make a product more powerful (e.g. personal computers) thus increasing the *rate of obsolescence* of older versions; i.e. economic maintenance due to the appearance of better alternatives. But some make a product more durable, therefore decreasing the rate of obsolescence (which goes against the argument of 'planned obsolescence' whereby firms deliberately force consumers to replace them more often).

Which effect dominates is hard to tell and the effects may well cancel each other out. However, in a recession – when consumer spending drops rapidly – the need to replace goods because of obsolescence may be the only thing that keeps them spending. Does that mean recessions will last longer in the future due to lack of consumer spending?

Source: The New Republic (31/12/2001)

5.4 Maintenance costs and the balanced growth equilibrium

As derived in section 5.3, the balanced growth equilibrium is determined by the point of intersection of the labor market equilibrium and the innovation equilibrium, as given in equations (5.14) and (5.15), respectively. Obviously, an equilibrium is only economically useful if it is in the first quadrant, such that the wage rate and the growth rate of the economy are both positive. Otherwise, the equilibrium growth rate of the economy is zero, innovation does not take place, the share of active firms is constant, and firms produce forever.

Balanced growth without maintenance costs

In the absence of maintenance costs, that is if $b = 0$, it follows that $f(g, w) = \infty$ and the LE line and the IE line simplify to equations (5.14') and (5.15') respectively:

$$ag + \frac{\alpha}{w} = L \tag{5.14'}$$

$$wa = \frac{1-\alpha}{\rho + g} \tag{5.15'}$$

Solving these equations leads to $g\big|_{b=0} = (1-\alpha)\frac{L}{a} - \alpha\rho$ and $w\big|_{b=0} = \frac{1}{a\rho + L}$ which is identical to the solution in Grossman and Helpman (1991, Ch. 3 with knowledge spillovers).

To analyse the properties of the balanced growth equilibrium it is useful to define the auxiliary variable $z \equiv e^{fg} = (1-\alpha)/bw$, where the second equality follows from equation (5.13). The natural logarithm of z therefore indicates the time a variety is actively produced times the growth rate of the economy. Noting that $1 - e^{-fg} = (z-1)/z$, that $z > 1$ for an interior solution, and that $w = (1-\alpha)/bz$, equations (5.14) and (5.15) change to:

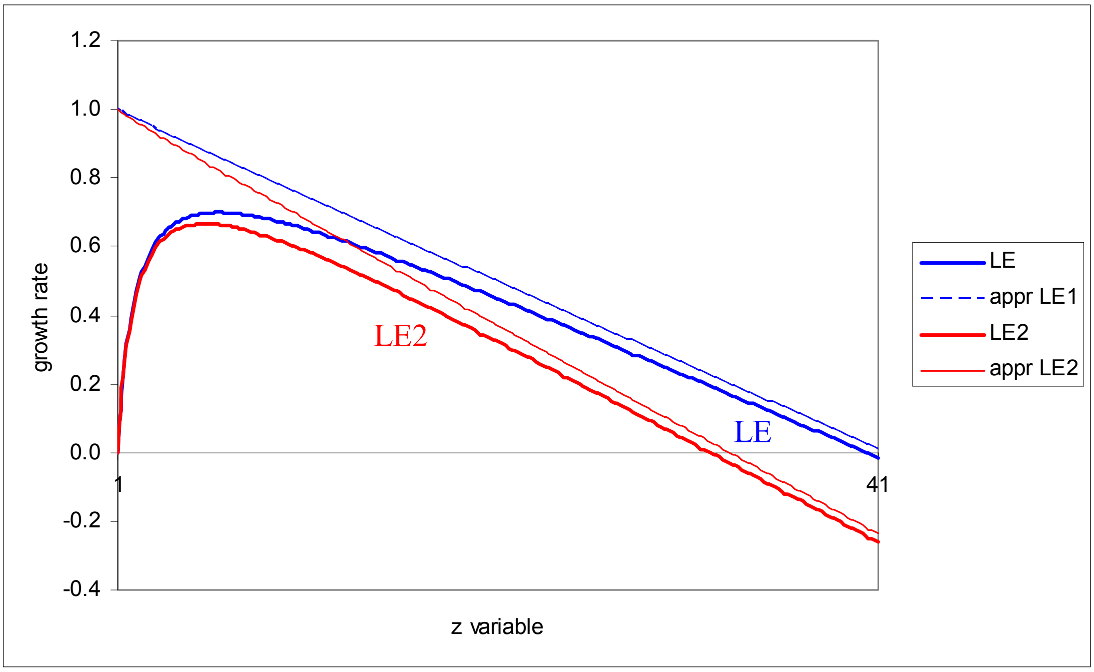
$$g = \frac{(z-1)}{z}\frac{L}{a} - \frac{b}{a}\left[\frac{\alpha}{(1-\alpha)}(z-1) + \ln(z)\right] \equiv h(z) \qquad \text{LE-line} \tag{5.16}$$

$$(\rho + g)(a\rho + b) = b\rho z + bgz^{-\rho/g} \qquad \text{IE-line} \tag{5.17}$$

Note that the function $h(z)$ (i.e. the LE-line) is bounded from above by $\frac{L}{a}-\frac{b}{a}\left[\frac{\alpha}{(1-\alpha)}(z-1)+\ln(z)\right]$, which in turn is bounded from above by $\frac{L}{a}-\frac{b}{a}\left[\frac{\alpha}{(1-\alpha)}(z-1)\right]$. Furthermore, $h(1)=0$ while $h'(z)>0$ for $z < z^*$ where $z^*=\frac{1-\alpha}{2b\alpha}\left[-b+\sqrt{b^2+4b\alpha/(1-\alpha)}\right]$.

This is illustrated in figure 5.2 in (g,z)-space.

*Figure 5.2: Labor equilibrium line**



**Other parameters:* $\alpha=0.75;\quad L=1;\quad \rho=3;\quad a=1$

Figure 5.2 shows that with a rising value of *z*, the growth rate initially increases sharply, reaches a maximum and then starts to drop until eventually, when *z* is sufficiently large, the growth rate becomes zero.[69] Also in figure 5.2, the linear approximations show how the LE-line is bounded from above for any value of *b*.

[69] It will not become negative since firms in that case will opt for no longer producing the variety which leads to zero-growth.

The LE-line is the one with lower maintenance costs. When maintenance costs are increased from 0.008 to 0.01 (LE = 0.008 and LE2 = 0.01), we observe that the LE-line shifts downwards to LE2, i.e. for the same value of the auxiliary variable z, the growth rate has dropped.[70] This is in line with (5.14) and (5.16) and intuitively understandable: when maintenance costs rise, there are less resources available for growth (R&D) or production which leads to a lower growth rate.

The IE-line in (g,z)-space

In (g,z)-space, for $g = 0$, the IE line starts at $1 + a\rho / b > 1$ and is bounded from below. The IE-line is upward sloping in (g,z)-space because a rise in z because of lower maintenance costs ceteris paribus or because of lower wages – representing lower costs for R&D – leads to higher economic growth. That is so, because the number of time periods a firm will actively produce a new variety will rise because the maintenance costs drop relative to the revenue generated by the mark-up over marginal costs, i.e. the firms are not so quickly driven out of business.

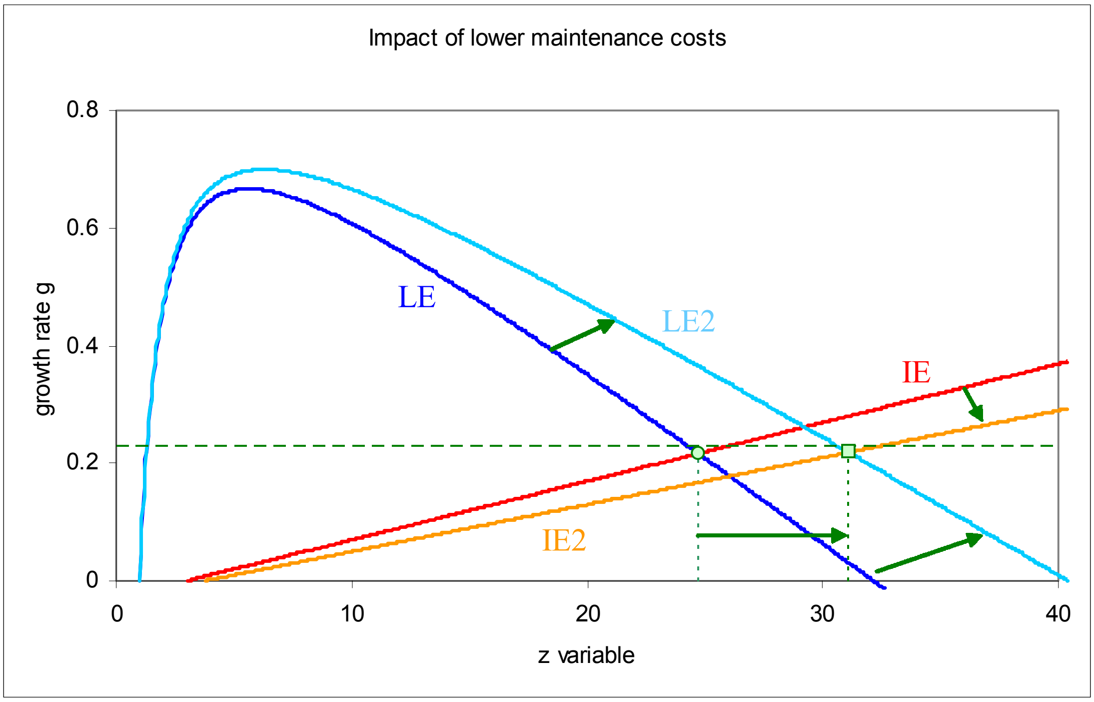
Impact of maintenance costs and obsolescence

To discuss the impact of positive maintenance costs and obsolescence, we compare the balanced growth equilibrium of equations (5.14) and (5.15). In the presence of maintenance costs, we can distinguish between three different effects. First, as discussed in section 5.3, a drop in the maintenance costs b implies that less workers have to maintain the production processes in working condition, such that more workers are available for research and develop new varieties. This shifts the labor market equilibrium line in figure 5.3 up from LE to LE2 (like in figure 5.2) such that the equilibrium moves to the right, with a higher growth rate and a higher value for z. At the same time, if a lower share of the firms becomes obsolete because of lower maintenance costs, the productivity of the labor force for research and maintenance is increased. This effect simultaneously shifts the labor market equilibrium line up and leads to a higher value for z as well as a higher growth rate. Third, a decrease in the maintenance costs increases the firm's profitability, which shifts the innovation equilibrium line down from IE to IE2 in (g,z)-space, moving the equilibrium even further to the right. The value for z and the growth rate of the economy are therefore

[70] Note that also the bound from above has dropped accordingly.

higher as a result of lower maintenance costs and obsolescence. This follows from (5.13), (5.16) and (5.17).

*Figure 5.3: Impact of lower maintenance costs**



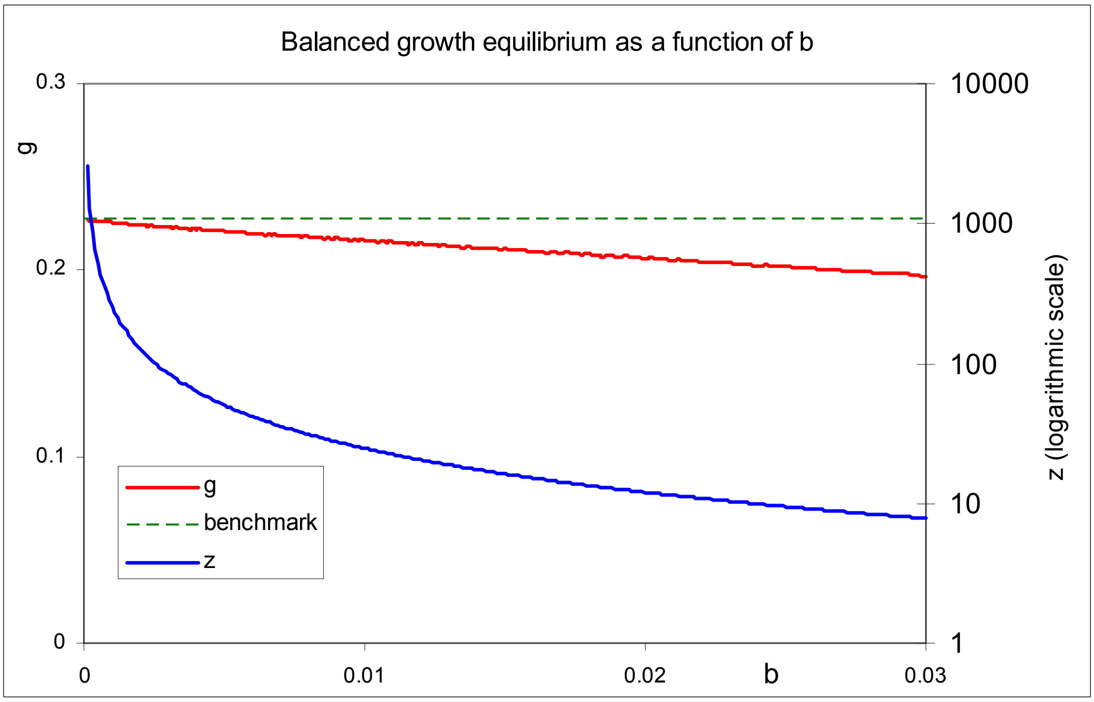
**Other parameters:* $\alpha = 0.75; \quad L = 1; \quad \rho = 3; \quad a = 1$

So when, as illustrated in figure 5.3, maintenance costs drop, the LE-line rises and the IE-line drops. This leads to an increase in the value of our auxiliary variable *z* and the growth rate, *g*. The latter is not immediately obvious from figure 5.3 so we will come back to this in the next section.

The equilibrium as a function of maintenance costs

The discussion above, illustrated in figure 5.3, gives only the results of two balanced growth equilibria. We argue that an increase in the maintenance costs will decrease the growth rate of the economy. To get a better view of this claim, we ran many simulations and calculated the equilibrium of figure 5.3 for many different values of the maintenance costs *b*. The results are depicted in figure 5.4, with the maintenance costs and growth rates on the axes.

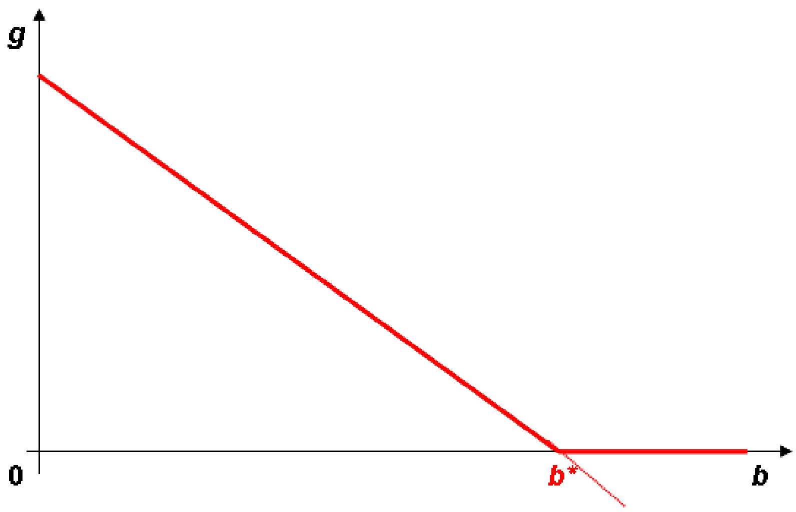
*Figure 5.4: Balanced growth and maintenance costs I**



**Other parameters:* $\alpha = 0.75$; $L = 1$; $\rho = 3$; $a = 1$

Figure 5.4 depicts all equilibrium combinations in *(b,g)*-space. When maintenance costs are zero, economic growth maximal (in this setting around 0,23) and the auxiliary variable, $z \rightarrow \infty$. This outcome is identical to the Grossman-Helpman result (Grossman & Helpman, 1991, Ch. 3). As the maintenance costs rise the rate of innovation decreases (in accordance with the graphical results obtained in figure 5.3), both because innovation becomes less profitable and because a larger share of the labor force is engaged in maintenance activities, and therefore no longer available for production or R&D. This leads to lower levels of economic growth, which can be seen directly from figure 5.4. The higher the maintenance costs, the higher the rate of obsolescence, the lower the rate of economic growth in an economy. So eventually, there is a value for b, b^*, where the growth rate becomes zero (we have assumed that growth be non-negative). For any size of the maintenance costs higher than b^*, the growth rate will also be zero. This is illustrated below in figure 5.5.

Figure 5.5: Balance growth and maintenance costs II



Welfare

The final issue to address is the impact of incorporating maintenance costs on the welfare level achieved by the economy in the balanced growth equilibrium. Here we did not find any surprises. As shown in Appendix 4, for a given level of the elasticity of substitution, the welfare level achieved by the economy in the balanced growth equilibrium is proportional to $g\ln(L_x)$. An increase in maintenance costs, which reduces the share of workers available for production and R&D and reduces the profitability of R&D, leads to a reduction in the rate of innovation, and thus to a reduction in the welfare level of the economy. The fact that, for high levels of maintenance costs, the share of the workforce L_x engaged in production may rise a little bit if the maintenance costs increase (and the degree of obsolescence falls) is never powerful enough to lead to an increase in welfare in any of our simulations.

5.5 Conclusions

We analyze the impact of obsolescence of economic inventions by incorporating maintenance costs in the endogenous growth model of expanding product varieties. This contrasts with the existing literature, which ignores maintenance costs and uses the model of quality improvements to describe obsolescence. Firms invest funds in R&D to invent and introduce new products continuously. The profitability of these new products diminishes over time as a result of the invention and introduction of even newer products, and as a result of the ever higher costs of maintaining the production process in working condition. If the maintenance costs become too high, the operating profits become negative and the firm stops producing the older varieties. We show that in a partial equilibrium framework, that is, other things being equal, the economic life span of innovations, that is the period during which a new variety is actually produced before the product becomes obsolete and is replaced by even newer varieties, is longer (i) the lower the growth rate of the economy, (ii) the lower the maintenance costs.

"Other things" are, however, not equal. The rate of innovation and the share of active firms are determined endogenously within the structure of the model, thereby affecting the speed of obsolescence. We show that an increase in maintenance costs (i) reduces the rate of innovation, (ii) reduces the period of active production of a newly invented variety (i.e. increases obsolescence) up to a critical level, (iii) reduces the welfare level, and (iv) reduces economic growth.

Chapter 6: Conclusions

... is the art of looking for trouble, finding it, misdiagnosing it, and then misapplying the wrong remedies.

Groucho Marx

Throughout this thesis, the concept of economic growth has been at the centre and via theoretical and practical research we have attempted to gain new insights into factors that influence growth and the mechanisms through which this happens.

Most inventions and new ideas become obsolete over time, reducing the growth rate of an economy. Uncertainty has a negative impact on economic growth levels. Moreover, it seems to exert pressure on a country to become more closed because of volatility in international (primary product) prices. But countries that are more closed may experience negative dynamic welfare effects and may forsake the import of new technologies and ideas that others have invented in the first place. It seems as if a delicate balance needs to be found.

Economic growth and uncertainty

Long-run growth depends on the introduction of new goods and new state-of-the-art practices to become more efficient given the resources available. From all growth models it becomes clear that technology growth is the engine for economic growth – whether modeled exogenously or not.

For the research done, we show that higher levels of uncertainty have a negative impact on the rate of technological innovation and economic growth. If firms are not sure about the process of technological development at the micro-level, growth rates drop. It is not realistic to assume that firms operate in a world of certainty where inventions will happen for sure at the individual firm-level. In a stochastic environment, the costs must equal the expected revenues. And the expected revenues can be calculated by the revenues of newly developed varieties times a certain probability that a firm is successful. From chapter two it becomes clear that only if we look at knowledge capital as a public good, a country can consistently show a positive rate of technological innovation and thus growth. It is the public knowledge character that causes the overall level of knowledge in the economy to go up so that everyone can benefit from this generated knowledge. A constant positive growth rate can this time be sustained because even though the returns of developing a new variety decrease so do the costs of product development due to the existence of a pool of general knowledge capital. More uncertainty causes the expected discounted profit levels to drop and thus reduces the incentive for domestic firms to invent new varieties, lowering the potential for economic growth.

Technology imports and the endogeneity of openness

If we analyse the growth issue from the perspective of a small developing country – the underlying assumption in the articles presented in this PhD thesis – we note that by far the largest share in R&D does not take place inside the developing countries but rather in the developed world.

This means that for developing countries a crucial channel through which technology can be acquired is through openness to international trade and investment. Through foreign direct investment and the import of goods, new technologies and inventions incorporated in those goods and services are produced by multinationals inside the country or imported. This mechanism for growth is important as we recall that most developing countries do not engage R&D themselves but largely rely on technological progress in the developed world. The level of openness of a country determines how easy that dispersion process is.

The regression analysis in chapter three confirms the positive empirical relationship between openness and growth for a set of 53 countries over the 1970 – 2000 period. Openness and secondary education are the two variables that affect output growth positively according to the regression outcomes.

Chapter four claims that the negative dynamic welfare effects of trade restrictions are highly underestimated, making the case for openness even stronger than suggested. In chapter four, the static and dynamic costs of a change in trade restrictions for a small developing economy which combines labour and (intermediate) capital goods in its final goods production process are analysed. The economy depends on successful R&D projects undertaken in the rest of the world and then introduces them onto its domestic market for an increase in the range of available capital goods. Any newly invented capital good is only introduced on the market in the developing economy if the (expected) discounted value of operating profits is larger than the costs of introduction. Since operating profits decline as the level of trade restrictions increases, the share of capital goods introduced on the market is a declining function of the level of trade restrictions. The developing economy evolves over time to a balanced growth path in which income, welfare, and the share of capital goods introduced on the market in the developing economy increase if the level of trade restrictions falls. The optimal level of trade restrictions is therefore zero, while a government wishing to maximize government revenue will set a strictly positive level of trade restrictions. Additionally, there is an asymmetric adjustment path of the developing economy after a change in trade restrictions. A decrease in the level of trade restrictions – which leads to more openness - may lead the developing economy to embark on a rapid catch-up process of economic growth by benefiting from the backlog of previously-invented-but-not-yet-introduced capital goods which may now, as a result of the increase in operating profits, be introduced after the fall in trade restrictions. The case of North- and South-Korea illustrates the point of how profound the long-run impact of trade restrictions is. Static analyses cannot explain such large differences but a dynamic analysis based on the invention and introduction of new goods, can.

Technological innovations lead to economic growth and the lower the level of uncertainty the higher the level of innovations (chapter two); the more open a country (i.e. the lower a country's trade barriers) the stronger the positive dynamic welfare effects through – amongst others – innovation (chapter four). Chapter three establishes the positive empirical relationship between openness and growth.

However, in chapter three we also show that volatility (uncertainty) has a negative effect on economic growth and on openness especially of small developing countries. Terms-of-trade volatility affects the export sectors of some countries more than others. When we observe empirically that volatility in primary product prices on the world markets (natural resources like oil, copper or basic primary commodities like coffee and sugar) is relatively high compared to price volatility of manufacturing goods and when we measure higher shares of primary products and natural resources in the exports of small developing countries, the latter are especially prone to the negative impact of terms-of-trade volatility.

In a stylised Armington-model we define two sectors: the tradable and non-tradable sector within which we distinguish between export and import goods in order to address the terms-of-trade volatility. We have a CES composite good at the demand-side (consumption of domestically produced goods and imports) and a CET composite good that is supplied (domestic production and exports). When we solve for quantities and prices, we derive a system of equations that show that the overall impact of uncertainty on real returns and the equilibrium capital stock in the economy is negative (how negative depends on the characteristics of the *j(T)*-function). This in turn leads to a lower transitional growth path towards a (lower) steady-state. However, on top of the economy-wide impact, certainty equivalence arbitrage leads to sectoral re-allocation of resources. Within the given equilibrium framework, it is the export sector that experiences higher levels of volatility due to erratic movements in world prices (with developing countries experiencing this effect more strongly than developed countries due to the aforementioned volatility in primary product prices on the world market). In order to compensate the export sector for higher levels of uncertainty, the marginal product for the composite good produced must go up. It is shown in chapter three that this can only be achieved through a reduction in exports and a subsequent allocation of the surplus of marginal product to capital. The consequences are reductions in both exports and imports which implies that the country is becoming more closed. We thus conclude that openness is endogenously determined through volatility in the terms-of-trade (amongst others) in a negative way. When empirically testing these findings, we conclude that there is a weak link through the volatility – openness to economic growth channel but that the direct effect of terms-of-trade volatility, though small, is significant at the 10% level. Running growth regressions shows that terms-of-trade volatility can explain about 4% of the variation in growth rates. Also we find that volatility has a negative impact on openness but this seems to be more a long-run phenomenon: higher volatility for a prolonged period of time causes structural adjustments in the economy. At the same time we observe that the terms-of-trade volatility is higher in poorer countries suggesting that the negative endogenous impact on developing countries could be stronger.

In chapters three and four we argue in favour of more openness to enhance inflows of capital and technology because it leads to higher levels of economic growth. Now we see that because of volatility as described in chapter three there is an endogenous force – albeit a long-run and not too strong one – that pushes a small developing country towards a smaller tradable sector, essentially closing the economy from the riskier international markets with terms-of-trade volatility. The price of export orientation and higher levels of openness to attract technology and international capital seems to have the effect of creating more volatility also. An economy that tries to diversify risk may very well do that through investing in less risky (non-tradable) sectors. Governments in developing countries should be very well aware of these forces.

Openness and growth

But openness is worth pursuing because it attracts investments and raises the rate of innovation in the developing country, thus promoting economic growth, does it not? In general it does, but we should be careful not to overestimate the effects of openness on technological innovation. The message to be careful comes, among others, from chapter five where we model and analyse successfully the impact of obsolescence of economic inventions by incorporating maintenance costs in the endogenous growth model of expanding product varieties despite warnings that one needs to look at vertical models of quality improvements. We show that if obsolescence is introduced by expanding the Grossman and Helpman (1991) model into a three-sector model, obsolescence leads to lower rates of innovation and lower levels of economic growth.

Firms invest funds in R&D to invent and introduce new products continuously. The profitability of these new products diminishes over time as a result of the invention and introduction of even newer products and as a result of the ever higher costs of maintaining the production process in working condition; i.e. as a consequence of obsolescence. If the maintenance costs become too high, the operating profits become negative and the firm stops producing the older varieties. We show that in a partial equilibrium framework, that is, other things being equal, the economic life span of innovations, that is the period during which a new variety is actually produced before the product becomes obsolete and is replaced by even newer varieties, is longer (i) the lower the growth rate of the economy, (ii) the lower the maintenance costs, and (iii) the lower the elasticity of substitution between different varieties. But the rate of innovation and share of active firms are determined within the general structure of the model, thereby affecting the speed of obsolescence endogenously. The direct effect of an increase in maintenance costs (speeding up obsolescence) dominates initially, while eventually the indirect effect of an increase in maintenance costs, reducing the rate of innovation (and reducing obsolescence) prevails.

Back to Pakistan

My quest for new insights into the phenomenon of economic growth has taken me past technology, uncertainty and volatility, openness, obsolescence and trade and government policy. I am still in touch with Mr. Malik in Peshawar via the digital highway that he – good for him – has access to. He has asked me about my PhD work and after my explanation wondered how my work could help the people in Peshawar and Mayar that I got to know. That was a confrontational yet very good question. Good, because I believe it the purpose of a social science like economics to be socially involved and to assist in improving the quality of life of peoples all around the world. Confrontational because he asked it in such a way – although polite – that I felt forced to leave the mathematics and general conclusions and translate my findings into what they could really mean for poor rural Pakistan.

I answered to Mr. Malik that my work has given me some very valuable and new insights that are relevant to Mayar and its people but also that it is limited in scope and does not try to explain the world. The insights generated are the need to reduce uncertainty in the Pakistani economy, the need for more openness of the Pakistani economy and permanent technological innovation, mostly imported from abroad.

Reduced uncertainty

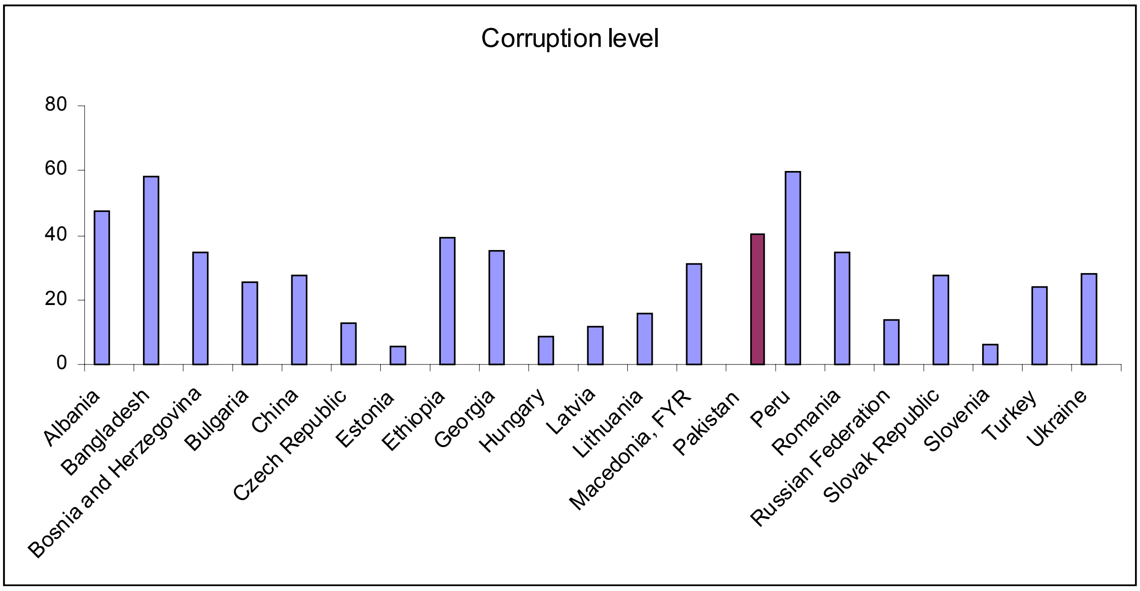
According to chapter two, the major decision for a firm is not simply to look at labour productivity in an R&D sector, but at the probability the R&D sector is successful in inventing a new variety thus changing the value of a Pakistani firm and the economic growth rate of the private sector and the economy as a whole. The higher the level of uncertainty – due to internal problems of the firm, due to red tape and bureaucracy, due to political interference or uncertainty, the lower the rate of growth. Higher levels of education for more people – on the other hand – lead to a higher probability of new inventions which raises the level of innovation and economic growth rate. The sustainability of the innovation process also depends largely on the public goods character of knowledge. The larger the spill-over effects, the stronger the self-sustainable character of innovation. Spill-overs are larger, the stronger the public goods character of knowledge and the more open Pakistan becomes. The openness of Pakistan leads to the import of new technologies instead of having to invent everything domestically. Trade policy uncertainty and trade policy changes have a profound effect on this engine for technological innovation as chapter four has illustrated.

Economic and political uncertainty in Pakistan

Uncertainty at the economic and political levels is very high and detrimental to development in Pakistan. Economic uncertainty comes from three main sources: bureaucracy and corruption inside Pakistan, trade policies of Pakistan's trading partners and volatility of the terms-of-trade for Pakistan.

Pakistan suffers from very high levels of corruption as figure 6.1 shows for the year 2002. In the surveyed World Bank dataset for 2002, only Albania, Bangladesh and Peru show higher levels of perceived corruption than Pakistan (measured by the share of managers surveyed that rank corruption as a major business constraint in the country).

Figure 6.1. Corruption levels



Source: WB WDI 2006

Secondly, trade policies of Pakistan's trading partners (like the European Union) are discriminating against cheap labour producing countries like Pakistan especially in areas like clothing and textiles and primary agricultural commodities.[71] If we look at the exports of Pakistan in table 6.1 we see that it is exactly clothing, textiles and leather that constitute the top-15 of most exported products of the country. We also see that the absolute size of these exports is increasing rapidly from 2000 to 2004. Though not shown in this figure, the share of the top-15 exported goods is increasing as a share of Pakistan's total exports, indicating an increased dependency – or specialisation if you will – of the country on these – primary product – sectors.

[71] We only need to remember the 'War on textiles' in 2005 between China, the EU and the USA to have an enlightening example of how protective the developed world is regarding cheap labour-intensive imports.

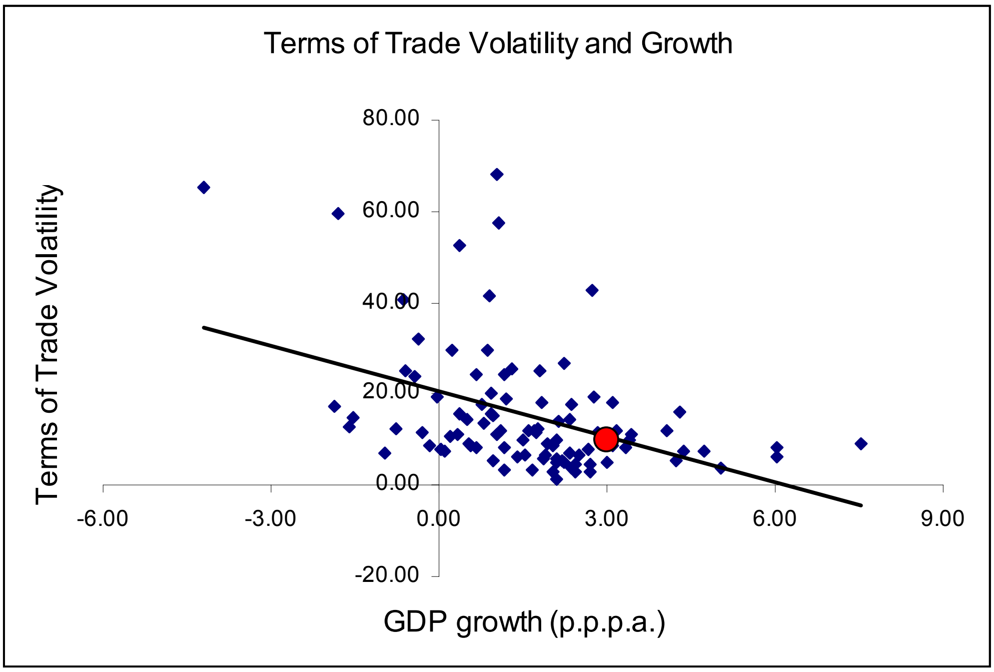
Table 6.1. Top-15 exports of Pakistan (2000, 2002, 2004)

Product group	**Value 2000**	**Value 2002**	**Value 2004**
	US$ '000	**US$ '000**	**US$ '000**
658 - MADE-UP TEXTILE ARTICLES	1.354.148,00	1.761.462,00	2.344.959,00
652 - COTTON FABRICS, WOVEN	1.072.969,00	1.241.891,00	1.769.612,00
651 - TEXTILE YARN	1.188.501,00	972.971,00	1.114.919,00
843 - MEN/BOY WEAR KNIT/CROCH	513.009,00	509.863,00	748.752,00
845 – ARTICLES OF APPAREL NES	311.711,00	302.455,00	686.550,00
042 - RICE	534.063,00	463.132,00	682.793,00
841 - MENS/BOYS WEAR, WOVEN	540.397,00	523.108,00	517.969,00
848 - HEADGEAR/NON-TEXT CLOTHG	399.180,00	306.551,00	427.293,00
653 - MAN-MADE WOVEN FABRICS	509.238,00	447.432,00	341.029,00
334 - HEAVY PETROL/BITUM OILS	56.810,00	126.806,00	317.629,00
894 – BABY CARR/TOY/GAME/SPORT	282.478,00	326.634,00	315.858,00
611 - LEATHER	204.231,00	240.387,00	284.839,00
846 – CLOTHING ACCESSORIES	143.796,00	270.343,00	282.288,00
659 - FLOOR COVERINGS ETC.	282.021,00	243.587,00	252.349,00
842 - WOMEN/GIRL CLOTHING WVEN	132.609,00	173.194,00	193.284,00

Source: International Trade Statistics

The third source of uncertainty stems from terms-of-trade volatility. The empirical results from chapter three show, that there is a negative direct effect of terms-of-trade volatility on economic growth as well as a negative (but weaker) indirect effect on economic growth via openness. On top of that, figure 6.2 shows a negative trend for a large set of countries between terms-of-trade volatility and economic growth, in support of the evidence from chapter three (Pakistan is shown by the red dot).

Figure 6.2. Terms of trade volatility and economic growth.



Source: WB WDI 2006

More openness

This thesis clearly establishes a theoretical and empirical (direct and indirect) link between openness and economic growth. More openness leads to the imports of new technologies which may enhance the economic growth rate of Pakistan both because of these imports and because of the self-sustainable process of technological innovation. These technological innovations do not just have static but more importantly dynamic welfare effects for the Pakistani economy in the longer run when the number of new varieties in the Pakistani economy is affected. Moreover, their effects are asymmetric: if President Musharraf decides to lower trade restrictions, a rapid increase in production is predicted. However, if he decides to increase trade restrictions, only a gradual deterioration of the level of production will follow. Free trade will allow Pakistan to reap most benefits for the Pakistani citizens in general and inhabitants of Mayar in particular.

Ongoing technological innovation

Technological innovation is the engine for long-run growth of Pakistan. Even though in the shorter run, many economic gains can come from accumulation of labour and capital, in the longer run, the way forward is through innovation: spill-over effects will be sufficiently large, levels of openness allow foreign technologies to enter Pakistan, the newest products and processes from abroad are imported leading to consumer and producer gains and dynamic welfare effects in the long run. New technologies from abroad serve as an engine to economic growth because they increase productivity and efficiency of production, thus increasing the level of welfare in Pakistan.

Three warnings are in place for Pakistan regarding technological innovations in this respect. First, let North-Korea serve as an example of what a prolonged period of economic (and political) isolation can do to a country. Second, for a set of countries the asymmetric effect of trade restrictions was illustrated. Third, chapter five serves as a warning as it shows that technologies may well become obsolete over time as a consequence of higher maintenance costs. Given the Pakistani climate and terrain conditions, maintenance costs for certain innovations (e.g. agricultural ones) may be relatively high which means – in line with chapter five – that growth levels in Pakistan's agriculture may not benefit as much from new technologies as expected.[72]

It is not the aim of this thesis to provide Pakistan with all the answers it needs for economic growth and rural development. Admittedly, we have only looked at a small part of the problem. Also it is much easier to criticise wrong policies and to just identify the problems facing development of a country rather than to come up with actual policy recommendations that turn out to be successful. Besides, even when Pakistan does grow economically, there is no guarantee that the benefits will accrue to the poor and rural populations, for example in Mayar. Despite the fact that a 'holy grail of development' does not exist, some major conditions that may lead to economic growth of Pakistan have been addressed: technological innovations, level of openness, level of maintenance costs and rate of obsolescence and the (perceived) level of uncertainty.

"Economic growth is everything, but it is not the only thing".

[72] Importing new high-technology tractors and machines for rural Pakistan, for example, may be recommended from the theoretical growth model point of view. However, these tractors will only be beneficial if the local population is educated enough and trained enough to work with them. In reality, most of these machines break down and rust away in the same year they are received. In essence these imports are becoming obsolete rapidly because there is no maintenance available.

Appendix 1: Reduced form constants.

Reduced form constants, A_j, used in the stylised model of Armington-based trade used in Section 3.4.

$$A_1 = A_1$$
$$A_2 = A_2$$
$$A_3 = A_3$$
$$A_4 = (a \cdot A_3)^{\frac{1}{1-a}} \cdot \bar{r}^{\frac{1}{a-1}} \cdot L$$
$$A_5 = \left(\frac{1-\alpha}{\alpha}\right)^{\frac{\Omega}{s+\Omega}} \cdot \left(\frac{1-\beta}{\beta}\right)^{\frac{s}{s+\Omega}}$$
$$A_6 = A_2^{-1} \cdot \alpha^{\frac{-1}{h}}$$
$$A_7 = \left(\frac{1-\alpha}{\alpha}\right)^{1-\phi\Omega h} \cdot \left(\frac{1-\beta}{\beta}\right)^{\phi\Omega h}$$
$$A_8 = A_5 \cdot A_2^{-1} \cdot (1-\alpha)^{\frac{-1}{h}}$$
$$A_9 = \left(\frac{1-\alpha}{\alpha}\right)^{\phi\Omega h-1} \cdot \left(\frac{1-\beta}{\beta}\right)^{-\phi\Omega h}$$

As mentioned in footnote 56, for the parameter ϕ we note that $\phi = \frac{s}{s+\Omega}$.

Appendix 2: Empirical data Growth and Openness Regressions.

BASIC DATA	PCGRGDP7000	PCGDP70	XGDP7000	ToTV7000	SE7000	PF7000	GDP70
Argentina	0.68	6830.00	8.45	24.23	65.32	3.18	31.40
Australia	1.89	13636.00	16.46	6.48	94.28	1.00	38.76
Austria	2.69	16053.00	34.40	2.95	99.02	1.00	14.97
Belgium	2.44	16209.00	64.68	2.85	107.55	1.07	25.60
Bolivia	0.22	856.00	23.02	29.49	35.75	3.32	1.09
Botswana	7.55	590.00	56.78	8.93	35.76	2.32	0.10
Brazil	2.36	2394.00	8.76	17.84	38.65	3.30	34.79
Cameroon	1.16	508.00	23.97	24.26	22.84	5.82	1.07
Colombia	1.83	1377.00	15.76	18.27	47.50	2.86	7.40
Costa Rica	1.92	2347.00	35.01	9.17	43.16	1.13	0.99
Cote d'Ivoire	-0.77	927.00	37.23	12.54	20.08	5.41	1.65
Denmark	1.67	23446.00	33.23	3.33	107.36	1.00	16.17
Dominican Republic	3.41	874.00	27.28	10.00	43.68	2.52	1.30
Ecuador	1.29	879.00	26.13	25.56	52.81	3.11	1.57
Iceland	3.00	13733.00	35.52	5.17	94.30	1.00	0.51
India	2.67	212.00	7.32	7.92	39.29	2.79	62.88
Indonesia	4.30	298.00	26.44	15.88	40.37	5.32	11.00
Ireland	4.24	7908.00	56.08	5.36	99.79	1.11	4.36
Italy	2.35	10801.00	21.73	7.05	78.92	1.41	107.30
Jamaica	0.36	1951.00	43.02	15.85	61.76	2.20	1.72
Japan	2.83	20015.00	11.46	11.49	95.34	1.34	203.74
Korea, Rep.	6.03	2164.00	30.12	8.14	86.25	3.84	8.87
Malawi	0.79	121.00	25.04	13.60	7.36	5.61	0.35
Malaysia	4.37	1371.00	66.15	7.30	54.04	3.93	4.21
Malta	6.05	1927.00	80.17	6.29	80.71	1.63	0.19
Mexico	1.81	2295.00	16.74	25.19	52.82	3.70	40.20
Nepal	1.54	154.00	13.38	6.82	28.24	4.02	0.85
New Zealand	1.02	12467.00	28.05	11.19	91.61	1.00	6.45
Nicaragua	-1.61	917.00	23.69	12.96	39.76	4.38	0.49
Norway	3.15	15669.00	38.76	12.02	101.75	1.00	12.66
Papua New Guinea	0.75	870.00	43.69	17.79	12.26	2.34	0.60
Paraguay	1.70	1064.00	22.35	11.78	32.07	4.46	0.52
Peru	0.21	2359.00	15.63	10.75	62.26	3.98	7.24
Philippines	1.10	845.00	28.97	11.96	69.16	3.79	6.58
Portugal	3.44	5016.00	26.57	11.06	65.78	1.91	7.14
Rwanda	0.88	263.00	9.68	29.68	5.86	6.11	0.30
Spain	2.50	8507.00	17.65	6.68	99.09	2.20	38.80
Sri Lanka	3.10	340.00	30.03	17.97	65.07	3.38	3.16
Swaziland	2.14	784.00	71.86	13.82	42.17	5.21	0.13
Sweden	1.86	19598.00	32.07	5.89	99.58	1.02	34.48
Switzerland	1.16	35490.00	35.18	3.16	95.56	1.00	21.35
Syria	2.25	578.00	22.18	26.81	49.90	6.52	1.73
Turkey	2.08	1633.00	12.71	10.08	43.82	3.64	18.02
Uruguay	1.52	4013.00	19.14	10.00	73.88	3.29	2.02
Zambia	-1.82	699.00	36.31	59.67	20.49	4.70	1.22
Zimbabwe	0.58	607.00	26.96	8.75	37.46	4.95	1.62

OPENNESS	**ln_XGDP**	**ln_TOTV**	**ln_size**
Argentina	2.13409654	3.1875915	3.4468716
Australia	2.801066217	1.8687205	3.6572856
Austria	3.537929615	1.0818052	2.705781
Belgium	4.169380025	1.047319	3.2424752
Bolivia	3.136367775	3.3840512	0.0870947
Botswana	4.039130388	2.1894164	-2.282782
Brazil	2.170650707	2.8814431	3.5493012
Cameroon	3.17660224	3.1888289	0.0657877
Colombia	2.757317957	2.9052604	2.0010745
Costa Rica	3.555492715	2.2159373	-0.015114
Cote d'Ivoire	3.617242898	2.5289235	0.4995624
Denmark	3.503603363	1.2029723	2.783034
Dominican Republic	3.306014007	2.3025851	0.2639015
Fiji	3.911113825	2.4932055	-1.227583
Finland	3.376177969	1.512927	2.4076656
France	3.059839386	1.5993876	4.9869094
Greece	2.919349835	2.1621729	2.4641085
Iceland	3.570195603	1.6428727	-0.675307
India	1.990087858	2.0693912	4.1412441
Indonesia	3.274769974	2.7650605	2.3976225
Ireland	4.026830286	1.678964	1.4724721
Italy	3.078836281	1.9530276	4.6756007
Jamaica	3.761639367	2.7631695	0.539996
Japan	2.438594911	2.4414771	5.316825
Korea, Rep.	3.405327711	2.0967902	2.1823365
Malawi	3.220614429	2.6100698	-1.049822
Malaysia	4.191912621	1.9878743	1.4362743
Malta	4.384167724	1.8389611	-1.660731
Mexico	2.817929569	3.2264471	3.6938172
Nepal	2.593722839	1.9198595	-0.161343
New Zealand	3.333947181	2.4150205	1.8633046
Nicaragua	3.16524166	2.5618677	-0.709277
Norway	3.657476403	2.4865719	2.5386054
Oman	3.995465956	3.7534961	-0.534435
Papua New Guinea	3.777194868	2.8786365	-0.517515
Paraguay	3.107031424	2.4664032	-0.648174
Peru	2.749490678	2.3749058	1.9789304
Philippines	3.366175614	2.4815677	1.8837307
Portugal	3.279924178	2.403335	1.9651524
Rwanda	2.269884056	3.3904734	-1.214023
Spain	2.870772519	1.899118	3.6585233
Sri Lanka	3.402349256	2.8887037	1.1502555
Swaziland	4.27475511	2.6261168	-2.009915
Switzerland	3.56057395	1.150572	3.0609112
Syrian Arab Republic	3.099396333	3.288775	0.5475432
Turkey	2.542382438	2.3105533	2.8914268
Uruguay	2.951697681	2.3025851	0.7050758
Zambia	3.592037534	4.0888294	0.2021242
Zimbabwe	3.29442376	2.1690537	0.4811908

GROWTH	GRGDP	ln_Y70	R_lnXGDP	lnSSE	lnPF
Argentina	0.68	8.82908	-0.503678	4.179262	1.15643
Australia	1.89	9.5204686	-0.247149	4.546216	0
Austria	2.69	9.683651	0.0565431	4.595279	0
Belgium	2.44	9.6933219	0.7701187	4.677956	0.06899
Bolivia	0.22	6.7522704	-0.022109	3.576658	1.20039
Botswana	7.55	6.3801225	0.0612812	3.576918	0.84218
Brazil	2.36	7.7807209	-0.553031	3.654615	1.195
Cameroon	1.16	6.2304814	-0.051798	3.128565	1.76155
Colombia	1.83	7.2276625	-0.228933	3.86073	1.04982
Costa Rica	1.92	7.7608932	-0.016953	3.764914	0.11778
Cote d'Ivoire	-0.77	6.8319536	0.2408996	2.999724	1.68838
Denmark	1.67	10.062455	0.0768087	4.676198	0
Dominican Republic	3.41	6.7730804	-0.188275	3.77689	0.92341
Ecuador	1.29	6.7787849	0.1192255	3.966623	1.1337
Egypt, Arab Rep.	3.32	6.1696107	-0.213195	4.156928	1.63761
El Salvador	0.34	7.3932631	-0.244629	3.316809	1.20039
Fiji	1.62	7.4656553	0.2207372	3.957761	1.07451
Finland	2.68	9.6290507	-0.01113	4.688979	0.45199
France	2.24	9.7057681	0.1527258	4.548098	0.38137
Greece	2.04	8.8025225	-0.237935	4.487926	0.76214
Iceland	3.00	9.527557	-0.311982	4.546481	0
India	2.67	5.3565863	-0.90548	3.670957	1.0245
Indonesia	4.30	5.6970935	0.3102987	3.698178	1.67174
Ireland	4.24	8.9756302	0.5323434	4.603115	0.10178
Italy	2.35	9.287394	0.2372207	4.368381	0.3441
Jamaica	0.36	7.5760973	0.471796	4.123256	0.78683
Japan	2.83	9.9042373	-0.125297	4.557496	0.29214
Korea, Rep.	6.03	7.6797136	0.1766149	4.45722	1.34529
Malawi	0.79	4.7957905	-0.39906	1.996211	1.72404
Malaysia	4.37	7.2232957	0.7958482	3.989725	1.36828
Malta	6.05	7.5637197	0.3962213	4.390804	0.48551
Mexico	1.81	7.7384881	0.2364996	3.96681	1.30737
Nepal	1.54	5.0369526	-1.104684	3.340814	1.39075
New Zealand	1.02	9.4308404	0.1573751	4.517486	0
Nicaragua	-1.61	6.8211075	-0.411247	3.682861	1.47591
Norway	3.15	9.6594395	0.6232161	4.622545	0
Oman	2.73	8.0471896	0.8536169	3.652434	1.80065
Papua New Guinea	0.75	6.7684932	0.3416428	2.505979	0.85015
Paraguay	1.70	6.9697907	-0.491148	3.467765	1.49611
Peru	0.21	7.7659931	-0.420472	4.131319	1.38182
Philippines	1.10	6.7393366	0.21574	4.23635	1.33123
Portugal	3.44	8.5203881	0.1171935	4.186282	0.64748
Rwanda	0.88	5.572154	-1.113863	1.768881	1.80946

Spain	2.50	9.0486446	-0.166918	4.596076	0.78683
Sri Lanka	3.10	5.8289456	0.2617531	4.175412	1.2164
Swaziland	2.14	6.664409	0.4926888	3.741796	1.6514
Sweden	1.86	9.8831828	0.366732	4.600951	0.0177
Switzerland	1.16	10.477006	0.1645862	4.559708	0
Syrian Arab Republic	2.25	6.3595739	-0.010897	3.910021	1.87455
Turkey	2.08	7.3981741	-0.489888	3.779994	1.29277
Uruguay	1.52	8.2972944	-0.46547	4.302428	1.18958
Zambia	-1.82	6.5496507	0.6926562	3.020138	1.5468
Zimbabwe	0.58	6.4085288	-0.207161	3.62314	1.59867

Appendix 3: Static and dynamic welfare costs in terms of welfare.

Defining the static and dynamic welfare costs of an increase in trade restrictions analogously to the static and dynamic costs in terms of income, see equations (4.19) and (4.20), and using (4.7), (4.16)-(4.18), and the definitions in (4.1'), (4.14), and (4.15), we get:

$$\text{(A1)} \quad W^{costs}_{static}(t_1^+) \equiv 1 - \frac{W(t_1 | t_1^+)}{\lim_{t \uparrow t_1} W(t_1 | t_1^+)} = 1 - \frac{T_1 x(T_1) + (1-\alpha) L^{1-\alpha} x(T_1)^{\alpha}}{T_0 x(T_0) + (1-\alpha) L^{1-\alpha} x(T_0)^{\alpha}}$$

$$\text{(A2)} \quad W^{costs}_{dynamic}(t_1^+) \equiv 1 - \frac{\int_{t_1}^{\infty} \left[(1-\alpha) Y(t | t_1^+) + G(t | t_1^+) \right] e^{-\rho(t-t_1)} \, dt}{\int_{t_1}^{\infty} W(T_0) e^{-(\rho-g)(t-t_1)} \, dt} =$$

$$= 1 - \frac{W(T_1)}{W(T_0)} - \frac{(\rho - g)\left[\beta(T_0) - \beta(T_1)\right] N_0 \left[T_1 x(T_1) + (1-\alpha) L^{1-\alpha} x(T_1)^{\alpha} \right]}{\rho W(T_0)}$$

Executive Summary (English)

The issue of economic growth and its causes is one that has intrigued us for many hundreds of years. Adam Smith (1776) was not the first nor was he the last to look at peoples' levels of income and changes in income over time. Since Smith many economists have worked on economic growth and various growth models have been developed: the Harrod-Domar and the Solow models of exogenous economic growth and since 1986 the various endogenous growth models. The scientific aim of making models is to try to explain that what is observed in the world around us in an abstract and structured way.

The aim of this thesis is to look at economic growth and address some important omissions or even misinterpretations in the literature that, at the same time, bring the growth models closer to being practically relevant. More specifically, I focus on the following four problems with respect to economic growth: uncertainty in endogenous growth models, terms-of-trade volatility and the endogeneity of openness, the dynamic effects of trade restrictions and the phenomenon of obsolescence in endogenous growth models of expanding product varieties. These topics have been neglected among economic growth researchers or even misrepresented.

Uncertainty

What is the effect of uncertainty on economic growth? Although it is intuitively understandable that we expect and find a negative relationship between the two, what matters is the mechanism between uncertainty and economic growth. If we can understand the ways in which one affects the other, we may more effectively address any negative consequences for people's levels of income and income growth when looking at uncertainty, because many of us would not agree with Ursula Le Guin when she says that *"The only thing that makes life possible is permanent, intolerable uncertainty; not knowing what comes next"*. In chapter two, I introduce uncertainty into an endogenous growth model to analyse the impact uncertainty has, to show how the mechanism of uncertainty translates into economic growth and to emphasise the fundamentally different interpretation when we leave a deterministic world for one in which outcomes are only expected outcomes in a probabilistic world.

Chapter two shows that with minor mathematical changes from the Grossman and Helpan (1991) model, the mechanism and interpretation of economic growth alter fundamentally. If we live in a world of uncertainty, we can no longer simply look at productivity in a certain research and development sector. Instead we have to look at the probability the research and development sector is successful in inventing new varieties, thus changing the value of the firm and the growth rate. The probability of a successful R&D sector, and subsequently the self-sustainability of a process of innovation, then depends on the public good character of knowledge, the level of education and training of researchers, the number of researchers that are active and the ease with which foreign technological findings can be imported. The public good character of knowledge has a lowering effect on the costs of product development. If the pool of general knowledge is large enough continuous growth of the economy is ensured. This also depends on the size of the economy, how patient people are, how successful R&D departments are to invent new varieties and how much variety in consumption households have. Also because we introduce uncertainty, the model now incorporates an important fact of life.

Terms-of-trade volatility and the endogeneity of openness

Another type of uncertainty for an economy is volatility in the terms-of-trade. Since the Prebisch-Singer (1950) hypothesis that developing countries experience deteriorating terms-of-trade, economists have argued and disagreed as to what matters for growth: the trend or the volatility in the terms-of-trade. In chapter three, I use first a general then an Armington specification (with CARA preferences) to analyse the effects of terms-of-trade volatility on economic growth and show – through formulations and properties of a *j*-function – that a higher level of volatility leads overall to a lower real expected rate of return on capital as well as a lower level of capital. This means the economy is less efficient when subject to terms-of-trade uncertainty. Additionally, in chapter three, I show implicitly that sectoral re-allocation of resources takes place because we need certainty equivalence to be equalised. The only way to achieve equal certainty equivalent returns economy-wide is through reducing the number of exports because a reduction leads to a higher marginal product to the composite good which is needed to offset the reduction in mean returns as a consequence of volatility in the terms-of-trade. In the optimum, the tradable sector will shrink exactly enough to raise the expected rate of return in that sector to equal the marginal product of capital under certainty plus the certainty equivalent (CE). The entire surplus from the tradable sector is allocated to capital for risk compensation which leads to a lower marginal product of labour and thus lower wages. Fully in line with the finance literature, this result implies that through diversification away from the risky sector, investors decrease the variance at the expense of lower mean returns. This means that uncertainty in the level of terms-of-trade leads to a more 'closed' economy and that this effect on openness is endogenous. I show by running several regressions that there is a negative and significant direct effect of terms-of-trade volatility on economic growth. The volatility – openness – growth mechanism is also empirically observed but weak. The direct link between volatility and growth is significant at the 10% level with volatility explaining about 4% of the variation in economic growth rates.

Dynamic effect of trade restrictions

Traditionally, economists have measured welfare effects of trade restrictions by using classical micro-economics and resulting Harberger-triangles. These measure the re-distributional welfare effects in a world where everything exists, i.e. where we live the interior of goods space. But if we have already invented everything, why then is the so much focus on R&D, innovation and knowledge economies and why then do we measure technical and process innovations to play such an important role in economic growth? Romer (1994) is the first to mention the fact that we should not look at the world through static but rather dynamic glasses. I argue in chapter four that it is indeed the dynamic welfare effects of trade restrictions we need to look at and show that we can do so by using an endogenous growth model. What are the main findings? First, the estimated static costs of trade restrictions are smaller than the dynamic costs of trade restrictions if, and only if, the increase in trade restrictions reduces the *share* of invented capital goods introduced on the market. In this dynamic setting it is therefore not the fact that we ignore the Dupuit triangles of newly invented goods in estimating the effects of an increase in trade restrictions, as it is in the Romer (1994) model, but the fact that an increase in the trade restrictions affects the share of newly invented goods not introduced on the market. Second, as a result of the sunk-cost nature of the introduction costs, there is an asymmetric adjustment path of the developing economy after a change in trade restrictions. An increase in the level of trade restrictions will slow-down economic growth and put the economy on a transition path to a new balanced growth rate. If the new level of trade restrictions exceeds a critical value, the new growth rate will be zero and stagnation occurs. If trade restrictions fall, the developing economy may embark on a rapid catch-up process of economic growth by benefiting from the backlog of previously-invented-but-not-yet-introduced capital goods which may now, as a result of the increase in operating profits resulting from the decrease in trade restrictions, be introduced on the market in the developing economy. The second effect, I believe, is one of the main reasons for the observation that economies that have been isolated and closed for prolonged periods of time (e.g. North-Korea) have failed to bring prosperity and growth to their citizens.

Maintenance costs and obsolescence

One important aspect in every day life is the fact that – besides innovations and new products – old ones become obsolete. In the vertical endogenous growth literature of quality improvements the phenomenon of obsolescence has been explored and developed. However, in the strand of endogenous growth models used in this thesis, the horizontal endogenous growth models of expanding product varieties, this has not been the case. Moreover, Aghion and Howitt (1998) and Grossman and Helpman (1991) are quoted saying this is not possible: Aghion and Howitt (1998, p.39) argue that *"in order to formalize the notion of (technical or product) obsolescence, one needs to move away from horizontal models of product development à la Dixit and Stiglitz (1977) into vertical models of quality improvements"* and Grossman and Helpman (1991, p.46) say: *"[The] ... complete symmetry between new and old commodities eliminates any possibility of product obsolescence. Fortunately the model of quality improvements ... can address this shortcoming of the present formulation…"*

In chapter five, contrary to the abovementioned international opinions, I introduce the notion of various types of maintenance costs that lead to product obsolescence when the maintenance costs rise over time. A firm will only produce its variety invented at a certain time if the operating profits are positive at any later time. Equivalently, the firm will stop production if the operating profits become negative. This allows us to determine the range of active firms using the obsolescence criterion. If the range of active firms is non-decreasing and the wage rate is constant, as will be assumed, then the flow of firms from active to obsolete is on a first-in-first-out basis (FIFO). In equilibrium we have a non-negative solution where the innovation equilibrium and labour equilibrium balance. When maintenance costs rise, more workers have to maintain the production processes in working condition, such that less workers are available for R&D and production of new varieties. Also when a lower share of firms becomes obsolete because of lower maintenance costs, the productivity of the labor force for research and maintenance is increased. These effects, lead to a higher profit for the firm and higher levels of economic growth. Therefore, contrary to the assertions by Aghion and Howitt (1998) and Grossman and Helpman (1991), obsolescence can – via the concept of maintenance costs – be successfully introduced in horizontal models of expanding product varieties, making this strand of models much more realistic.

Overall, uncertainty has a negative influence on economic growth, either through a reduction in the profitability of the R&D sector or via an indirect effect through reduced level of openness which is a consequence of risk aversion in an economy. The level of openness has a positive effect on economic growth through allowing the imports of new goods and ideas. While the a higher level of openness because of a drop in trade restrictions leads to static welfare gains through competition and lower prices, dynamic welfare gains can be much higher if the share of goods and technological innovations that is introduced in an economy rises. Trade policy has an asymmetric effect on the transitional paths to new steady states, depending on whether trade restrictions rise or drop. Economic growth is negatively influenced by rising maintenance costs of processes and production.

Samenvatting (Nederlands)

Het onderwerp van economische groei en haar oorzaken heeft veel mensen gedurende honderden jaren geïntrigeerd. Adam Smith (1776) was noch de eerste, noch de laatste die naar inkomens en inkomensgroei heeft gekeken Sinds Adam Smith hebben veel economisten gewerkt aan economische groei en verschillende groeimodellen zijn ontwikkeld. Van de exogene groeimodellen (bv. het Solow-model) tot de endogene groeimodellen vanaf 1986.

Het doel van deze dissertatie is het bekijken van de relatie tussen onzekerheid, technologie en economische groei. Daarnaast worden in deze dissertatie ook enkele omissies en verkeerde academische conclusies aan de kaak gesteld en oplossingen aangedragen om dit te veranderen.

In het algemeen heeft onzekerheid een negatieve invloed op economische groei, danwel via een afname van de effectiviteit van de onderzoekssectoren in bedrijven, dan wel via een indirect effect via een afname in de openheid van een land vanwege risicomijdend gedrag van ondernemingen. Het niveau van openheid heeft een positieve invloed op de economische groei omdat hierdoor importen van nieuwe goederen, methoden en technologische uitvindingen wordt gestimuleerd. Een land dat opener is, ondervindt niet alleen statische welvaartsvoordelen zoals in de klassieke micro-economie wordt bekeken. Als het aandeel van goederen in technologische uitvindingen toeneemt als gevolg van het afnemen van handelsbarrières, vinden er bovenop de statische effecten ook dynamische welvaartseffecten plaats die veel groter van omvang zijn en een positief effect hebben. Als gevolg van deze welvaartseffecten en het feit dat uitvindingen 'sunk cost' zijn, heeft handelsbeleid een asymmetrisch effect op de transitie van een economie naar een nieuw evenwicht, afhankelijk van of het handelsbeleid. Economische groei wordt ook negatief beïnvloed door stijgende onderhoudskosten. Via onderhoudskosten is het mogelijk om in horizontale endogene groeimodellen economische obsolescence te verklaren. Dit in tegenstelling tot wat veel top-economen beweerd hebben en/of beweren.

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