8.1 Summary

The main purpose is defined as gaining insight into investment behaviour on a sectoral level. Our study is a logical extension of our earlier work on investment behaviour in a putty-clay vintage framework. This study does not compare various investment models empirically but rather takes the vintage model as superior to alternative models. This assumption is supported by a large literature.

The first part of this study extensively discusses the development of theories explaining investment behaviour. The acceleration principle relating net investment to the change in output is criticized because of lack of theory and weak empirical performance. The theory on investment developed by Keynes has triggered off an extensive debate on what Keynes really meant. Is his theory in line with Fisher's choice theoretic framework? Is Keynes making a stock-flow error when he relates the rate of investment to the rate of interest? Witte and LeRoy answer both questions in the negative.

During the last few decades neoclassical theory and Tobin's g theory dominate the investment literature. Jorgenson derives an investment equation from the neoclassical theory of optimal capital accumulation in a world of perfect competition. Dynamics are introduced by assuming costly installation of capital goods. Tobin relates investment to deviations between the marginal efficiency of capital and the interest rate in a typical Keynesian manner. Both models are based on economic theory but show some weaknesses when it comes to empirical implementation.

In the present study we stay close to economic theory and rigorously derive input demand equations from present value optimization. Unlike most standard neoclassical models we do not assume homogeneous capital, but we assume that the stock of capital consists of capital of different vintages. More specifically, we assume a putty-clay vintage model—that is ex ante, before equipment is installed, the firm can choose a production technique or a combination of inputs in accordance with the relative prices of those inputs. The production structure is based on a putty-clay vintage framework with a two-level, three input ex ante production function. Besides capital and labour we add energy as a third factor of production. In simple vintage models only the optimal production technique—the ratio between inputs—is determined. In our model adjustment costs are introduced in order to derive levels of inputs and output simul-
taneously and consistently with the optimal production technique. Technical lifetime of equipment is modelled by a flexible S-shaped Gamma decay function, the parameters of which have been determined simultaneously with the other parameters in the model. Actual economic lifetime of equipment is endogenous, and aggregation over profitable vintages yields total capacity demands for inputs and output. Aggregation in this way requires brute-force vintage bookkeeping. For practical purposes we can dispense with vintage bookkeeping—at the expense of losing one of the characteristics of the vintage approach—to make the model more manageable, for instance in a full-fledged model environment. Finally, vintage modelling allows for a more elaborate modelling of technical progress.

The model is applied to a number of industrial sectors of the economy of the Netherlands rather than being applied to macroeconomic data. The sectors we distinguish here are:

- Food, beverages and tobacco
- Textiles, clothing, shoe and leather industry
- Other industry: wood, furniture and publishing
- Chemical industry and rubber industry
- Metal industry

Although some services sectors—such as public utilities, transport and communication, and commercial services—may be suited for vintage modelling, we have not considered these sectors here. We restrict our attention to the five industrial sectors listed above.

### 8.2 Conclusions

Vintage modelling in the literature usually comes in two types. The first type is brute-force vintage modelling or the structural approach to vintage modelling. The second type is a sort of quasi-vintage modelling or a reduced-form approach. The former type keeps track of individual vintages, whereas the latter approach exploits typical vintage characteristics, usually in a single-equation model. The Bischoff model is an example of the reduced-form approach. We favour the structural approach taking the computation burden for granted.

The reduced-form approach is not without difficulty either. The Bischoff model requires that investment, relative prices and changes in output are of the same order of integration. As we have indicated in chapter 5, the data for the five industrial sectors in our study do not satisfy these requirements.

We present a structural vintage model of the putty-clay variety extended with convex costs of adjustment. Here, we repeat the main assumptions underlying our model. In the first place, we assume a putty-clay technology with a production function \( \phi \) which exhibits constant returns to scale. \textit{Ex post} the technology is characterized
8.2 Conclusions

by fixed capital/labour, capital/output and capital/energy ratios. Secondly, we assume that firms are price-takers in all markets. In the third place, there are supposed to be convex adjustment costs associated with the sale and purchase of investment goods, and with the installation and maintenance of capital. Fourthly, demand constraints, financing constraints and capacity constraints are not taken into account.

There are other assumptions as well, most of which ease the analysis. These assumptions are a constant discount rate, and constant rates of growth of prices and technical progress. Technical decay is modelled using a cumulative Gamma distribution.

With respect to the production function, we use a twice-differentiable two-level CES production function, combining inputs of energy \( J \), investment \( I \) and labour \( N \) with output \( X \). We assume separability between labour and the capital-energy bundle \( (I,J) \).

Ex post input coefficients are fixed. Figure 6.1 in chapter 6 illustrates the nested production function. Elasticities of substitution are indicated by \( \sigma \) and \( \sigma_1 \). The elasticity of substitution within the capital-energy bundle \( (I,J) \) is \( \sigma_1 \), the elasticity of substitution between the capital-energy bundle \( (I,J) \) and labour \( N \) is \( \sigma \).

Entrepreneurs have to make a number of decisions. In the first place, they have to decide how much to invest. Secondly, they have to choose the optimal production technique. And, finally, they have to decide which vintages must be scrapped on economic grounds. The model is derived from net present value maximization and solved numerically. It is shown that the elasticities of substitution \( \sigma \) and \( \sigma_1 \) in the nested production function determine what happens in case relative prices change.
Chapter 8 Summary and conclusions

Some examples are presented in order to illustrate the working of the model. The results of these experiments are repeated here. The outcomes are qualified by pointing at the partial nature of the model. An adequate assessment of the quality of the model can only be given if the model is integrated in a full-fledged macroeconomic framework.

Suppose that, initially, we are in point A in figure 8.1. If for instance energy becomes relatively expensive, the expansion path in figure 8.1 will become steeper. Price changes induce substitution processes, so levels of inputs adjust to the new relative prices, and so will output. If, as a result, the isoquant moves inward, input \( J \) is reduced. It is ambiguous, however, what happens to investment \( I \). On the other hand, if the isoquant moves outward, investment increases, and it is not clear what happens to energy use. Our analysis leads to the conclusion that if \( \sigma \leq \sigma_1 \) investment decreases, and that if \( \sigma_1 < \sigma < 2\sigma_1 \) investment increases. If \( \sigma \geq 2\sigma_1 \), then the results are ambiguous.

If we look at the estimation results, we can conclude that \( \sigma < 2\sigma_1 \) in all sectors. Diagrammatically, all sectors are in the area above the \( \sigma = 2\sigma_1 \)-line [see figure 8.2]. Two sectors fall within the area enclosed by the \( \sigma = \sigma_1 \)-line and the \( \sigma = 2\sigma_1 \)-line. These sectors are the food sector and textiles manufacturing. In these sectors investment increases in case energy becomes relatively expensive. However, the analysis is partial in nature, since the demand side is not modelled and output prices are assumed to be unaffected by changes in the price of energy.

What will happen after the shock depends on whether the shock is temporary or not. Even if the shock is temporary, there are some forces that prevent the model from returning immediately to its pre-shock values. One force has to do with expectations formation and scrap, another with the adjusted stock of capital. The latter in turn affects future investment due to the fact that adjustment costs are assumed to be dependent on the capital stock.

A second experiment changes the price of labour. From the analysis it follows that an increase in wages will most likely reduce investment and output in all sectors. But, again, the analysis is partial and should be taken with some caution.

Above, attention has been paid to estimation results with respect to the elasticities of substitution. If we look at technical progress, we can conclude that it is mainly embodied. More specifically, on average most embodied technical progress is labour-augmenting. This corresponds to most empirical vintage models for the economy of the Netherlands. The exception is chemical industry: in this sector labour-augmenting embodied technical progress is slow and energy-augmenting technical progress is fast. Here, we also find fast disembodied technical progress.

As to the overall fit of the model, we have to conclude that there is still some room to improve the model. One way to improve the fit of the model is to intensify the search for a global optimum. Another way is to reexamine the assumptions underlying the model. The need for improving the model is not only based on the statistical fit.
8.2 Conclusions

Figure 8.2 Elasticities of substitution

- **FB**: Food, beverages and tobacco
- **TE**: Textiles, clothing, shoe and leather industry
- **OI**: Other industry: wood, furniture and publishing
- **CR**: Chemical industry and rubber industry
- **ME**: Metal industry
of the model, the values of some of the parameters indicate that results should be improved in order to increase the empirical relevance of the model as a whole.

### 8.3 Further research

In this study we have gone from theory to empirical modelling. The model as developed in the preceding chapters is close to theory. In order to increase the empirical relevance of the model, the assumptions underlying the model will have to be altered, and the model should be derived in consistence with these alterations. In the theoretical part some suggestions have already been put forward. One suggestion is to account for uncertainty of prices and future demand. After all, investment is likely to be sensitive to uncertainty. Another suggestion is to explicitly allow for demand and employment constraints as well as financial constraints. These modifications may have far-reaching consequences, and will certainly not simplify analytical rigour.

Another line of research may be to endogenise price behaviour and incorporate the vintage model in a full-fledged economic model. These measures are indispensable if we want to analyse policy experiments.

More recently, there has been a renewed interest in investment behaviour: investment in R&D and human capital, plays a pivotal role in the new theories explaining persistent growth. In our framework this means that the stock of R&D and human capital should be included in the production function. However, the large uncertainty surrounding R&D projects poses problems: "It is possible that some of this uncertainty is not probabilistic: if 'Knightian uncertainty' shows up anywhere, it could be here" [Solow (1994), page 52].

Finally, investigating alternative, non-vintage, investment models, whether data or theory based, might be worthwhile, even if only as a benchmark model to confront other investment models with. All these suggestions might help to further increase the understanding of the characteristics of investment.