STRUCTURAL CHANGE AND ECONOMIC DEVELOPMENT

by

PETER WILLIAMS

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DISSERTATION APPROVAL PAGE

Student: Peter Williams

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This dissertation has been accepted and approved in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Department of Economics by:

Dr. Shankha Chakraborty	Chair
Dr. Chris Ellis	Member
Dr. Bruce Blonigen	Member
Dr. Jean Stockard	Outside Member

and

Richard Linton	Vice President for Research and Graduate Studies and Dean of the Graduate School

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DISSERTATION ABSTRACT

Peter Williams

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Approved: ____

Dr. Shankha Chakraborty

This dissertation emphasizes three aspects of structural change in economic development. Structural change is the process by which the distribution of economic output shifts from one sector to another and is crucial to understanding overall economic growth. The first chapter demonstrates that property rights and the relative value of land in rural credit markets have significant implications for the rate and level of economic development. When borrowers have little net worth, access to credit is limited and the transition from agriculture to industry proceeds at a slower rate. A quantitative model provides estimates of the welfare cost of such frictions. The second chapter argues that differential costs of technology adoption across developing countries can explain the failure of some import-substitution strategies.

An analytical model demonstrates the importance of such adoption costs, and an empirical section finds evidence in support of it. The primary result is that import-substituting policies aimed at rapid industrialization may in fact inhibit economic growth, explaining why some countries have experienced lower rates of economic development. The third chapter uses a robust econometric procedure to estimate sector-specific productivity growth for a sample of OECD countries. It finds that the sources of productivity growth vary widely across countries. Productivity growth is not concentrated in industrial sectors alone but can also result from advances in service sectors.

CURRICULUM VITAE

NAME OF AUTHOR: Peter Williams

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene
Boise State University, Boise, Idaho
Univeristy of Puget Sound, Tacoma, Washington

DEGREES AWARDED:

Doctor of Philosophy, Economics, 2011, University of Oregon
Bachelor of Science, Economics, 2002, University of Puget Sound

AREAS OF SPECIAL INTEREST:

Economic Growth and Development
Macroeconomics

PROFESSIONAL EXPERIENCE:

Graduate Teaching Fellow, Department of Economics, University of Oregon, Eugene, 2005-2010

AWARDS AND HONORS:

Graduate Teaching Fellowship, Economics, 2005-2010

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DEDICATION

For my family.

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CHAPTER I

STRUCTURAL CHANGE WITH ENDOGENOUS CREDIT CONSTRAINTS

1.1. Introduction

This chapter provides a quantitative assessment of the effect of credit market frictions on structural change. Credit markets have been long thought to play a critical role in the developmental path of an economy. With structural change, the distribution of economic output shifts from agriculture to industry and then to services. Easy access to capital markets is necessary to invest in productive capacity.

Specifically, when capital and labor are complements in agricultural production, access to capital markets affects labor productivity. Market frictions restrict the supply of capital to the agricultural sector, reducing the productivity of labor. When preferences are nonhomothetic, implying that a subsistence amount of the agricultural good must be produced, a decrease in labor productivity in the agricultural sector implies that a disproportionate share of labor is employed in agriculture and a lower share in the industrial sector. This reduces the rate of structural change, resulting in delayed development and a measurable decrease in GDP per worker.

The specific mechanism that generates credit market frictions is poor property rights over land. In rural households, where capital markets are underdeveloped, landholdings can constitute the bulk of assets. When a household's asset base determines access to credit markets, the saleability of household assets, in this case land, matters. Sufficient evidence exists, in the form of both recent empirical work and legal code cited from a number of countries, that the tradeability of land varies widely across countries. Exploiting variation in the tradeability of land, this chapter identifies the link between property rights over land, capital investment and structural change.

I implement a dynamic general equilibrium framework to quantify the structural implications and welfare costs of market frictions. Empirical work on property rights and investment indicates that land is significant both as a productive input and as collateral in rural capital markets. These studies provide a set of reasonable parameter values concerning property rights and the salability of land. The model calibrated to fit this empirical evidence suggests that credit market frictions can potentially generate cumulative output losses of close to 40% of present discounted GDP per worker, depending on parameters. In addition, it explains over 50% of the variation in agricultural employment shares, another key impediment to structural change. Given the extreme poverty of the poorest countries in the world, these results show that poor property rights are an important source of stagnation.

This chapter contributes to several lines of literature. An older literature on structural change suggests that an economy needs to achieve an adequately productive agricultural sector before industrialization can occur (see Matsuyama [55], Kogel [46] and Strulik and Weisdorf [68]). This paper maintains that result, but highlights the importance of imperfections in credit markets in aiding that transition. A second body of literature studies the relationship between credit constraints and output growth, demonstrating that output may be reduced by credit constraints that adversely affect the value of collateralized assets (see Kiyotaki and Moore [45]). This chapter introduces simple, reduced-form, credit constraints and demonstrates how such constraints may have lasting effects.

In addition, a large literature documents the relationship between the existence of property rights and investment rates (see Besley [12], Carter and Olinto [15] and Goldstein and Udry [28], amongst others). The expected result that enforceable property rights results in greater investment rates is consistently documented.

The model adopted in this chapter builds on Gollin, Parente and Rogerson [29] who propose a dynamic general equilibrium model of structural change. However, Gollin et al. assume the existence of two agricultural sectors and maintain the status quo that capital markets are perfect. Their model is used to explain variations in the 'time to development' where variation in the timing is exogenous. In contrast, this chapter explains differences in the time paths of endogenous variables by exploring variation in the degree of land rights.

Relying on the microeconomic evidence linking the value of assets to the saleability of land, and highlighting land's role as collateral in credit markets, the rest of this chapter is devoted to linking variations in the institutional framework to the observed developmental patterns in the developing world. Section 2 provides important background information. Section 3 reviews the literature on the subject, and section 4 presents the model. Section 5 discusses the results and extensions of the model and, finally, section 6 concludes.

1.2. Background

The inverse relationship between agriculture's output share and income level is a consistent stylized fact of economic development. The share of employment in agriculture also steadily decreases as labor moves to the service and manufacturing sectors. Figure 1 presents some of the evidence by country-group[1].

In the original labor-surplus models (see Lewis ([53] and Todaro et al. [37]), it is technological progress in the industrial sector that induces structural change, while in later renditions (Matsuyama [55], Gollin et al. [29] and Echevarria [22]) the role of technological progress in the agricultural sector also plays an important role by releasing labor for work in other sectors. While the original labor-surplus model did not emphasize the role of capital inputs in the primary, or agricultural, sector, more recent models allow for the industrialization of food production. This is largely consistent with the global pattern of food production, with labor receiving a small

[1] Data from http://www.oecd.org

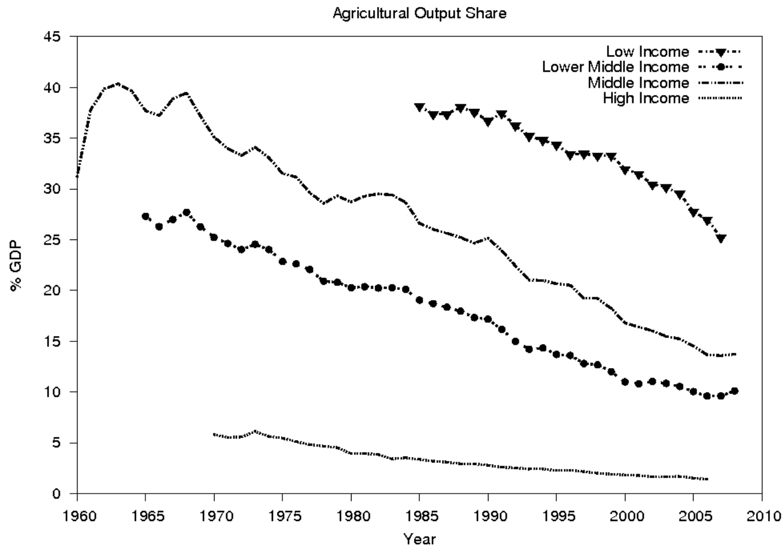

FIGURE 1. Agricultural GDP share

fraction of factor payments in agriculture in the developed world. In all dynamic general equilibrium versions of these models, markets are assumed to be frictionless, with capital accumulation in any sector governed by prices alone.

1.2.1 Institutional Framework

Well functioning credit markets are often missing in the developing world. A common feature of the market for credit is uncertainty regarding repayment. When repayment is uncertain, lenders may require some form of collateral in order to secure loans. The form of collateral varies widely, and may be in the form of cash, capital or, as the current paper explores, land. When land comprises the bulk of assets, its role as collateral, in addition to its role as a productive asset, becomes important. It follows that the structure of the land market has important implication with respect to value of land in securing loans. This motivates the structure of land markets as a determinant of access to credit in rural, and often agricultural, sectors of the economy.

The structure of land markets varies widely.[2] For example, in Lesotho, tribal hierarchy supersedes the national government in allocating land. Bassett notes that the legal code governing land provided that "chiefs could revoke rights . . . and allocate the land to families in need," and that "land not properly cultivated for a period of two years could be revoked and allocated to another." The Land Reform Act, meant to quell growing concern over customary land rights, stated that "land remains the property of the nation and is held in trust by the king." Though the code permitted the conversion of customary tenure to a sellable lease right, the process was so bureaucratic and cumbersome that sharecropping persisted as the primary form of agricultural production. The central point remains the same: individual title to land is absent, eliminating land as an instrument in collateral markets.

Somalia presents another example. Legislation passed in 1975 abolished the system of customary tenure and transferred property rights over land to the central government. The rationale was that state administered leases would provide better tenure security than the then current system of tribal laws. However, the bureaucratic nature of the problem implied that leaseholders were hesitant to rent

[2] Case studies are from Bassett [8]

land for fear of being unable to reclaim it, and sales were administered through the state. Indeed, a survey by Roth [67] revealed that of fifty six respondents only one had ever sold land and seven had ever purchased it. Coupled with legislation forbidding the ownership of more than one parcel, this greatly diminishes land's role as an asset. This example again highlights the importance of poor property rights. Tenure security, while certainly improving the incentives for investment, do not enhance land's role as an asset (though it certainly provides for some degree of income security). It is land's potential role as collateral that improves access to credit markets, a benefit that complete tenure security does not provide when land is ultimately the property of the government.

Botswana presents a different case. Towards the end of the 1960's a growing concentration of elites with commensurate political power resulted in a concentration of land in the hands of those with the ability to enforce property rights. With wealth determining access to credit markets, the mechanization of agriculture generated increases in the level of output and efficiency of production. Centers of agriculture developed, with wells, irrigation, combines and tractors. Ignoring the distributional implications of the transition, it is evident that the ability to enforce property rights has the potential to induce the capitalization of agriculture. The evidence is visible in figure 2, which charts the number of tractors in use for Botswana, Somalia and Lesotho.[3]

[3] Data are from FAOSTAT, http://www.faostat.org

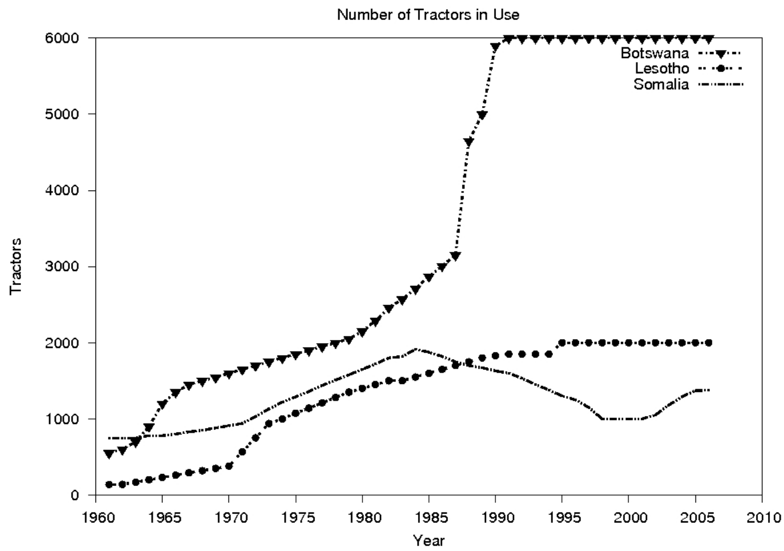

FIGURE 2. Tractors in use

1.2.2 Micro evidence on Property Rights

While it is evident that property rights are imperfect, the question of "how much so?" remains. A useful estimation of the *degree* of property rights is made by Lanjouw et al. [50]. In their work they estimate the probability that a 'landowner' can enter into contracts to sell or rent their land to *strangers* using a probit model. Because households may differentially be able to sell to family or friends the distinction is clear, and the model conditioned on the relationship between the selling household and purchasing parity. Their estimation is based on survey data collected from Ecuador and reveals an interesting relationship between the saleability of land characteristics of the market participants. First, the probability that an individual can sell his/her land depends positively on the value of the both land and non-land assets. A number of other factors are significant as well. These include age and gender of tenant, the existence of a legal document and whether the property was previously subject to jurisdiction.

A second, and admittedly less structural estimation of the saleability of land is provided by Besley [12]. His empirical study of the relationship between property rights and investment in Ghana reveals that only 78% of respondents could sell their land without first obtaining permission from a tribal or government authority. I use this estimate as another potential candidate for the estimation of the degree of property rights in the model.

In general, using variability in the transactability of land is a reduced form approach to modeling credit market frictions. It could easily be argued that variation in the ability to transact land is isomorphic to a poorly functioning financial sector. Or, it could be the case that differences in the composition of assets, and not the measured level of, is what drives credit market frictions. In other words, a family might be relatively wealthy as measured in land or animals, over which property rights are perfectly well defined, but does not possess assets that have value as collateral in formal credit markets.

As such, the model should be interpreted with some care. A similar parameter could represent intermediary fees in the financial sector which, if proportional to the value of assets or the transaction, could produce identical results. A more structural model would incorporate a more micro-founded approach that could effectively separate these different channels, but for the purposes of quantifying these friction, generally defined, this will suffice.

1.3. A Brief Review of the Literature

Two sector models of economic transition begin with Lewis's [53] work. His argument was that there is essentially an unlimited supply of labor working in rural agriculture that is available for employment in the industrial sector. Because the opportunity cost of working in the industrial sector cannot be lower than the industrial wage itself, Lewis argued that rural workers receive the average product of their labor. This allows for a zero marginal product of labor (which would imply a zero wage in standard marginal cost pricing models) and positive employment. The result is what economists refer to as *disguised* unemployment. As industrial production increases, labor moves out of agriculture "with their food on their backs" and engages in industrial production. The Lewis framework was formalized using non-homothetic preferences by, among others, Matsuyama [55] who highlights the role of productivity growth in agriculture as a precursor to development [4]. Continued interest in the topic is evident in more recent work by Echevarria [22], Galor and Weil [27], Kogel [46], Strulik and Weisdorf [68] and Gollin et al. [29].

A related, but more recent literature explores the role between credit market frictions and investment. Kiyotaki and Moore [45] demonstrate that endogenous

[4] The original Lewis model relied on productivity advances in *industry* to generate economic transition.

credit constraints can generate large and persistent aggregate fluctuations in the face of small shocks to productivity. In their model, negative productivity shocks result in lower asset prices, reducing their value in collateral markets. This results in a lower demand for investment as well as a general equilibrium effect that further reduces the price of the asset and magnifies the original effect.

Laitner [48] specifically identifies the price of land and its role in investment decisions. In an overlapping generations model young agents invest in land and capital. Nonhomothetic preferences drive the result that, as incomes increase, demand for the manufactured good increases. Because future generations value manufactured output more, capital becomes relatively more valuable as an asset. However, structural change is a byproduct of the model, as his central theme is the change in asset portfolio composition.

The role of credit market frictions, and the value of land, in asset markets during structural transition are facts that should be considered in theories of economic development. A number of empirical papers establish that imperfect property rights, with specific emphasis on land, can generate substantial efficiency costs in the allocation of resources in agricultural sectors. Using survey data from China, Benjamin and Brandt [11] find that administrative land allocation, and the absence of efficient rental markets generates large discrepancies in worker productivity. Specifically, worker productivity on small farms is significantly higher than on large farms. This is consistent with a property rights approach to the problem when returns to scale are positive. Larger farms should have more scope for investment, increasing worker productivity. However, the opposite obtains, and is only partially offset by secondary labor market. Deininger and Jin[21] offer a similar prediction, namely that the development of rural land markets would dramatically increase labor efficiency using survey data from rural provinces in China. In their paper the development of rental markets permits a more efficient allocation of resources and the associated productivity gains.

Slightly contrary evidence is presented by Li [54] who argues that when transaction costs are sufficiently high, imperfect property markets might be second best. Carter and Olinto [15] use data from Paraguay to demonstrate that poorly defined property rights result in greater investment in movable versus non-movable assets. Besley [12] and Goldstein and Udry [28] find similar result using Ghanaian data. Besley also finds evidence in favor of endogenous property rights. As investment increases, the transferability of land increases, suggesting that sufficient investment generates *de facto* ownership. Barham et al. [5] find evidence that non-price rationing generates larger allocative inefficiencies when property rights are poorly defined in Guatemala. Though based on capital investment among competing firms, Claessens and Laevin [16] find that allocative investment decisions are more efficient when property rights are well-defined.

1.4. The Model

The model consists of a population $N_t = N_0(1+\gamma_n)^t$ of infinitely lived households where $\gamma_n \in (0,1)$ is the rate of population growth. Households can be thought of as yeomen farmers who are proprietors of a unit mass of land. They are also endowed with a unit of labor and which they supply inelastically to either the agricultural or industrial sector.

1.4.1 Technology

1.4.1.1 Agricultural Firms

Agricultural firms are owned and operated by households. They rent labor, land and capital to produce food using the following technology:

$$Y_{a,t} = (1+\gamma_a)^t L_{a,t}^{\phi} N_{a,t}^{\mu} K_{a,t}^{1-\phi-\mu} \tag{1.1}$$

$L_{a,t}$ denotes land, $N_{a,t}$ labor and $K_{a,t}$ the quantity of capital in use. γ_a is the factor neutral rate of productivity growth and I assume that $\phi + \mu < 1$.

1.4.1.2 Industrial Firms

Industrial firms rent labor and capital and produce output according to

$$Y_{y,t} = (1+\gamma_b)^t N_{y,t}^{\alpha} K_{y,t}^{1-\alpha} \tag{1.2}$$

where γ_b is total factor productivity growth, and $\alpha \in (0, 1)$. Because production is constant returns to scale firm ownership is not of concern. Firms hire all inputs in competitive factor markets and maximize profits.

1.4.1.3 Banks

Finally, a competitive banking sector plays two roles in the economy. First, in any time period t, they issue a one-period asset to households in exchange for the households' savings, S_t. Formally, they offer a return of $\bar{r}_t$ on each unit of household savings.

Second, they operate an investment technology that permits the one-to-one conversion of savings today into capital which becomes available for use in the next period. Therefore, $K_{t+1} = S_t$. Banks then lend capital to firms for use in production, upon which it depreciates fully. They choose the allocation of capital to maximize profits,

$$\pi = \max_{K_{y,t+1},K_{a,t+1}} \left\{ r_{k_y,t+1}K_{y,t+1} + r_{k_a,t+1}K_{a,t+1} - \bar{r}_t K_{t+1} \right\} \tag{1.3}$$

subject to

$$K_{t+1} = S_t \tag{1.4}$$

$$K_{t+1} = K_{a,t+1} + K_{y,t+1} \tag{1.5}$$

Consider firms in the banking sector. If it were the case that $r_{k_y,t+1} \neq r_{k_a,t+1}$ then banks would only be willing to lend to the sector in which r_t is higher. This has the effect of reducing the rate of return on capital in that sector, until in equilibrium we must have

$$r_{k_y,t+1} = r_{k_a,t+1} = \bar{r}_t \tag{1.6}$$

It is assumed that agricultural firms enter within-period contracts with banks to buy capital. Capital is delivered at the beginning of the time period, firms produce output, and then pay for capital following production. However, agricultural firms may choose to default on their obligation to pay for capital. Because there is the potential for default, banks will require collateral to secure the loans for agricultural capital. Use of price to equate the expected return on capital would fail because it increases the marginal cost of repayment, therefore increasing the likelihood of default. Agricultural producers must then use their land as collateral to secure capital for use in production. If agricultural producers default, banks collect their land. By assumption capital depreciates fully, so there is none to be recovered.

Whether agricultural firms default on a loan depends on their incentives. The cost of repayment in time period t is $r_{k_a,t}K_{a,t}$ and the expected cost of default is $\rho p_{l,t}L_t$. ρ can be interpreted as either the probability that the land can be recovered and liquidated, or the fraction of the value of land that can be recovered. This introduces a mechanism by which the fungibility of land as an asset influences the potential for agricultural producers to use capital in production. This results in the constraint that

$$K_{a,t} < \frac{\rho p_{l,t}L_t}{r_{k_a,t}} \equiv \hat{K}_{a,t} \tag{1.7}$$

which is effectively a participation constraint on the part of banks. Because households will choose to default for any value of $K_{a,t} > \hat{K}_{a,t}$, banks would never agree to issue capital in excess of $\hat{K}_{a,t}$.

1.4.2 Implications of the credit constraint

The incentive compatibility constraint lends itself to a rather simple analysis. Consider the demand for agricultural capital given rental rate $\bar{r}_t$

$$K_{a,t} = \frac{(1-\phi-\mu)\bar{a}N_t}{\bar{r}_t} \tag{1.8}$$

and the constraint on the quantity of capital that will be lent (1.7).

The 'gap' in credit markets, $\tilde{K}_{a,t}$ is the difference between demand and (restricted) supply[5] or

$$\hat{K}_{a,t} = \frac{(1-\phi-\mu)\bar{a}N_t - \rho p_{l,t}L_t}{\bar{r}_t} \tag{1.9}$$

Given that the price of land is[6]

$$p_{l,t} = N_t\left[\frac{\phi\bar{a}}{\bar{L}}\left(\frac{1+\gamma_b}{1+\gamma_b-\beta}\right)\right] \tag{1.10}$$

this implies that the 'gap' in capital markets is

$$\tilde{K}_{a,t} = \frac{\bar{a}N_t}{\bar{r}_t}\left(1-\phi-\mu-\rho\phi\frac{1+\gamma_b}{1+\gamma_b-\beta}\right) \tag{1.11}$$

This expression will be positive when the constraint binds and equal to zero when it does not. The likelihood of a gap depends negatively on ϕ. When ϕ falls, land's share of factor payments decreases, causing a fall in the price of land and therefore the cost of borrowing. At the same time, a large ϕ reduces the demand for capital because it implies that the elasticity of output with respect to capital is smaller. An increase in μ decreases the probability of the gap because it reduces the demand for capital and has no impact on the borrowing constraint.

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[5]Here I substitute $\bar{r}_t$ for $r_{k_a,t}$. Per 1.6, they are equivalent in equilibrium.

[6]See Appendix A for derivation.

Total factor productivity growth in manufacturing decreases the likelihood that the constraint binds because of its depressive effect on the price of land. The population, N_t affects only the magnitude of the constraint. If the parameters dictate that it binds, then a larger population increases the demand for capital and the constraint on how much can be accumulated at the same rate, causing a proportional increase in the gap. The interest rate on capital induces a proportional change in the magnitude of the gap.

1.4.3 Households

Households consume a manufactured good, c_t, and an agricultural good a_t. Their preferences are specifically chosen to highlight the fact that food is a necessity. The following utility function maintains analytical simplicity and is consistent with Engel's Law (that the share of income spent on food declines as incomes rise):

$$u(c_t, a_t) = \begin{cases} ln(c_t) + \bar{a} & \text{if } a_t \geq \bar{a} \\ a_t & \text{if } a_t < \bar{a} \end{cases}$$

where c_t denotes the consumption of a manufactured good, and a_t denotes consumption of an agricultural good, both *per capita*. The lifetime utility of the household is

$$U_0 = \sum_{t=0}^{\infty} \beta^t N_t u(c_t, a_t) \tag{1.12}$$

where $\beta \in (0,1)$ is the subjective discount factor. Agents are paid in claims to output. The output of the manufacturing sector can be either consumed as c_t or saved as S_t. The portion that is saved is deposited with the banking sector where it is converted into capital for use in production the following time period, receiving a rate of return $\bar{r}_t$. In addition to income earned from last period's savings, household earn rental income from land, $r_{l,t}$ and labor income w_t.

Importantly, when the households are credit-constrained they may be unable to allocate as much capital to the agricultural sector as they would like. If agricultural capital is subject to the credit constraint (1.7) it may be the case that its rate of return exceeds that of capital in the industrial sector. However, because all capital is rented in a competitive market, borrowers pay the same rate. This implies that households receive an excess rate of return on agricultural capital, which will be denoted π_t. When the credit constraint does not bind, $\pi_t = 0$. When it does bind, it represents the value of agricultural output net of factor payments. This does not materially affect the intertemporal problem: the rate of return on savings is determined by the rental rate in industry, as it represents the allocation of any marginal unit of capital.

Households' utility maximization problem is subject to

$$[N_t c_t + S_t]p_{c,t} + N_t a_t + p_{l,t}(L_{t+1} - L_t) \leq w_t N_t + \bar{r}_t S_{t-1} + r_{l,t} L_t + \pi_t \tag{1.13}$$

and the evolution of the capital stock is governed by (1.4). The budget constraint is similar to that proposed in Farmer and Wendner [25], eq. 12. Note first that in equilibrium $L_{t+1} = L_t$ and all terms on the right-hand side represent income. Because they represent the output of the same sector in a real economy, the price applied to investment and consumption is the same, and agricultural output is numeraire.

Households maximization over the choice of S_t implies that the consumption paths will obey

$$\frac{c_{t+1}}{c_t} \leq \frac{\beta}{(1+\gamma_n)} \bar{r}_t \tag{1.14}$$

1.5. General Equilibrium

The model proceeds as follows: At the beginning of time period t, banks hold savings S_{t-1} and carry debt to households. They make a capital portfolio choice, subject to the constraint (1.5). Capital is delivered, factors are allocated, and production takes place. Following production, factor payments are issued, loans repaid, the households' purchase the output of the industrial sector, and make their consumption/savings decision. This determines S_t and therefore K_{t+1}. The following first order conditions characterize profits maximization on the part of firms and economy-wide resource constraints:

$$\phi(1+\gamma_a)^t L_{a,t}^{\phi-1} N_{a,t}^{\mu} K_{a,t}^{1-\phi-\mu} = r_{l,t} \tag{1.15}$$

$$\mu(1+\gamma_a)^t L_{a,t}^{\phi} N_{a,t}^{\mu-1} K_{a,t}^{1-\phi-\mu} = w_t \tag{1.16}$$

$$(1-\phi-\mu)(1+\gamma_a)^t L_{a,t}^{\phi} N_{a,t}^{\mu-1} K_{a,t}^{-\phi-\mu} = r_{k_a,t} \tag{1.17}$$

$$p_{c,t}(1+\gamma_b)^t \alpha N_{y,t}^{\alpha-1} K_{y,t}^{1-\alpha} = w_t \tag{1.18}$$

$$p_{c,t}(1+\gamma_b)^t (1-\alpha) N_{y,t}^{\alpha} K_{y,t}^{-\alpha} = r_{k_y,t} \tag{1.19}$$

$$L_t = \bar{L} \tag{1.20}$$

$$N_{a,t} + N_{y,t} = N_t \tag{1.21}$$

$$K_{y,t} + K_{a,t} = K_t \tag{1.22}$$

$$Y_{a,t} = \bar{a} N_t \tag{1.23}$$

$$K_{a,t} < \frac{\rho p_{l,t} L_t}{\bar{r}_t} \tag{1.24}$$

1.5.1 Calibration

To calibrate the agricultural technology I rely on a number of empirical studies. Echevarria [23] uses data from several Canadian provinces to calculate the income shares of land, labor and capital in agricultural production. Though her work uses data from a fully developed country, her parameter estimates are close to those suggested by studies from developing countries. Hayami and Rutton [38] estimate an agricultural production function in which capital inputs broadly describe the use of machinery as well as livestock. Of course, these depart from the standard notion of capital, but evidence exists to suggest that household may accumulate livestock as a form of insurance against uncertain outcomes (see Rozenzweig [66]), implying that its dual role in production and as an asset bring it quite close to standard notions of capital.

Bassett [8] estimates agricultural income shares using data from the Punjab region of Pakistan. Capital includes plow, fertilizer as well as seed. The final set of estimates used in calibration are those suggested by Gollin, Parente and Rogerson [29]. Their work draws on empirical estimates of income shares from the United Kingdom during the industrial revolution.

An additional set of estimates are provided by the African Association of Agricultural Economists. While providing useful insight into the nature of agricultural technology in the developing world, I omit them from the calibration exercise because they suggest that technology is strongly increasing returns to scale. This alone would result in a higher rate of growth, and be of little help in the way of comparative static analysis.

The full set of parameters are presented in table 1.

Three-factor agricultural technology

Source	Land	Labor	Capital
Echevarria	0.096-0.223	0.295-0.653	0.251-0.483
Battese et al.	0.261-0.382	0.107-0.176	0.464-0.716
Hayami et al.	0.097-0.117	0.336-0.490	0.422-0.545
AAAE	0.72	0.75	0.07
Gollin et al.	0.3	0.6	0.1

Factor Productivity/Population Growth

Parameter	Value
$\gamma_a{}^{\mathrm{f}}$	0.011-0.014
$\gamma_b{}^{\mathrm{g}}$	0.0033-0.009
$\gamma_n{}^{\mathrm{g}}$	.02

TABLE 1. Parameter estimates: technology

I make use of data provided in Lanjouw et al. [50] and Besley [12] to calibrate the credit constraint. Lanjouw et al. uses a probit regression to estimate the probability that an individual can sell land *to a stranger* and the probability that an individual can rent property to a stranger Their results are based on survey data from Ecuador. Besley [12] uses survey data from Ghana to estimate the effect of property rights on the rate of investment in agricultural areas, and reports the fraction of tenants who can sell their land without permission. These estimates are quite different, but given the paucity of empirical work that estimates such a parameter, these results will serve our present needs. The coefficients are presented in table 2.

Source	$\rho \in (0, 1)$
Besley [a]	0.78
Lanjouw et al. [b]	0.33/0.22

[a] Besley reports the fraction of households that could sell their land without tribal authority.

[b] Lanjouw reports the unconditional probability that a household may transact land with a non-relative.

TABLE 2. Parameter estimates: property rights

The final parameter, β, is assumed to be 0.96.

1.5.2 Computational Strategy

To compute the equilibrium growth path I proceed as follows: The economy is endowed with an initial capital stock sufficient to produce the minimum amount of the agricultural output ($\bar{a}N_t$) given competitive markets. Otherwise, the economy would allocate all capital to agriculture, upon which it would depreciate fully, and the exercise terminates. Given an initial stock of capital, factor arbitrage according to equations 1.15 - 1.19 yields the competitive allocation and prices. This determines the initial output of the manufacturing sector. At this point I implement a shooting algorithm. Equilibrium along the balanced growth path is determined by noting that

$$\frac{c_{t+1}}{c_t} = \frac{\beta}{(1+\gamma_n)}\bar{r}_t \tag{1.25}$$

must always be satisfied. Moreover, given an exogenous rate of total factor productivity growth,

$$(1+\gamma_b)(1+\gamma_n) = \beta\bar{r}_t \tag{1.26}$$

where $\bar{r}_t = (1+\gamma_b)^t(1-\alpha)N_t^{\alpha}K_{y,t}^{-\alpha}$. This implies capital stock at time T is

$$K_{y,T} = \left[\frac{\alpha(1+\gamma_b)^T N_T^{1-\alpha}}{\frac{(1+\gamma_b)(1+\gamma_n)}{\beta}}\right]^{\frac{1}{1-\alpha}} \tag{1.27}$$

Given an initial capital endowment, and corresponding output $Y_{y,t}$ a guess for the initial consumption-savings decision is initiated. If the time path, conditional on an initial guess, results in a terminal capital stock greater than $K_{y,T}$ then the initial guess is adjusted accordingly. I repeat the procedure until the time path converges to within a tolerance of the terminal capital stock.

In addition, the mechanics of the model imply that I place some *ad hoc* restrictions on the allocation of capital. Consider the following:

$$\left(\frac{\bar{a}N_t}{(1+\gamma_a)^t\bar{L}^{\phi}(N_0(1+\gamma_n)^t)^{\mu}}\right)^{\frac{1}{1-\phi-\mu}} \tag{1.28}$$

is the minimum amount of capital necessary to produce the subsistence level of food employing all labor in agriculture. If $K_{a,t} <$ (1.28) then $N_{a,t} = N_0(1+\gamma_n)^t$ which implies that $N_{y,t} = 0$ and therefore $Y_{y,t} = 0$. Given zero industrial output, and thus a zero upper bound on savings, it must be that $K_{t+1} = 0$ which is a trivial result. Therefore I impose that

$$K_{a,t} \geq \left(\frac{\bar{a}N_t}{(1+\gamma_a)^t\bar{L}^{\phi}(N_0(1+\gamma_n)^t)^{\mu}}\right)^{\frac{1}{1-\phi-\mu}} \tag{1.29}$$

Intuitively this is the requirement that the level of capital in agriculture is high enough that there is some excess supply of labor, given the perfectly inelastic demand for food. Because capital is required to produce agricultural output, this guarantees a labor surplus for industry, which in turn guarantees industrial output for use in subsequent time periods.

1.6. Quantitative Results

I make use of the production function parameters estimated in Bassett [8], Hayami et al. [38] and Gollin et al. [29]. The point estimates in Echevarria are sufficiently close to those in Bassett that using both sets of estimates would provide little additional insight, and I avoid the use of the parameter estimates from the AAAE because of the implication that the technology is increasing returns to scale. In addition to the parameter estimates provided by Besley [12] and Lanjouw [50] I report the counter-factual case of no probability of being able to sell land ($\rho \simeq 0$). I consider $\rho \simeq 0$ to approximate the case in which land is entirely government owned, as mentioned in the Somali and Mosotho case studies cited above. This is admittedly less rigorous than the use of an appropriately calibrated value, but provides a useful reference point. Note that the constraint in 1.11 provides an explicit limit on ρ above which the constraint will not bind. For example, the parameterization implied by Hayami requires $\rho < .228$ for the constraint to bind. This implies a difference between $\rho = .22$ and $\rho = 0.33$, but no difference for values of ρ greater than 0.33. Because the results of the model are identical for $\rho = 0.78$ and $\rho = 1$, $\rho = 0.78$ is considered first best. For all cases the midpoints of the factor productivity growth estimates are used.

Graphical results are presented in Appendix B. The results presented are for the parameter values suggested by Hayami et al. Different factor shares affect the time paths, and the welfare implications of credit market frictions, but do not generate qualitative differences.

1.6.1 Consumption

The time paths for the level of consumption reveal that slight changes in property rights can have lasting, and even permanent effects on consumption levels. Consider first parameter values of $\rho = 0.33$ and $\rho = 0.78$. Per the constraint in 1.7, borrowers of agricultural capital will not be constrained along the balanced growth path. However, because the model is a two-sector economy, there are important dynamic implications before the economy approximates the balanced growth path. During periods for which the majority of resources are employed in the agricultural sector, the rental rate of land is low relative to the balanced growth path values (see figure 3). This implies that the borrowing constraint may bind before the economy has reached the balanced growth path, and because the state variable (capital) is endogenous, this has lasting effects.

The net effect in the simulation is an additional 6 time periods for which the constraint binds. This is arguably insignificant in the context of an infinitely lived economy where the empirical counterpart of a time period is one year, but it has permanent effects on consumption, and therefore welfare, for each of the 150 time periods in the simulation.

As ρ falls to 0.22 the predicted gap in demand becomes positive.[7] For this calibrated value the economy is subject to the constraint on capital accumulation for

[7]Note that for current parameter values the gap will be positive if $(0.487 - \rho(0.1)\frac{1.006}{0.046}) > 0$, or $\rho > 0.2226$.

the duration of the simulation which results in significant impacts on consumption levels and welfare. The more extreme case of $\rho = 0.01$ implies an even more severe penalty. These costs in terms of consumption occur because the agricultural sector is severely constrained in its ability to use capital. As the level of capital employed is small, a larger share of the population is required to produce the subsistence amount of food. This severely constrains the resources that are available for the industrial sector, and prevents the economy from reaching a self-sustaining level of industrial output under which sufficient capital is produced at a low enough cost that it can be used as the primary input in agricultural production.

1.6.2 Capital

An initially low level of capital precedes the transition to a regime where capital accumulates at a rate that depends on the parameters of the model. The best case scenario, for which $\rho = 0.78$, is characterized by an initially constant level of capital followed by a transition to capital accumulation unperturbed by the borrowing constraint. The capital stock is initially constant because productivity gains in the industrial sector are insufficient to produce capital in excess of that required to *reproduce* capital required in agriculture. Effectively, increases in industrial output allow for factor substitution (agriculture becomes more capital intensive) permitting increased use of labor in industry. As total factor productivity increases, the rise in the rental rate of capital justifies an increased savings rate and capital begins to accumulate.

Some components of the capital path are artifacts of the model. Initially the actual capital stock may decline, which is an artifact of the model. Per our earlier discussion, the need for a minimal amount of agricultural capital is such that this lower bound, given in 1.29, governs the capital stock. Eventually, with sufficient increases in total factor productivity, which lower the price of output, capital begins to accumulate. However, the delay initiated by imperfections in the market for agricultural capital again has lasting effects.

The best case scenario, $\rho = 0.78$ displays an initially constant level of aggregate capital. During this time, output of the industrial sector is just sufficient to replace existing capital and satisfy demand for the consumption good. Given sufficient time, and a commensurate increase in total factor productivity, capital is produced in sufficient quantities to be both consumed and saved, which introduces the 'modern growth period' in the model.

For the case characterized by poorer property rights, the level of capital stock may initially decline. When this is the case, the capital stock is constrained by the equality in 1.29, which requires that the capital stock not fall below a threshold level lest it be insufficient to produce even the required quantity of the agricultural good in the subsequent period. For intermediate values of ρ it converges to the first best capital path, but the initial decline in capital has permanent effects on the level of welfare. For the extreme case of $\rho = .01$ there is a lasting effect, and the capital stock converges to a different path that is permanently below the one that corresponds to perfectly tradeable land.

In either case, it is evident that poor land rights are sufficient to drive substantial delays in capital accumulation. Even though the level of capital may converge to the first-best level, there are permanent welfare costs associated with initial constraints governing its allocation.

1.6.3 Employment Shares

The model predicts substantial delays in the movement of labor from the agricultural to the industrial sector. Small changes in property rights have permanent effects, visible in the level differences in the share of labor employed in the agricultural sector. Though the differences appear substantial, they tend to under-predict the degree of of rural-urban labor migration.

Table 3 reports the Food and Agriculture Association's projected agricultural employment shares in 2020, along with those predicted by the model for various parameter values. The labor shares generated in the model are calculated by comparing the share of labor for equivalent per capita incomes. Data on per capita incomes suggests that least developed economies (LDC's) are approximately 75 years behind the developed countries in terms of per capita income given growth rates. I assume for comparative purposes that property rights in North America are represented by values of $\rho > .33$, that the case study from Ecuador ($\rho = 0.22$)

applies to South America, and that LDC's represent the group for which property rights are the most poorly defined ($\rho = 0.01$).

FAO		Model	
Region	Labor Share (%)	Parameter value (ρ)	Labor Share (%)
North America	1.49	> 0.33	1.58
South America	12.35	0.22	7.91
LDC's	89.67	0.01	49.96

TABLE 3. Agricultural Employment Shares

The tendency of the model to under-predict the share of agricultural labor is likely due to the fact that the model omits many important determinants of the rural-urban labor migration decision, including uncertainty with respect to employment and the structure of wages. However, the results in the model are driven by a single parameter, which is capable of explaining a significant share of the variation in employment shares by sector. This adds credence to the claim that landed property rights are an important determinant of economic development.

1.6.4 GDP

Relying on the gross value of output is a broad measure of welfare, the modified model generates a quantifiable loss relative to the perfect case of perfect property rights. Discounted GDP *per capita* in the model, for t periods, is $\sum_t \beta^t \left[\frac{p_{a,t}Y_{a,t}+p_{y,t}Y_t}{N_t}\right]$. Table 4 presents the results, for 250 time periods given each parametrization.

The difference in welfare loss for the different specifications is alarming. The

Hayami et al.

$\rho = 0.78$	$\rho = 0.33$	$\rho = 0.22$	$\rho = 0.01$
0.0%	13.87%	25.38%	27.71%

Bassett et al.

$\rho = 0.78$	$\rho = 0.33$	$\rho = 0.22$	$\rho = 0.01$
0.0%	22.80%	39.15%	43.91%

Gollin et al.

$\rho = 0.78$	$\rho = 0.33$	$\rho = 0.22$	$\rho = 0.01$
0.0%	0.008%	0.013%	5.9%

TABLE 4. *per capita* GDP loss

Gollin et al. parametrization reports a relatively small welfare loss for given values of ρ. This is due to the disproportionately small share of factor payments received by capital. A smaller factor share accruing to capital implies a lower interest rate in equilibrium, which implies that present consumption is less costly. This results in a lower rate of capital accumulation, and lower future output. Because differences in GDP are driven by differences in the output of the industrial sector, a lower rate of capital accumulation results in lower future GDP.

Alternatively, consider the cross-sectional *per capita* GDP implications. Evaluating per GDP at time period $t = 250$ reveals the predicted level difference as it depends on variation in property rights alone.

The model predicts a per capita GDP cost of close to 40% relative to the first best. This is substantially less than current variation in per capita incomes (per capita income in Luxembourg is more than 240 times that in Liberia!) but credit market frictions alone are capable of explaining a large degree of the variation in per

Hayami et al.

$\rho = 0.78$	$\rho = 0.33$	$\rho = 0.22$	$\rho = 0.01$
0.0%	0.0%	24.62%	42.54%

Battese et al.

$\rho = 0.78$	$\rho = 0.33$	$\rho = 0.22$	$\rho = 0.01$
0.0%	0.0%	31.56%	48.71%

Gollin et al.

$\rho = 0.78$	$\rho = 0.33$	$\rho = 0.22$	$\rho = 0.01$
0.0%	0.0%	1.48%	2.13%

TABLE 5. End of simulation *per capita* GDP loss

capita incomes. The previous argument, that these results are driven by variation in a single parameter applies equally here. A multitude of factors are responsible for variation in income levels, among them landed property rights. That they are capable in a relatively simple growth model of explaining this much variation in output levels highlights them as an important policy matter.

1.7. Conclusion

This chapter provides a quantitative assessment of credit market frictions induced by imperfect land markets. It shows that the collateral value of land has significant implications with respect to structural change in developing economies. Specifically, poor property rights lower the value of household assets by reducing the tradability of land. When wealth determines access to credit markets a household's ability to invest in capital may be severely constrained. This reduces the agricultural sector's ability to accumulate capital, and results in a disproportionate share of labor employed in the agricultural sector. This inhibits both structural change, as well as aggregate economic growth. For reasonable parameter values the model generates quantifiable, and significant, welfare losses.

Using a dynamic general equilibrium framework, and empirical evidence on both property rights and agricultural technologies, the model estimates several important time series. The calibrated model predicts the small changes in the degree of property rights, measured as the probability of being able to transact land, can have permanent effects of the level of structural change, as well as output.

The model demonstrates that imperfect property rights can account for up to 40% of GDP differences and over half of the variation in agricultural employment shares across countries as a function of property rights over land alone. This is a contribution to the current literature on structural change in which the role for credit market imperfections is largely ignored. In addition to substantial variation in output, the model explains a significant share of labor migration from agriculture to industry which, in addition to the GDP losses, signal significant welfare losses, quantified by present value utility streams.

The model suggests an important policy implication: land reform efforts, especially those cited in the Somali case, are inadequate to the extent that they are expected to achieve developmental gains. Tenure security, while certainly superior to the absence of property rights, does not endow the tenant with the ability to exploit land's potential role as an asset. While it results in productivity gains and greater security of incomes, it falls short of providing the population of landowners with the means necessary to access credit markets. Land reform policy, where applicable, needs to emphasize the private ownership of land, which is distinctly different from tenure security.

Several future areas of research are evident. Because landholding are often unequally distributed, and access to capital may be determined by the size of landholdings, an exploration of the relationship between wealth heterogeneity and economic development may yield important insights. In addition, factor endowments that favor certain types of agricultural investment may be more or less conducive to investment in agriculture. These topics, amongst others, are sure to provide valuable insight into the mechanisms that make economic development a more natural outcome in some cases, and an ongoing struggle in others.

CHAPTER II

IMPORT SUBSTITUTING INDUSTRIALIZATION AND TECHNOLOGICAL CROWDING OUT

2.1. Introduction

This chapter demonstrates that adopting foreign technologies can be growth reducing if the use of imported technology crowds out domestic innovation. More specifically, when the adoption of imported technologies is costly, fewer resources may be devoted to domestic, productivity enhancing, research activities. Because productivity gains derive from two sources, differences in the costs of development between them have implications with respect to aggregate productivity growth. When the adoption of technologies from abroad is costly, the balanced growth path is characterized by a disproportionate share of resources dedicated to their adoption, and thus a lower share of resources employed in potentially more productive domestic development. As the rate of productivity growth determines equilibrium income levels, this has the potential to explain GDP differences as a function of the cost of adopting foreign technologies.

The intent is to explain the variety of outcomes associated with import substitution industrialization policies. Several developing countries, as a result of policies undertaken in the post-World War II era, have been appropriately labeled "import substituting industrializers." Their aim, almost universally, was to protect domestic industry from the more competitive global markets, permitting fledgling industries to develop.

However, many countries suffered from the inability to effectively begin industrialization without importing a specific subset of goods from abroad. These included basic technologies as well as intermediate industrial inputs which in some cases represented products with a substantial amount of embodied technology. A common strategy was thus to subsidize, either directly or via currency programs, the intermediate inputs necessary for industrialization. A characteristic of many import-substituting countries was to procure through great effort the inputs necessary for industries whose output was protected under the import-substitution regime. The focus of this paper is not the protected output markets, but rather the crucial input markets that were also distorted in the race to development.

As an example, Colistete [19] states that "a strategy favored by local companies was to establish partnerships with foreign companies to import, assimilate and adapt technologies" in describing Brazilian automobile manufacturers affinity for relying on foreign technology to develop a manufacturing base for replacement parts. Another, more dramatic, example is the construction of the Akosombo Dam in Ghana, a project that relied exclusively on technological support from American firms. When the American firms financing the project realized that profits from the project (centered primarily on the production of aluminum) had been overstated, they withdrew from the project, leaving behind a monument to failed economic development.

Both of these are clear examples of strong reliance on foreign technologiy to develop a domestic manufacturing sector. The Brazilian experience with automobiles, which relied heavily on German technology, was largely unsuccessful. The Ghanaian experience is a stark example of the difficulty surrounding use of technology well in advance of the domestic frontier, and reminds us that technological adoption is far from frictionless.

The central point is that imported technologies have the potential to mitigate domestic technological progress, even though they effectively embody a much more advanced technology than the importing country is capable of producing. This mechanism helps to explain why some import-substitution industrialization strategies resulted in lower long run rates of industrial, and overall economic, growth, despite the fact that they were heavily dependent on the use of technologies from more technologically advanced economies. It provides a formal exposition of why import-substituting policies, many of which continue today, may be counter-productive. Moreover, in an era where technological progress is understood to be a fundamental determinant of long run economic progress, it reiterates questions raised in Grossman et al [33] regarding the potential benefit of having access to a technolgies well in advance of those that have been developed domestically.

The implications of the model differ from a wide body of research that argues that the diffusion of ideas should generate convergence in incomes levels (see Sala-i-Martin [6], Hansen and Prescott[36] and Benhabib et al.[10], amongst others). However, their results are dependent on the costless flow of ideas, and the presumption that new technologies can be mimicked more easily than they can be generated. Parente and Prescott[60] demonstrate that even small costs of adoption are sufficient to generate disparities in incomes levels on par with what we observe today. Acemoglu and Zilibotti [2] show that the costless *flow* of ideas is irrelevant when technologies are human capital specific and human capital levels differ between economies. These latter examples corroborate the notion that frictions in the diffusion of ideas are an important concept when considering technology adoption.

The empirical evidence is less conclusive than one might imagine. A well received paper by Coe and Helpman [18] finds empirical support for increases in total factor productivity as a function of the level of research and development spending of trade partners, weighted by trade patterns. Park [61] finds similar evidence. However, both studies rely on data from OECD countries, which brings into question the true costs of adopting ideas, given similar levels of human capital. Indeed, Keller [43] turns both paper on their head by demonstrating that randomly matched trade partners generate *larger* spillovers using the same data! Given the theoretical and empirical treatment of the idea in Parente and Prescott I find the costly adoption of foreign technologies a plausible assumption. An important contribution of this chapter is that it defines the flow of technology as a function of human capital differences. This provides a mechanism by which imported technologies yield different benefits.

The results of this chapter suggest that increases in the level of technology embodied in imports can result in lower growth rates. The effect is stronger for countries that are poorer and less educated on average (i.e. face significant costs of adoption) and insignificant or slightly positive for countries in higher income groups. In other words, holding constant the level of education and income, an increase in the level of technology embodied in imports results in lower *future* growth rates. This effect is strongest for groups of countries classified as low and middle income, and even stronger for countries that have been labeled 'import-substituters,' regardless of their income level. This helps to explain why import substitution policies have not seen results on par with expectation.

The primary result of the model, that policies intended to induce rapid industrialization are growth reducing begs an interesting question: "Why would a government support such a policy?" While the current paper does not explicitly model these important additions, several sources point to reasonable justifications for such policies. Bridgman et al. [13] demonstrate that the ability of small coalitions to overcome free-rider problems may result in the adoption of policies that block new technologies. In addition, these policies were pursued during an era in which they often appeared succesful. The Soviet Union, which aggressively pursued oil exports with the intent of amassing foreign currency did so with the end goal of buying inputs for industrialization(see Yergin [72]). Initially, onlookers viewed the Soviet Union as a force of industrialization, long before its eventual collapse. Another explanation is offered by Grabowski et al. [30], who state that "the 1950's were dominated by theories in support of import substitution." They follow by explaining: "a number of . . . events. . .dispelled the myths associated with the success of import-substitution." It seems reasonable then, to think that these policies seemed legitimate for a period, and were pursued with the expectation of success.

The following section continues a brief review of related literature; section 4 develops a theoretical model. Section 5 then presents the regression results and section 6 concludes.

2.2. Review of the Literature

The current paper uses an analytical framework that extends the endogenous growth literature popularized by Romer[64]. Specifically it is modeled on Grossman and Helpman [34], a continuous variant of Romer's work. This framework's flexibility allows for the consideration of both trade in goods and trade in ideas, a central theme of this chapter. In addition, yields analytical results that are both intuitive and simple. The popularity and analytical flexibility of the model make it a natural choice for the current work.

Building on the same class of models, Grossman and Helpman[33] model the dynamic gains from trade in goods and ideas in a number of different circumstances. An early example, Grossman and Helpman[34], demonstrates that when one industry generates a spillover, that a subsidy can achieve the first best outcome in the absence of endogenous growth, and a contemporaneous publication, Grossman and Helpman[33] considers the relationship between trade and spillovers in an endogenous growth setting. Not surprising, they find that when spillovers are present, that tariffs on imports reduce growth. However, their paper does not address the specific nature of the relationship between spillovers and growth, leaving functional forms general.

Recent extensions to this line of research include Kiley [44], Acemoglu [1], Acemoglu and Zilibotti [2] and Grossman et al. [35]. These papers collectively argue that even when all technologies are freely available, differences in factor intensities or technologies that are human-capital specific can overturn the result that the costless flow of ideas is universally beneficial. At the other end of the spectrum, Young [74] and Yifu-Lin [73] argue that under-developed countries may be at a first best in autarky or behind the technological frontier respectively.

Other efforts at analyzing protective policies include Clemhout and Wan[17] and Melitz[56]. Each demonstrate that the dynamic benefits may exceed that temporary costs of industry protection when increasing returns (a form of market failure) are present. Ros [65] echoes this intuition, arguing that developing economies might achieve higher growth rates by placing tariffs on import-competing goods.

Rebelo[62] develops an endogenous growth framework and demonstrates that taxes in developing countries may be growth-reducing under certain conditions, and Lee[51] finds empirical evidence that less government intervention is associated with *higher* growth rates. All of these works, and others (Krueger [47] for example), suggest that there is a potential role for government intervention with respect to trade policies and growth. Moreover, this relationship is more potent when trade in ideas and trade in goods are mutually dependent. This chapter maintains that trade in goods and ideas are complementary, but argues that the adoption of ideas may generate excessive costs. The end result, and a contribution of the paper, is that these policies may be appropriate for some countries, and harmful for others.

Which conditions must exist, and how industrialization via the exchange of goods and ideas is achieved, is a subject of much debate. Rodrik [63] suggests that a combination of government intervention and a relatively large human capital endowment are the reason for the successes of South Korea and Taiwan. Specifically the government worked to solve a coordination failure at the industry level. While South Korea and Taiwan practiced traditional import-substitution policies with respect to final output prior to their success in export markets, they still needed certain raw materials and intermediate inputs as part of the production process which were obtained and distributed under government jurisdiction. Indeed, a substantial component of South Korea's development strategy was government support of cheap capital for industries deemed important in the pursuit of industrialization. An additional distinction that must be made, according to Rodrik, was that these countries benefitted from relatively rigorous education systems, and in the case of South Korea substantial industrial training due to ties with Japan. Education and benevolent governance were absent in countries with poorer outcomes as governments were more likely to seek private benefits from industrialization. This separates South Korea from countries with similar policies, like Brazil and Mexico, where similar policies existed (recall Brazil's barriers to automobile trade but affinity for German components) but education levels fall far below South Korea. The Barro-Lee data set reports 1.4 years of primary education for Brazil in 1960 and 4.3 for Korea! In 2010 the numbers are 7.5 and 11.8 respectively, and Mexico's numbers align closely wiht Brazil's. This points to a significant gap in the ability to absorb new technologies, and motivates Rodrik's argument.

Industrial sectors consistently failed to reach self-sustaining levels of growth. Balance of payments crises as a result of fiscal mismanagement often led countries to turn to the international organizations for assistance. The resulting rate of technological advance was typically unimpressive, and balance of payments crises owing to overvalued exchange rates resulted in currency devaluations that brought progress to a halt. In sum, artificial support of the industrial sectors is an unsure means of sustaining growth. Westphal and Pack [59] state that

> *"it has been found that firms cannot achieve or maintain international competitiveness without technological effort. Experience in production, and in investment to expand production, is necessary for gaining the capability needed for international competitiveness."*

and follow it by stating

> *"there are substantial information and absorption costs for the acquisition of even non-proprietary technologies."*

These quotes suggest the need for a formal analysis of policies intended to boost industrial progress, but do so via programs that rely on substitution towards imported goods that effectively crowd out the domestic learning process.

These sentiments do not imply that there are no potential benefits from trade in goods and ideas. Lee [51] expands the endogenous growth framework of Rebelo [62] to show that imported capital goods can increase the growth rate of a developing economy. The empirical component of Lee's paper demonstrates a positive relationship between the ratio of capital goods imports to total investment and *income growth* is positive. However, this result is an artifact of capital accumulation, rather than technological progress, being the primary source of economic growth in Lee's model.

2.3. The Model

The model consists of a small open economy populated by $\bar{L}$ homogeneous agents with identical instantaneous utility functions

$$U(c_t) = \ln(c_t) \tag{2.1}$$

where the composite good c_t is 'assembled' from intermediate goods according to

$$Y_c = \left[\int^{n_f+n_d} k_i^{\alpha} di \right]^{\frac{1}{\alpha}}, \alpha \in (0,1) \tag{2.2}$$

Production is constant returns to scale, and depends on the use of foreign-derived, denoted n_f, and domestically derived intermediate inputs, denoted n_d. This functional form implies that all intermediate goods have the same elasticity of substitution, $\frac{1}{1-\alpha}$, and that constant, though not necessarily equal, shares of income will be spent on each.

The instantaneous utility function implies that the lifetime utility function of an infinitely lived agent is

$$U_t = \int_0^{\infty} e^{-\rho t} \ln c_t dt \tag{2.3}$$

2.3.1 Industry

There are explicitly two types of industrial inputs, each having the same value in production. The first type, sub-scripted d must first be developed domestically and then manufactured. The second type is copied (or adopted from foreign abroad), and sub-scripted with an f. I assume that there is a limitless stock of ideas available to be copied. The development of both types of intermediate goods takes place in an active research and development sector which uses labor as the sole productive input. The blueprint for an intermediate input is developed according to

$$\dot{n}_d = \frac{L_d f(n_d, n_f)}{a} \tag{2.4}$$

$$\dot{n}_f = \frac{L_f f(n_d, n_f)}{b} \tag{2.5}$$

where L_i is the labor employed in research sector i $\in \{d, f\}$ and n_i the number of previously-developed goods in sector i at time t. a and b denote the labor productivites in each sector. This formulation requires that public returns to the development of ideas depend generally on the number of both domestic and foreign inputs that have been used. Romer [64] considers cases where $f(n_d, n_f) = 1$ and $f(n_d, n_f) = n$. The functional form here has implications for whether there is growth in equilibrium.

Once developed, domestic intermediate goods must then be manufactured. The technology for producing goods domestically (regardless of whether they were developed domestically or copied) is linear in labor, with each unit requiring one unit of labor per unit of time to manufacture.

2.3.2 General Equilibrium

Equilibrium in the model consists of two independent problems, one static and one dynamic. We will proceed by first analyzing the static equilibrium, and proceed to the dynamic, general equilibrium of the model.

Consumers, who wish to maximize utility from the manufactured good will do so subject to a given level of expenditures, $E = E_f + E_d$. The explicit maximization problem is

$$\max_{k_i} \left[\int^{n_f+n_d} k_i^{\alpha} di \right]^{\frac{1}{\alpha}}$$

subject to

$$\int_0^n k_i p_i di \leq E$$

This implies that the demand for each intermediate good, given expenditure E, is

$$k_i = \frac{p_i^{-\varepsilon}}{\int^n p_j^{1-\varepsilon} dj} E \tag{2.6}$$

where $n = n_f + n_d$.

Given demands for each intermediate good, potential firms face a cost $\frac{wa(1-\sigma_d)}{f(n_d,n_f)}$ to develop an idea domestically or $\frac{wb(1-\sigma_f)}{f(n_d,n_f)}$ to copy a foreign idea where $\sigma_i \in \{0,1\}$ denotes a government subsidy to the cost of technology adoption. This is the mechanism in the model by which the government can strategically use proceeds from the tax levied on exports to subsidize technological progress.

In either case, firms developing a new blueprint are granted an indefinite patent and corresponding stream of profits.[1] Once they have developed an idea, they must

[1]Bertrand price competition ensures that, in equilibrium, no firm would choose to develop the same intermediate good and enter, as they would never recover their initial capital outlay

manufacture the intermediate good, done using 1:1 labor input-output technology. Their profit maximization problem is

$$\pi_i = [p_i - w]k_i \tag{2.7}$$

and results in the standard, constant markup over marginal cost pricing equation

$$p_i = \frac{w}{\alpha} \tag{2.8}$$

which applies to all intermediate goods.

To develop an idea requires $\frac{a}{f(n_d,n_f)}$ units of labor at cost $\frac{wa(1-\sigma_d)}{f(n_d,n_f)}$, and the cost of adopting a foreign technology is $\frac{wb(1-\sigma_f)}{f(n_d,n_f)}$. Increases in the number of existing firms reduce the per firm rate of profit. Firms will enter until the value of the present discounted stream of profits that a monopolist accrues is driven down to the cost of entry, which we may express as two equilibrium conditions:

$$v_d = \frac{w(1-\sigma_d)}{f(n_d, n_f)a} \tag{2.9}$$

$$v_f = \frac{w(1-\sigma_f)}{f(n_d, n_f)b} \tag{2.10}$$

where

$$v_i = \int_t^{\infty} e^{-r(\tau - t)} \pi_i(\tau) d\tau, \quad i \in \{d, f\} \tag{2.11}$$

The rate of change in the value of a firm with respect to t

$$\dot{v}_i = r \int_t^{\infty} e^{-r(\tau - t)} \pi(\tau) d\tau - \pi(\tau) = rv - \pi_i \tag{2.12}$$

provides an equilibrium relationship between the interest and discount rates, profits, and the value of the firm which will be used to characterize equilibrium below.

Given that n_d goods are produced domestically, their manufacture requires $n_d k_i$ units of labor. The n_f foreign technology-based goods require $n_f k_i$ units of labor in the adoption process and of course $\frac{\dot{n}_d}{f(n_d, n_f)} a + \frac{\dot{n}_f}{f(n_d, n_f)} b$ units of labor are employed in the research sector.

In a stationary equilibrium, the value of any firm will be constant. Thus, when $\dot{v}_i = 0$,

$$v_i = \frac{\pi_i}{r} \tag{2.13}$$

This implies that the value of a firm is equal to the present discounted value of future profits. As per above, equality between the cost of a new idea and the value of a new firm dictates that

$$\frac{\pi_d}{r} = \frac{wa(1-\sigma_i)}{f(n_d, n_f)} \tag{2.14}$$

$$\frac{\pi_f}{r} = \frac{wb(1-\sigma_i)}{f(n_d, n_f)} \tag{2.15}$$

The dynamic component of equilibrium requires that consumers maximize their present discounted utility functions. The present framework makes the assumption of perfect capital markets. This implies that all new inventions are financed by loans to consumers, who then receive the stream of dividends earned by the monopolistically competitive firms. The consumers problem is

$$\max \int_0^\infty e^{-\rho t}[\ln c(t)]dt$$

subject to

$$\int_0^\infty e^{-rt}w(t)dt + W_0 \geq \int_0^\infty e^{-rt}c(t)p_t dt$$

The first order condition with respect to consumption at time t implies that

$$p_t c_t e^{t(\rho - r)} = \frac{1}{\lambda} \tag{2.16}$$

where λ is the LaGrange multiplier. Noting that $p_t c_t = E$ and differentiating with respect to time yields the following expression:

$$(\rho - r)Ee^{t(\rho - r)} + \dot{E}e^{t(\rho - r)} = 0 \tag{2.17}$$

or that

$$\frac{\dot{E}}{E} = r - \rho \tag{2.18}$$

which is the familiar result that the level of expenditures will be increasing through time if the interest rate is greater than the discount rate, and vice versa. By normalizing nominal expenditures to 1 ($E = 1$) we have that $r = \rho$, as is standard in this class of models.

We can now express profits per domestic firm[2] as

$$\pi_i = \frac{1 - \alpha}{n_i} E_i, i \in \{d, f\} \tag{2.19}$$

which implies that the wage rate in equilibrium is

$$w = \frac{(1 - \alpha)E_d}{a\rho} \frac{f(n_d, n_f)}{n_d(1 - \sigma_d)} = \frac{(1 - \alpha)E_f}{b\rho} \frac{f(n_d, n_f)}{n_f(1 - \sigma_f)} \tag{2.20}$$

Equilibrium in the labor market requires that $\frac{E_d}{a} = \frac{E_f}{b}$. This is a minor restriction that maintains equality in the value of research and development in both the domestic and foreign based sectors.

[2]Because all firms face the same marginal cost of production, and thus behave symmetrically, subscripts have been dropped.

2.3.3 Balanced Growth Path

Along the balanced growth path we seek an allocation of labor that is constant across sectors and growth rates of the stock of ideas in each sector such that their ratio is constant. Along the growth path, both domestically developed and copied technologies contribute to the stock of knowledge. This implies that the externality must depend (as is implied) on both n_d and n_f. To assure that growth is positive, and non-increasing in the long run, f must be linearly homogeneous in its arguments. If f were increasing returns to scale, marginal technologies would have a larger effect on the cost of developing new ones, which would lead to an increasing rate of growth. For the purposes of exposition I assume that $f(n_d, n_f) = n_d^{\delta} n_f^{1-\delta}$.

Given a fixed supply of labor, these can be combined to yield

$$\bar{L} = n_d k_i + n_f k_i + a\frac{\dot{n}_d}{n_d} + b\frac{\dot{n}_f}{n_f} + L_a \tag{2.21}$$

Using the equilibrium conditions in (6), (9), (11) and (21) this can be rewritten as

$$\bar{L} = \frac{\alpha}{1-\alpha}\rho\left(a\frac{n_d}{n_f}^{\delta} + b\frac{n_f}{n_d}^{\delta}\right) + \frac{\dot{n}_d}{n_d}a + \frac{\dot{n}_f}{n_f}b \tag{2.22}$$

An example economy would proceed as follows: The economy starts with an endowment of technology (n_f and n_d arbitrarily small). Given the wage rate w which is nominally constant, entrepreneurs copy foreign technologies, which are reverse engineered to produce variety n_f of the intermediate inputs. New technologies reduce the cost of producing new ones at a constant rate, determined by f.

Along the balanced growth path we must have $\frac{\dot{n}_d}{n_d} = \frac{\dot{n}_f}{n_f} = g$. This permits us to solve analytically for g:

$$g = \frac{\bar{L} - \frac{\alpha}{1-\alpha}\rho\left(a(1-\sigma_d)\left(\frac{n_d}{n_f}\right)^{1-\delta} + b(1-\sigma_f)\left(\frac{n_f}{n_d}\right)^{\delta}\right)}{a\left(\frac{n_d}{n_f}\right)^{1-\delta} + b\left(\frac{n_f}{n_d}\right)^{\delta}} \tag{2.23}$$

Along the equilibrium path, $\frac{\dot{n}_f}{n_f} = \frac{\dot{n}_d}{n_d} \rightarrow g$ and the ratio $\frac{n_d}{n_f} > 0$ parameterizes the domestic to foreign technologies in equilibrium. The result in this model is analogous to that obtained in Grossman and Helpman[34] with some minor technical modifications.

The rate of growth is increasing in the population at large, an artifact of this framework that constitutes a well-known empirical irregularity. It is also decreasing in the cost of development, and an increasing function of a subsidy in either sector. However, because the government must balance its budget, the effect of a change in the subsidy to one sector must account for the corresponding decrease in the level of the subsidy to the other sector. This is addressed shortly.

The cost of reverse engineering technologies is the focal point of the paper. When b is higher, a larger share of the workforce is employed adopting foreign technologies. As can be seen from 2.20 this corresponds to a higher share of aggregate expenditure on foreign-derived intermediate goods. Because the externality generated by each activity is subject to a decreasing spillover, this amounts to a lower rate of economic growth when δ is high (i.e. domestic technologies generate a larger externality).

The rate of growth depends critically on δ and its relationship with b and a. A high value of δ implies that domestic technologies bear a greater contribution to the stock of public knowledge. In this case, the rate of growth will be higher when a is low relative to b, or when domestic research and development is less costly than copying ideas. The opposite case obtains when δ is low. When foreign technologies have a greater effect on the stock of public knowledge, growth will be high only when b is low relative to a.

The interplay between a, b and δ is important because it provides a more flexible description of the various growth outcomes experience by import-substituting countries. For growth to be high, it must be the case that the social returns (δ) vary positively with the least-cost source of innovation. When the social returns to domestic technologies are high, but the cost of local development is high relative to copying, then growth will suffer.

It is worth noting that the model does not incorporate dynamic policy as in Melitz [56]. This is primarily a modeling convenience, but does have implications with respect to the model's interpretation relative to its historical motivation.

Import-substitution policies of the sort discussed in this paper were intended as temporary measures, to be repealed once industrialization had taken root. These can be theoretically justified in the presence of learning-by-doing, or externalities that allow a tradeoff between future gains and present costs. The present model does not incorporate the mechanisms necessary to justify temporary policy.

2.4. Government Policy

The point of departure of the paper was that government may support technological development with the intent of promoting growth, but that those policies may be counter-productive. As a simple means of exploring this, consider an *ad valorem* tax levied on expenditures that can be used to subsidize the cost of technological development in either sector. The normalization in 2.18 implies that nominal expenditures are always unity, so the amount of tax revenue collected is equal to the tax rate, τ. Given nominal tax revenue of τ, the government may provide a subsidy σ_i, $i \in \{d, f\}$ to either sector such that the government maintains a balanced budget. The subsidy is provided to the cost of research (or copying in the case of foreign technologies) as a subsidy to the wage rate, lowering the fixed cost of the development of new technologies. The balanced budget equation is therefore

$$\tau = \frac{w}{f}\left(\frac{\dot{n}_f}{b}\sigma_f + \frac{\dot{n}_d}{a}\sigma_d\right) \tag{2.24}$$

Evaluating a marginal change in the distribution of the subsidy, recalling that

$\frac{w}{f}$ is constant in equilibrium (and replacing f with its functional form) implies that

$$\frac{\partial \sigma_d}{\partial \sigma_f} = \frac{a}{n_d}\frac{n_f}{b} \tag{2.25}$$

Thus, the cost (corresponding decrease in the subsidy to domestic research and development) of an increase in the subsidy to reverse engineering is increasing in the ratios $\frac{a}{n_d}$ and $\frac{n_f}{b}$. The intuition is straightforward: When $\frac{a}{n_d}$ and $\frac{n_f}{b}$ are low, it is consistent with a country in which domestic research is both productive and developed (n_d is high), and reverse engineering is rather unproductive and undeveloped (n_f is low). In this case a subsidy requires a very small cost in terms of foregone productivity. The opposite case, when $\frac{a}{n_d}$ and $\frac{n_f}{b}$ are high, implies that the country is effectively backwards. That is, domestic research is costly and undeveloped (n_d low) and copying ideas is productive and well-practiced (n_f high).

It follows that when a country that is relatively good at, and has substantial practice, copying ideas, the act of subsidizing that sector is much more costly in terms of foregone research elsewhere. This is largely because of the diminishing marginal contribution of new technologies to the stock of knowledge capital. When many ideas have been developed in one research sector, the marginal 'product' in the other sector becomes high, and thus the cost of a subsidy (even if the country has a comparative advantage in the subsidized sector) becomes high. Depending on the parameters of the model, this can have a deleterious effect on overall growth, and helps to explain why countries who subsidize an activity for which they are thought to have a comparative advantage are doing far more harm than good.

The effect of a marginal change in the subsidy provided to the reverse engineering sector can be seen by differentiating (24) with respect to σ_f and conditioning on (26). The effect is

$$\frac{\partial g}{\partial \sigma_f} = \frac{\alpha}{1-\alpha}\rho\left(\frac{n_f}{n_d}\right)^{\delta}\left[\frac{a^2-b^2}{b}\right] \tag{2.26}$$

which is positive iff $a > b$. Put quite simply, if the cost of domestic development is relatively high, then a subsidy will increase the rate of growth. The opposite is true if b is large relative to a. Thus, policies aimed at domestic industrial development will have the intended effect if and only if the cost of adopting foreign technologies is small relative to the cost of developing them domestically.

2.5. Empirics

The model and preceding discussion suggest that if an economy faces a relatively high cost of adopting foreign technologies then the degree of crowding out will be higher and thus economic growth will be slower. Moreover, policies that promote imported intermediate goods will exacerbate this effect. This section uses data to examine whether this pattern is consistent with trends in economic development over the past several decades.

There are some limits to exploring this. The policies used to favor specific imports (effectively subsidizing industrial growth) varied greatly. The direct use of a subsidy and the resultant effect on trade volumes was less common than the use of currency manipulation (multiple exchange rates, rationed foreign exchange, etc.). However, the intent is merely to test for evidence suggesting that reliance on imported technology under the premise of import-substitution may have a differential impact on output growth rates.

The argument made is that policies to advance economic growth pursued by import-substituting countries will be counter productive when the costs of reverse engineering or adopting are higher. As this is undertaken by copying foreign technologies, I will use bi-lateral trade volumes as a proxy for the flow of technology between countries. This is consistent with the notion of embodied technology, where the extent to which one country may absorb the technology of another is a function of the volume of goods imported, often controlling for the type of good. Moreover, the effect of embodied technology on economic growth has been documented widely (see Keller [43], and Coe and Helpman [18] for examples), and has been shown to have a positive effect on economic growth rates. This chapter argues that this effect is a function of human capital. Countries with a relatively low cost of adopting foreign technologies may benefit in the form of higher growth rates, whereas countries with a high cost may see adverse effects.

The specific treatment of the cost of adopting foreign technologies is important. As a proxy for this, I will use education levels as reported in the recently available Barro-Lee 2010 [7] dataset on educational attainment. The dataset provides mean years of schooling by category for the population 15 years and older at five year intervals for a panel of 138 countries. I use the difference between the education levels of the exporting and importing countries as a means of controlling for the cost of adopting a foreign technology. Intuitively, when the gap in education levels is larger, the cost of adopting will be higher, and will thus bear a negative impact on growth.

2.5.1 Data

Data on trade volumes is sourced from the Feenstra United Nations world bilateral trade dataset. This data set provides bilateral trade volumes by 4-digit SITC code from 1962 to 2008, which allows us to consider the impact of specific sectors, i.e. whether the manufacturing sector has a more relevant impact, on average, than trade in general. In addition, they provide all trade volumes in constant-price international dollars, so that no further modifications are necessary.

Data on real GDP growth rates and levels is from the Penn World tables v6.2. When constructing the growth rate, I calculate the average of the growth rates for the 5-year period beginning with the sample year. This has the effect of ignoring the instantaneous effects of both education and technology absorption on growth, and instead considers the average effect over the subsequent five year period. I find this intuitively appealing, as the effect of any variable on the rate of growth of economic output may take some time. In addition, by using the *subsequent* five year period, we avoid worrying about reverse causation, as future growth is unlikely to impact current trade volumes or education levels. Moreover, as the education data is only available at 5 year intervals, it is a conservative approach to including the growth data, as including only those years for which there is education data available could likely generate spurious results.

The education data, again, is from Barro-Lee 2010 panel data set on education. The average years of education for the population 15 and older is used, primarily because it is the most general measure of education and suffers from few missing values relative to other variables in the dataset. Years of primary, secondary and tertiary schooling are used as robustness checks.

Countries are grouped by income level in an effort to uncover the differential effect by level of development. For the baseline regression, countries are grouped into income groups as defined by the World ank. Low income countries are those with *per capita* GDP less than $3,946, middle income up to $12,196 and high income in excess of $12,196. The model is also conditioned on those countries that have consistently been labeled import-substituters. The list of import substituting countries is based on anecdotal evidence from several papers. Bruton[14] discusses Brazil, India and South Korea at length. Hirschman [39] lists Brazil, Mexico and Columbia, as well as India and Pakistan as countries that offered protective policies to import-competing sectors. Argentina, per Pablo [20] presents another well known case of import-substituting policies. Out of these countries, Brazil, Mexico, India, Argentina, Pakistan and South Korea ared included in the import substitution category. The list of countries for each regression is listed in Appendix C.

2.5.2 Testing

The hypothesis is that the rate of *per capita* GDP growth will depend negatively on the cost of adopting technologies. As a proxy for the cost of adopting a technology I use the gap in education levels. Countries that imported crucial intermediate goods from exporters who are relatively advanced technologically (and thus in terms of education levels) face a higher cost of adoption, and thus a slower rate of technological and output growth.

To test the hypothesis I run the following empirical model:

$$\begin{aligned} \text{gr\_avg}_{it} &= \alpha_0 + \alpha_1 \log \text{real pcGDP}_{it} + \alpha_2 \log \text{Educ}_{it} \\ &+ \alpha_3 * \log \left(\text{Trade Vol.}_{ie} \times \frac{\text{Educ}_{et}}{\text{Educ}_{it}} \right) + \varepsilon_{it} \end{aligned} \tag{2.27}$$

The variables are abbreviated as follows: gr_avg is the 5-year average of real *per capita* GDP growth as recovered from the Penn World Tables, Trade Vol. is the volume of trade between countries i and e (i denotes importer, and e exporter). Educ is the years of education for the population over 15.

Real per capita GDP is included to account for the typical effect that income levels have on growth rates. I include the interaction between trade volumes by sector and the educational gap because I expect that the impact on growth that the gap between trading partners will have will be an increasing function of the volume of trade between them. However, I condition on the level of education of the importing to account for the fact that education levels alone will have a significant effect on economic growth rates.

The empirical specification is subject to some caveats. The use of trade volumes is an imperfect measure of import-substitution, and when applied to aggregate trade volumes is an imperfect measure of intermediate input use. This second concern is ameliorated by running the regression including only those sectors that can be accurately classified as intermediate industrial goods, and observing consistent results. The first concern begets the reminder that the purpose of the regression is to provide some cursory evidence that increases in trade volumes and the associated level of embodied technology have a variable impact on future growth rates. This provides some evidence that policies with this aim may be counterproductive.

Results from the baseline regression, which includes all trade categories, are presented in Table 6. For this regression I use average years of primary schooling as the education variable and in the construction of the VAR variable.

Dep. Variable: gr_avg[b]

	Pooled	Low income	Middle income	High income	ISI
log(intercept)	4.520	0.472	5.100	22.442	8.449
	(0.163)	(0.332)	(0.789)	(2.461)	(0.868)
log(real pcGDP)	−0.406	0.204	−0.518	−2.743	−0.601
	(0.022)	(0.044)	(0.081)	(0.220)	(0.091)
log(Educ)	1.141	0.398	1.452	4.521	−0.613
	(0.037)	(0.051)	(0.088)	(0.146)	(0.139)
log(VAR) [a]	−0.041	−0.060	−0.018	0.018	−0.054
	(0.005)	(0.008)	(0.006)	(0.014)	(0.011)
R^2	0.0219	0.008	0.0386	0.422	0.164
$FStat$	186.8	40.51	101.3	545.7	71.94

TABLE 6. Baseline Regression (Full Sample)

[a] VAR = Trade Vol.$\left(\frac{\text{Educ}_e}{\text{Educ}_i}\right)$, Educ = pop. avg. years primary education

[b] standard errors in parenthesis

The evidence in the regression supports the hypothesis: that growth rates depend negatively on the cost of adopting foreign technology, where the cost is proxied for by the difference in education levels of the exporting and importing country. What is more interesting is that the effect differs across income levels. Poor and middle income countries experience growth that is, on average, .06 and .018 point lower growth respectively during the subsequent five year period. Rich countries seem to be unaffected, as the coefficient for that set is not significantly different than zero. ISI countries experience an effect that is more negative, on average, than the full sample, despite the fact that they qualify as lower to middle income. This indicates that they are, in fact, outliers.

Further, we can estimate the regression including only industrial intermediate goods. This includes the SITC 4 categories under machinery and transport equipment, and includes all general industrial and machinery goods (categories beginning with 7 in the 4-digit classification). Estimating the regression using this subset is tantamount to including a sector fixed effect, but because there is substantial interest in this sector pursuant to the discussion in this chapter, it is presented as a stand-alone regression. The results are presented in Table 7.

Dep. Variable: gr_avg [b]

	Pooled	Low income	Middle income	High income	ISI
log(intercept)	4.678	0.465	3.949	20.736	8.613
	(0.206)	(0.412)	(0.998)	(3.144)	(0.842)
log(real pcGDP)	-0.433	0.214	-0.489	-2.636	-0.713
	(0.027)	(0.054)	(0.103)	(0.282)	(0.211)
log(Educ)	1.108	0.282	1.9224	4.614	-0.494
	(0.048)	(0.064)	(0.113)	(0.192)	(0.200)
log(VAR)[a]	-0.034	-0.062	-0.013	0.071	-0.051
	(0.006)	(0.009)	(0.006)	(0.017)	(0.018)
R^2	0.024	0.011	0.025	0.429	0.153
FStat	326.7	84.51	108.7	881.4	74.89

TABLE 7. SITC4 category 7

[a] VAR = Trade Vol.$\left(\frac{\text{Educ}_e}{\text{Educ}_i}\right)$, Educ = pop. avg. years primary education

[b] standard errors in parenthesis

The results in Table 7 validate our priors. When the sample is limited to trade in manufactured intermediate goods, the effect is slightly stronger for low income, high income and ISI countries. The regressions retain or improve upon their significance levels.

The change in the magnitude of the coefficients is as suspected, and we can conclude that dependence on import categories for which embodied technology is theoretically high has a negative impact on subsequent output growth rates.

Two final robustness checks provide some additional insight. First, I condition the sample such that the education level of the exporting country is greater than the education level of the importing country. This separates the marginal impact of trade with a more advanced exporting partner when the exporting partner already has a higher level of human capital. The results are consistent with the results presented in Tables 1 and 2, though they do report a negative effect for all country groups. This suggests that an advanced economy benefits from a marginally more advanced exporting partner when the exporter has a lower level of human capital than the importer. This regression also reports that the set of import-substituting countries has a more negative effect than even the set of low-income countries, lending further credence to the suggestion that they suffered disproportionately from increases in trade with more advanced economies.

Dep. Variable: gr_avg [b]

	Pooled	Low income	Middle income	High income	ISI
log(intercept)	4.578	0.142	-0.247	23.109	9.371
	(0.231)	(0.392)	(1.527)	(4.303)	(0.742)
log(real pcGDP)	-0.437	0.214	-0.238	-2.818	-0.913
	(0.030)	(0.052)	(0.162)	(0.379)	(0.119)
log(Educ)	0.987	0.256	3.240	5.109	-0.234
	(0.052)	(0.061)	(0.183)	(0.292)	(0.155)
log(VAR)[a]	-0.013	-0.026	-0.023	-0.009	-0.031
	(0.008)	(0.010)	(0.015)	(0.032)	(0.022)
R^2	0.017	0.005	0.0766	0.3778	0.123
$FStat$	122.8	27.79	104.4	291.5	72.08

TABLE 8. $\text{Educ}_e > \text{Educ}_i$

[a] VAR = Trade Vol. $\left(\frac{\text{Educ}_e}{\text{Educ}_i}\right)$, Educ = pop. avg. years primary education

[b] standard errors in parenthesis

An additional robustness check uses the level of secondary education in the construction of VAR, as well as the primary control in the regression. Use of secondary education rates has a small and insignificant effect on the magnitude and significance of the variables. Once again, the effect for high-income countries is negligible, and the effect for the ISI countries is negative and larger in magnitude than for the full sample. This implies the the results are robust to alternative measures of education as a proxy for technology level, and across income groups.

Dep. Variable: gr_avg [b]

	Pooled	Low income	Middle income	High income	ISI
log(intercept)	6.749	2.346	16.823	48.531	15.001
	(0.212)	(0.365)	(0.904)	(2.673)	(0.904)
log(real pcGDP)	−0.500	0.059	−1.581	−4.838	−1.401
	(0.024)	(0.043)	(0.096)	(0.243)	(0.111)
log(Educ)	0.782	0.453	1.319	2.125	1.112
	(0.027)	(0.034)	(0.060)	(0.162)	(0.162)
log(VAR)[a]	−0.064	−0.086	−0.039	0.016	−0.078
	(0.004)	(0.007)	(0.005)	(0.014)	(0.012)
R^2	0.022	0.017	0.042	0.309	0.134
$FStat$	302.7	139.1	183.2	522.7	96.71

[a] VAR = Trade Vol.$\left(\frac{\text{Educ}_e}{\text{Educ}_i}\right)$, Educ = pop. avg. years secondary education

[b] standard errors in parenthesis

TABLE 9. Educ = yrs. secondary education

Finally, I split the sample into pre- and post-1985. This split is meant to capture a difference in international policy, and to test for differences by identifying post-1985 as an era under which globalization resulted in the mass production of final goods in underdeveloped countries. The results are presented in Table 10.

Dep. Variable: gr_avg [b]

	Pooled	Low income	Middle income	High income	ISI
			Pre-1985		
log(intercept)	9.653	−1.41	19.578	67.225	9.093
	(0.261)	(0.464)	(1.287)	(8.622)	(0.823)
log(real pcGDP)	−1.042	0.443	−2.089	5.873	−0.675
	(0.034)	(0.061)	(0.135)	(0.782)	(0.115)
log(Educ)	1.613	0.445	1.967	1.08	−0.549
	(0.050)	(0.062)	(0.114)	(0.807)	(0.179)
log(VAR)[a]	−0.046	−0.021	−0.068	−0.23	−0.060
	(0.007)	(0.009)	(0.007)	(0.56)	(0.014)
R^2	0.0645	0.023	0.094	0.158	0.119
$FStat$	428.4	98.04	204.3	27.27	80.62
			Post-1985		
log(intercept)	0.844	2.836	1.6185	−9.898	9.982
	(0.240)	(0.558)	(1.2120)	(1.829)	(0.806)
log(real pcGDP)	−0.078	−0.375	−0.063	0.832	−0.896
	(0.032)	(0.079)	(0.1202)	(0.169)	(0.113)
log(Educ)	1.248	1.346	0.8163	2.241	−0.131
	(0.082)	(0.129)	(0.1662)	(0.109)	(0.171)
log(VAR)[a]	0.008	0.031	0.0130	−0.027	−0.026
	(0.010)	(0.004)	(0.0121)	(0.008)	(0.014)
R^2	0.018	0.0127	0.004	0.1347	0.121
$FStat$	104.4	38.72	8.251	150.8	83.42

[a] VAR = Trade Vol.$\left(\frac{\text{Educ}_e}{\text{Educ}_i}\right)$, Educ = pop. avg. years primary education

[b] standard errors in parenthesis

TABLE 10. 1985 as a discontinuity

There are some interesting revelations in these results. There is evidence for the notion that growth suffers, as the volume of imported goods weighted by education differences has a deleterious effect on growth in the pre-1985 sample, but less so in the post-1985 sample. The coefficient appears negative for all country-groups (though insignificant for high-income countries) in the former sample, as is expected. However, the post-1985 group sees a postive effect for low and middle income groups. This can potentially be a result of the end of policies (whether via fiat or via necessity) that supported large volumes of imported intermediate goods. In the post-1985 sample, low and middle income countries see a positive effect. Whether this is a result of lower costs of adoption due to higher education levels or due to the end of associated trade policies is not evident.

Worryingly we see negative coefficients on the education variable. It is only significant for the ISI group, in both the pre-1985 and full sample regressions. That higher levels of education result in lower future growth rates is highly unlikely, and it must be the case that this is driven by the size of the sample and the anomalous growth experiences of Brazil and Argentina during the 1960 - 1985 period. Severe financial crises as a result of political mismanagement resulted in periods of very low growth rates, despite levels of education that were high relative to the sample.

Finally, the coefficients are reported for each component of the weighted trade volume variable. The results provide some interesting insight into the difference between changes in trade volumes and trade with more tchnologically advanced partners. For the following set of regressions, the VAR variable reported in previous regressions is split into its component parts.

Dep. Variable: gr_avg[a]

	Pooled	Low income	Middle income	High income	ISI
log(intercept)	4.905	0.937	1.876	21.545	5.82
	(0.171)	(0.339)	(0.857)	(2.476)	(0.786)
log(real pcGDP)	−0.433	0.175	−0.310	−2.760	−0.435
	(0.021)	(0.044)	(0.084)	(0.219)	(0.098)
log(Educ)	0.913	0.110	1.827	4.853	−0.513
	(0.048)	(0.066)	(0.095)	(0.162)	(0.145)
log(VAR_{educ})	−0.284	−0.378	0.261	0.386	0.288
	(0.032)	(0.048)	(0.027)	(0.080)	(0.059)
log(VAR_{trade})	−0.021	−0.037	−0.025	−0.007	−0.066
	(0.005)	(0.008)	(0.006)	(0.015)	(0.011)
R^2	0.025	0.012	0.174	0.4334	0.1744
FStat	260	74.77	140.8	670.4	147.6

[a] standard errors in parenthesis

TABLE 11. Trade coefficient

A surprising result is that for each country-group the coefficient on trade is negative. The coefficient on education is positive for high-income groups and negative only for low income groups. That it is negative for the pooled group must be driven by the low-income group. This suggests that an increase in trade volumes has a poor effect on future growth rates, and that, conditional on the volume of trade, more educated trading partners has a positive effect on domestic growth rates, for middle and high-income countries, but a negative effect for low-income countries. It does not penalize the group of ISI countries in the sample, but does lend evidence that poorer countries, broadly defined, suffer lower future growth rates as a result of trade with more human capital endowed countries.

2.6. Conclusion

The intent of this chapter was to argue that the variable historical experiences with import-substitution policies depend on the ability of a country to adopt foreign technologies. While much of the literature assumes a costless flow of ideas, or that ideas are readily copied, this chapter posits that those crucial differences in the cost of adopting foreign technologies can explain why some countries were successful, and others were not. It employs a simple endogenous growth model to demonstrate that differences in the cost of adopting foreign technologies can play a significant role. In addition, it demonstrates that seemingly benign policies to promote industrialization will have an adverse effect on output growth under certain, plausible, circumstances. In addition, a simple empirical exercise demonstrates that this effect is an empirical regularity. In a broad sample of countries, the effect of import volumes, weighted by human capital differences, has an adverse effect on subsequent economic growth rates. That is, growth suffers when a country imports goods from a relatively more educated, or more technologically advanced, country. This effect is exacerbated when the sample is limited to goods that are industrial intermediate goods in nature, and carries greater economic significance for poor countries, and those that have been historically labeled import-substituting industrializers. The empirical implications are robust to alternative measures of education, and across income groups. Future research in the area would include a role for macroeconomic policies instead of simple trade patterns, as it is an effect that is collinear with the results in this chapter, but omitted for simplicity.

CHAPTER III

PRODUCTIVITY GROWTH: A GMM APPROACH

3.1. Introduction

This chapter applies an estimation procedure developed by Olley and Pakes [58] and modified by Levinsohn and Petrin [52] to quantify the sources of productivity growth in a sample of OECD countries. The first result of the study is an exposition of the sector-level sources of productivity growth. It reveals that the distribution of productivity growth is remarkably heterogeneous and transcends generalities. In some countries productivity growth is uniquely driven by manufacturing, in some it is hindered by manufacturing, and in others it is dispersed across the service sectors.

This provides an interesting counterpoint to the well-accepted point that service sectors experience lower rates of productivity growth than other economic sectors. Baumol [9] originally noted the relationship between the increasing size of the service sector and related productivity slowdowns. His cost-disease argument provides an explanation of why it is that wages in service sectors, which are inherently low productivity growth, can remain high despite relatively low advances in worker productivity. This paper suggests that it need not be the case that workers in service sectors are becoming less productive, and can help to explain why wages in some sectors have advanced despite notions that they are paid in under-productive sectors.

The second result is a revised estimate of aggregate productivity growth. Estimates of aggregate productivity growth implied by the procedure in the paper differ substantially from those predicted using least squares. The estimator in this chapter performs better in predicting aggregate productivity growth relative to least squares and provides an econometrically robust estimate when calibration of the production function is not possible. This result, along with the first, reiterate the value of data and measurement in assessing economic performance.

The study of productivity growth at an aggregate economic level gained great momentum with Solow's seminal work in 1964. Not only did he define 'total factor productivity' as we know it today, but he created the incipient framework for an analysis of the variation in incomes and productivity growth between countries and across time. Because of its flexibility, clarity and ease of modification it has been used extensively to study the issue. As productivity growth is thought to be a necessary means of sustaining income growth, the study of its sources and causes is an important, even if ancient, topic in economics. Indeed, continued interest on the part the academic community, as evidenced by ongoing research in the area, highlights the value of accurate measures of productivity growth and its determinants.

Because of its transparency and elegance, the classical framework for studying aggregate productivity growth is extremely popular. However, it suffers from a number of known pathologies. Recall that changes in aggregate output in a classical growth framework are the result of two things: the accumulation of productive factors and changes in productivity, tantamount to an affine transformation of the functional relationship mapping quantities of inputs to quantities of outputs. Measures of total (or multi-) factor productivity measure the difference between actual and predicted changes in aggregate output conditioned on changes in the quantity of inputs. This typically originates with an aggregate production function of the form

$$Y = AK^{\alpha}L^{1-\alpha} \tag{3.1}$$

While this representation excels in generality it relies on several assumptions that are somewhat misleading. The first is the property of linear homogeneity. That the production function is constant returns to scale implies that each productive factor receives its marginal revenue product. Or, per the above representation, that fraction α of national income accrues to labor and $(1-\alpha)$ to capital. One benefit of this is that the function can be calibrated without relying on econometric estimation, as the division of national income is a readily available statistic. However, this requires that each sector also be representable by a similar constant returns to scale technology, which is a much more stringent assumption. This introduces the next point.

The second assumption is that each sector within the economy, of which there are obviously many, is not just of the same functional form, but parametrically identical. The results presented in this chapter, and likely the reader's intuition, suggest that this is not the case. Intuitively one would expect that the share of factor payments accruing to labor be higher in a service sector than in manufacturing which is indeed the case. Addressing the cost of this assumption is one of the contributions of this chapter.

Given some of the assumptions necessary if one is to use an aggregate production function to study changes in productivity levels, the process of relaxing them in a number of ways is appealing. The first step that this chapter will make is to consider the output of an economy as being explicitly produced by a number of specific sectors. Of course, several authors have addressed the economy at a disaggregated level, but this is an important component of this study. In line with current methodologies, I will consider each of the 2-digit ISIC categories as an independent sector. Using data from the OECD-STAN database for structural analysis and the associated input-output tables, I am able to estimate independent parametric production functions for each sector. This requires econometric estimation of each sector-level production function, discussed below.

The second step is to apply an 'appropriate' econometric treatment of the problem. As mentioned, calculating total factor productivity first requires that the production function be calibrated. When using an aggregate, constant returns to scale, production function this is an easy task, and does not rely on econometric estimation. The value of α above can be imputed using the share of national income accruing to labor. Of course, this assumes that gross domestic product and gross national income are identical, but has been the *de facto* method of calibration for decades. However, at a highly disaggregated level, the factor payments accruing to each input are not available in national accounts. For this reason I implement a recently developed econometric procedure to address the possible endogeneity of the regressors. The results, while similar to those suggested by a naive ordinary least squares procedure, are different enough to produce alternative results at an aggregate level. Not only do they suggest different estimates of productivity growth, but they are more capable of matching the variation observed in productivity growth. To make this claim I use data from the Penn World Tables on the growth rate of *per capita* income. Provided that a country is on a balanced growth path (a dubious, though common, assumption) the rate of income growth is proportional to the rate of total factor productivity growth, making this a reasonable approximation for comparison.

The chapter is organized as follows: Section 3.2 provides a brief summary of the literature on the subject. Section 3.3 introduces the data and section 3.4 discusses the model used to estimate the technological coefficients. A fifth section discusses the results and a sixth concludes the paper.

3.2. Review of the Literature

A summary of the literature on productivity growth surely merits its own paper, both due to the sheer volume of output on the subject and the importance of the issue at hand. Though the idea that growth can be 'accounted' for is nearly as old as the field of economic growth itself, interest remains at a peak, as evidenced by many recent contributions to the subject.

A principal contribution of the Solow growth model was that it provided the first theoretical foundation for comparing measures of productivity across countries. Given data on factor income shares, changes in the levels of primary inputs and output could be used to determine the level of total factor productivity. The model itself could be neatly calibrated using factor income shares at an aggregate level, and then used to study cross-country differences in the level of predicted productivity. It is hardly worth noting that its performance as a predictor of international income differences was rather poor, requiring astronomical differences in the level of productivity to account for income differences of much smaller magnitudes. Several modifications to the theoretical framework, including the introduction of human capital and endogenous technical change provided frameworks that more closely aligned theory and data. A succinct summary of these trends, including application to topics addressed in what follows, can be found in Hulten [40].

The extension of growth accounting to include intermediate inputs has its origins in Hulten [41] who showed that total factor productivity growth can be expressed as a weighted sum of sector-specific growth rates. Productivity growth in each sector and Domar weights, the ratio of a sector total output to the total output of an economy, could be used to neatly aggregate sector specific growth rates to estimate aggregate productivity growth. Because a given share of the total output produced by a sector might be used as an intermediate input elsewhere, these weights would generally sum to more than one, and could be use to derive aggregate measures of productivity from information on specific sectors. Jorgenson [42] relied on this procedure to estimate sector level growth rates for the United States economy during the post-war era. His findings underscore the fact that productivity growth, taken at an aggregate level, is not a very informative means of addressing productivity in an aggregate economy. However, his empirical work relied on the use of value added as a dependent variable and includes only capital and labor as regressors. Later, Feenstra and Markusen [26] accounted for the expanded role of intermediate inputs in output growth. Their work serves as a very useful extension of the classical framework, but uses an intentionally mis-specified regression to account for productivity. More recent work by Wolfl et al. [70], [71] highlight the extent to which interaction between the different economic sectors influences measurement of productivity growth. Her work indicates that the share of productivity growth due to the increased use of intermediate inputs is substantial, and that the intermediate inputs channel is a potential conduit for productivity. Much of her work is based on the same data used in this chapter, but does not include a formal econometric treatment of productivity growth. However, because her work sheds important light on the increased role of intermediate inputs in production, it provides much of the motivation for this chapter.

An important purpose of the study is to address the notion that the service sector is the cause, or source of lower productivity growth rates in developed countries. A wide literature, dating back to Baumol [9] documents the relationship between the slowdown in productivity and the expanding role of the service sector. Oliner et al. [57], Griliches [32] and Landefeld et al. [49] argue the the immeasurability of the service sector drives a significant share of the apparent productivity slowdown. Indeed, questions of the sort "what is the price per unit of service?" or "what is a unit of service?" remain unanswered. How much of an effect difficulties in measuring service sector output will have is remains an unanswered question, and this chapter is agnostic with respect to service sector measurability. Data used to perform the analysis reports both prices and quantities as measured by the OECD, and represent the best available measure known to the author. With respect to the role of the expanding service sector in productivity growth the results in this paper suggest that the question is more nuanced, and that the issue can only be appropriately addressed on a country-by-country, sector-by-sector basis.

The literature on estimating production functions and productivity analysis is also an active area of research. It is well recognized that naive ordinary least squares represents an inappropriate econometric treatment of production functions. Because output and inputs are simultaneously determined, estimates produced via ordinary least squares will be biased. A number of creative methods, such as the stochastic frontier production function introduced in Aigner [4] and implemented by Fare et al. [24], Griffith [31] and Sveiskauskas et al. [69], addresses the estimation of a production function in a more theoretically consistent way, do not address the simultaneity inherent in the growth accounting framework.

This chapter relies on procedures developed in Olley and Pakes [58] and modified by Levinsohn and Petrin [52], and is the first to do so in a growth accounting framework. Their estimator was originally applied to firm level data to address the potential endogeneity of inputs when the dependent variable is output. This problem is equally present at the sector level, and amenable to a variant of their estimator. The benefit of their estimator is that, provided that some rather specific assumptions hold, the coefficients on a sector-level production function can be estimated unbiasedly. This then permits an accurate estimate of total factor productivity without relying on a calibrated production function. Some potential shortcomings of the estimator have been addressed. Per Ackerberg [3] it is acknowledged that the degree of collinearity is likely high. Indeed, collinearity in the model is high, but I am able to estimate the coefficients with a comfortable degree of precision. Because collinearity reduces the precision of the point estimates, but does not by itself introduce bias, this is not much of a detractor in the current framework. Provided that the assumed moment restrictions are valid, these estimates will be unbiased though measured with less efficiency than theoretically possible.

The measurement of total factor productivity receives less emphasis than the relationship between productivity growth and other economic variables. Common amongst these are the relationship between research and development, human capital accumulation and many trade related issues. Most studies take as given the measurement of productivity growth, relying on methods discussed above. This chapter does not make claims about the important links between economic activity and factor productivity, but seeks to address potential problems in its estimation. It is the author's hope that more accurate methods of estimating productivity growth will lend credence to the many factors driving the outcome itself.

3.3. Data

I use data sourced from the OECD-STAN database on structural indicators. The data available are a rich sample of yearly observations on sector specific variables for the full sample of OECD countries. Estimation requires rather detailed information at the sector level, which is not available for all countries. Because of this requirement, only Austria, Belgium, Denmark, Finland, France, Germany, Italy, Norway and Sweden have data sufficient for inclusion in the study. Lack of data on capital stock and output are the most frequent reasons for exclusion.

The intent of the paper is to estimate sector specific production functions including capital, labor and all intermediate inputs. For this reason I use data on volumes of output for each sector as the dependent variable. The set of regressors includes: net capital stock, hours worked by employees and the volume of intermediate inputs obtained from the input-output tables. It should be made clear that the use of value added as a dependent variable is appropriate if the set of regressors includes capital and labor *only*, as is the case in numerous other papers. When using a full set of regressors (i.e. all intermediate inputs) the theoretical underpinnings of the regression require that total output be the dependent variable.

The availability of input-output tables provides a means of disaggregating intermediate input use into the sector of origin. The STAN input-output tables provide the current price value of intermediate inputs sourced from each sector, for each sector. However, the tables are available only periodically. A maximum of three are available, one each from the mid 1990's, early 2000's and mid 2000's for each country. The lack of data for the interim years presents a problem for estimation. To generate a sufficient number of degrees of freedom I interpolate (linearly) the values for those years between the first and last available dates. I then deflate the values for the previously missing years using deflators provided by the OECD. Though this constitutes imputing data, it creates a minimal amount of artificial variation in the process. Also, for the majority of sectors the data suggest consistent trends in the use of intermediate inputs, implying that linear interpolation is likely a conservative approximation of the data.

Two other modifications are made to recover missing observations. For missing values of the net capital stock, values are imputed using a linear projection of the gross capital stock. For missing values of hours worked by employees the values are imputed using a linear projection of number of employees and number of persons engaged. Each of these regressions have an R^2 of very close to unity which for the purposes of imputing data is desirable, and missing data constitute a minority of observations. Lastly, values for which the quantity of intermediate inputs used are 0 are replaced with .0001 because logarithmic transformations of 0 are not defined, though this occurs only once in the data.

3.4. Estimation

The approach of this chapter is to use the estimation technique introduced by Olley and Pakes, and modified by Levinsohn and Petrin, to examine trends in productivity growth in the OECD[1].

Consider the following (logged) production function:

$$\ln(Y_{it}) = \ln A_{it} + \alpha \ln K_{it} + \beta \ln L_{it} + \sum_j \gamma_j \ln X_{it}^{(j)} + \gamma_t t + \eta_{it} + \varepsilon_{it} \tag{3.2}$$

K_{it} denotes capital, L_{it} labor and $X_{it}^{(j)}$ intermediate input from sector j used in sector i. A time trend is included to capture variation in productivity due to the passage of time, i.e. exogenous technological progress. Each input is characterized by its own peculiarities. For example, labor use might be affected by union contracts which are persistent through time, some forms of capital might be the result of investment decisions made a year ago or more, and intermediate inputs will adjust with varying speed to unexpected information. These idiosyncrasies are the motivating force behind the method of estimation presented herein.

In any case, it should be apparent to the reader that the set of regressors likely suffers from some degree of endogeneity. As observations on Y_{it} are, in fact, equilibrium outcomes, there is every reason to suspect that changes in demand, which partially determine Y_{it} will *cause* changes in the level of a given input used during an observational time period. In recognition of this it is assumed that η_{it} is correlated with the right-hand-side variables, while ε represents a classical disturbance. Thus, the regression immediately violates the assumptions necessary for linear regression, and needs further modification.

Capital is assumed to be a predetermined variable. That is, capital cannot respond contemporaneously to unexpected information (η_{it}). Unexpected changes to demand,

[1] The routine is coded in R, and is available upon request from the author

or productivity shocks, occurring at time t may induce investment in capital, but that investment is not usable until $t+1$. Explicitly

$$K_{t+1} = (1-\delta)K_t + I_t(\eta_t) \tag{3.3}$$

All other intermediate goods may freely respond to current period shocks. That is, labor and intermediate inputs may adjust as unexpected information deems necessary. In this sense changes in output are determined entirely by variation in the levels of what are termed 'free' variables. This clearly implies that all variables in the regression, with the exception of capital, are potentially endogenous. For the purposes of analysis this implies that

$$X_{it}^{(j)} = g(K_{it}, \eta_{it}) \tag{3.4}$$

where again, η_{it} represents any unexpected information arriving at t. That the use of input $X_{it}^{(j)}$ also depends on the level of capital is an assumption. Larger is a given sector, in terms of output produced, larger will be the stock of capital, and larger the adjustment of intermediate input use as contemporaneous information deems necessary.

Provided that $g(K_{it}, \eta_{it})$ increases monotonically in both of its arguments, the function may be inverted to yield

$$\eta_{it} = h(K_{it}, X_{it}^{(j)}) \tag{3.5}$$

In other words, the level of capital and intermediate good j correspond uniquely to the value of η which is observed at the sector level but unobserved to the econometrician. The monotonicity of g is critical. If g is non-monotonic then K_{it} and $X_{it}^{(j)}$ do not uniquely identify η_{it}. The validity of this assumption is tested post-estimation.

The model can now be specified as follows (using j to index the intermediate chosen as a proxy for the error term discussed above):

$$\ln Y_{it} = \beta \ln L_{it} + \sum_{-j} \gamma_j \ln X_{i,t}^{(k)} + \Psi_{i,t} + \varepsilon_{it} \tag{3.6}$$

where

$$\Psi_{it} = \ln A_{it} + \alpha K_{it} + \gamma_j \ln X_{it}^{(j)} + \eta_{it}(K_{it}, X_{it}^{(j)}) \tag{3.7}$$

The choice of $X_{it}^{(j)}$ is an important component of the analysis. The assumption has been made that X_{it} may respond to unexpected shocks. As such, it should correspond to an intermediate presupposed to quickly adjust to this information. In addition, a variable with as few missing observation as possible is desirable. I proceed on the intuition that service sector input is the most likely to adjust to unexpected information. This intuition is based on the observation that services, broadly defined, includes machine and equipment rentals, consulting, insurance and transportation of goods. Manufacturing consists of metal products, many forms of machinery and rolled metals etc. that I assume respond with less alacrity to unexpected information. The same applies for agriculture, where use of raw materials may imply some delay. A second desirable characteristic of service sector inputs is that they are more likely to adjust 'smoothly' to new information. Intermediate inputs with large fixed costs, or lumpy input use characteristics, may not respond fully to potentially minor innovations to η. Estimation using manufactures as the 'proxy' intermediate good result in minor deviations in the coefficient estimates, but does not significantly alter the results.

To estimate the coefficients for each sector across the sample I assume that the technological coefficients are constant for each industry through time and across countries. The benefit of this is that it provides a sufficient number of observations, and thus variation, to efficiently estimate the model. Estimating coefficients for each country-industry panel is impossible due to insufficient degrees of freedom (the model would have 13 coefficients and 11 observations). Furthermore, all of the countries in the sample are high income OECD countries, so the assumption that they operate with similar technologies is reasonable.

Thus, for each industry I estimate 3.6 where Ψ_{it} is replaced with a third-order tensor product polynomial in K_{it} and $X_{it}^{(j)}$. The coefficients on the polynomial are insignificant at higher levels, indicating that this captures a large degree of the variation present. This provides unbiased estimates of the coefficients on all coefficients $X^{(k)}$ and L, as well as an estimate of Ψ. The aim then is to recover from the non-parametric estimate of Ψ estimates of η, K and $X^{(j)}$.

As assumed, η is a first order Markov process, or

$$E[\eta_t|\eta_{t-1}] = \phi(\eta_{t-1}) \tag{3.8}$$

For each observational unit, a regression of Ψ_t on Ψ_{t-1} yields $\hat{\Psi}_t$, the expectation of Ψ_t conditional on its past value. Equation 3.6 can then be written as

$$\ln Y_{it} = \beta \ln L_{it} + \sum_{-j} \gamma_k \ln X_{it}^{(k)} + \gamma_j \ln X_{it}^{(j)} + \alpha K_{it} + \Psi_{it} - \hat{\Psi}_{it} + \varepsilon_{it} \tag{3.9}$$

where $\Psi_{it} - \hat{\Psi}_{it}$ denotes the unexpected component of the original error term. Let the residuals from (9) be given by $\hat{\varepsilon}$. The coefficients on $X^{(j)}$ and K are identified using the following moments:

$$E[K_{it}|\hat{\varepsilon}] = 0 \tag{3.10}$$

$$E[X_{it}^{(j)}|\hat{\varepsilon}] = 0 \tag{3.11}$$

$$\tag{3.12}$$

These moments imply that K_t does not respond to new information at time t, and that the use of intermediate good j a time $t-1$ does not respond to current period unexpected information. These condition provide two additional moments for the identification of the two remaining parameters. Levinsohn and Petrin use an additional 4 over-identifying assumptions. In exploring the use of additional restrictions I find that little is gained in efficiency, and so use only one additional, that $E[X_{it-1}^{(j)}|\hat{\varepsilon}] = 0$.

The final step implements a standard grid search algorithm to minimize

$$E([K_{it} + X_{it-1}^{(j)} + X_{it}^{(j)}]\hat{\varepsilon})^2 \tag{3.13}$$

Statistical inference is carried using bootstrap.

3.4.1 Results

The results of the regressions are presented in tables 12 and 13. For each industry the coefficients suggested by the procedure outlined above are compared next to the results from a naive OLS estimation, with standard errors in parentheses.

The most discernible trend is the level of significance attributed to the coefficients at large by least squares relative to the proposed alternative. Least squares attributes significance to a larger share of the coefficients, and does so at a higher level than when endogeneity is addressed. Bias in the coefficient estimates is evident, though most retain their signs and are within a comfortable distance of one another, which is reassuring. This is largely consistent with the prior that ordinary least squares would result in artificial high degrees of statistical significance. It is also worth noting that despite a high degree of collinearity between the regressors in the above estimation, the degree of significance on most coefficients is comfortable.

Negative values appear frequently, given that the theoretical underpinnings of the exercise require that they be positive. As troubling as this might seem, it is an occurrence in related literature as well (both Olley and Pakes [58] and Levinsohn and Petrin observe this). Measurement error may play a significant role, and econometric mis-specification is certainly possible. Negative coefficients most often appear simultaneously in both the least squares estimates and the modified regression, indicating that it is not a shortcoming of the methodology in the paper, but perhaps a result of the theoretical underpinnings or data mis-measurement. Because of its history and consistency with the least squares result I recognize this unpleasantry and continue.

TABLE 12. Dependent Variable: Log Output

	Agriculture		Mining		Manufacturing		Gas/Electric		Construction	
	L-P	OLS	L-P	OLS	L-P	OLS	L-P	OLS	L-P	OLS
K	0.2724	0.2748	1.1336	0.8071	0.5445	0.5451	0.4378	0.3220	0.1346	0.2110
	(0.0043)	(0.0254)	(0.0265)	(0.0620)	(0.0093)	(0.0365)	(0.0176)	(0.0468)	(0.0028)	(0.0321)
L	0.0025	0.0603	-0.3361	-0.0311	-0.1392	-0.1655	-0.0653	0.0204	-0.0647	-0.0239
	(0.0249)	(0.0179)	(0.0803)	(0.0419)	(0.0226)	(0.0184)	(0.0458)	(0.0252)	(0.0224)	(0.0208)
Agriculture	0.0078	0.0438	0.0526	-0.1126	-0.1239	-0.0946	0.1196	0.1528	0.0770	0.0431
	(0.0166)	(0.0146)	(0.0341)	(0.0247)	(0.0437)	(0.0259)	(0.0300)	(0.0261)	(0.0110)	(0.0061)
Mining	-0.0250	0.0434	-0.0068	0.0439	-0.0026	-0.0579	-0.1312	-0.0408	0.0060	0.1417
	(0.0150)	(0.0171)	(0.0445)	(0.0554)	(0.0126)	(0.0095)	(0.0272)	(0.0414)	(0.0367)	(0.0379)
Gas/Electric	0.4231	0.2379	-0.6930	-0.1144	0.2207	0.3742	0.8095	0.2905	0.5550	0.2658
	(0.0333)	(0.0242)	(0.2308)	(0.1499)	(0.0524)	(0.0469)	(0.1358)	(0.1495)	(0.0831)	(0.0802)
Manufacturing	-0.2152	-0.1142	0.4224	0.1402	0.0160	0.1331	0.0337	-0.0033	0.0468	0.0293
	(0.0374)	(0.0374)	(0.1094)	(0.0529)	(0.0314)	(0.0186)	(0.0437)	(0.0557)	(0.0361)	(0.0287)
Construction	-0.0028	-0.0483	-0.5300	-0.0573	-0.0438	-0.0703	0.1641	0.1809	0.0552	0.0437
	(0.0304)	(0.0333)	(0.0854)	(0.0297)	(0.0134)	(0.0124)	(0.0669)	(0.0507)	(0.0187)	(0.0131)
Wholesale	0.3219	0.4829	0.6030	0.1924	0.1767	0.0745	-0.6914	-0.1825	-0.1783	0.1197
	(0.0563)	(0.0650)	(0.1718)	(0.1371)	(0.0710)	(0.0224)	(0.1187)	(0.0968)	(0.1039)	(0.0879)
Telecomm	0.1537	0.1373	-0.4227	-0.0822	-0.1587	-0.1911	-0.5487	-0.4137	0.0138	-0.1028
	(0.0285)	(0.0331)	(0.1349)	(0.0714)	(0.0455)	(0.0438)	(0.0947)	(0.1216)	(0.0470)	(0.0414)
FIRE	-0.0769	-0.1203	0.4712	0.1149	0.0859	0.0660	0.6795	0.5445	0.2057	0.1334
	(0.0045)	(0.0432)	(0.0440)	(0.1150)	(0.0046)	(0.0416)	(0.0210)	(0.0912)	(0.0155)	(0.0565)
Social Services	0.1391	0.0611	-0.0824	0.0544	0.3573	0.3084	-0.0016	-0.0721	0.0420	0.1103
	(0.0400)	(0.0288)	(0.0737)	(0.0637)	(0.0532)	(0.0436)	(0.0637)	(0.0939)	(0.0315)	(0.0251)

TABLE 13. Dependent Variable: Log Output

	Wholesale		Transport/Telecomm		FIRE		Social Services	
	L-P	OLS	L-P	OLS	L-P	OLS	L-P	OLS
K	0.49167	0.3862	0.4399	0.5409	0.3194	0.2625	0.2879	0.3005
	(0.01142)	(0.0343)	(0.0066)	(0.0521)	(0.0015)	(0.0194)	(0.0021)	(0.0383)
L	0.08522	0.0311	-0.0993	0.0634	0.0317	0.0627	-0.0260	0.0280
	(0.01608)	(0.0090)	(0.0213)	(0.0267)	(0.0117)	(0.0118)	(0.0179)	(0.0178)
Agriculture	0.06770	0.0104	0.0102	0.0133	-0.0046	-0.0132	-0.0259	-0.0550
	(0.02214)	(0.0151)	(0.0083)	(0.0097)	(0.0095)	(0.0051)	(0.0132)	(0.0170)
Mining	0.00295	-0.0688	-0.0169	-0.0087	0.0188	0.0382	-0.0465	-0.0705
	(0.02674)	(0.0146)	(0.0090)	(0.0099)	(0.0095)	(0.0065)	(0.0102)	(0.0120)
Gas/Electric	-0.12561	0.2717	0.1444	-0.0597	-0.1705	0.0380	0.0967	0.1324
	(0.09023)	(0.0405)	(0.0517)	(0.0564)	(0.0317)	(0.0269)	(0.0476)	(0.0406)
Manufacturing	0.09119	0.0526	-0.0962	-0.5093	0.0914	-0.0026	-0.1035	-0.1199
	(0.04772)	(0.0444)	(0.0439)	(0.0627)	(0.0233)	(0.0222)	(0.0275)	(0.0259)
Construction	0.02210	0.0501	0.0224	-0.0106	0.0080	0.0595	0.0804	0.1572
	(0.04116)	(0.0243)	(0.0386)	(0.0441)	(0.0171)	(0.0170)	(0.0199)	(0.0223)
Wholesale	-0.17453	-0.1907	-0.1930	0.1405	0.0098	-0.0618	0.0405	-0.1213
	(0.04265)	(0.0312)	(0.0910)	(0.0979)	(0.0206)	(0.0200)	(0.0450)	(0.0500)
Telecomm	0.01676	0.0824	0.1218	0.2472	0.2028	0.2925	0.0547	0.2648
	(0.03446)	(0.0286)	(0.0407)	(0.0522)	(0.0323)	(0.0220)	(0.0510)	(0.0374)
FIRE	0.30505	0.2181	0.5880	0.4744	0.2916	0.2315	0.4696	0.3079
	(0.00929)	(0.0373)	(0.0042)	(0.0692)	(0.0016)	(0.0248)	(0.0086)	(0.0369)
Social Services	0.30853	0.2168	0.0236	0.1394	0.2055	0.1301	0.1325	0.1295
	(0.04139)	(0.0208)	(0.0337)	(0.0241)	(0.0220)	(0.0210)	(0.0192)	(0.0175)

3.5. Productivity

3.5.1 Sector level productivity growth

The next step in the analysis is to address productivity growth. I first examine productivity growth for each sector, and then proceed to the proposed Domar aggregation to study aggregate productivity.

For each sector, an estimate of total factor productivity can be obtained as follows:

$$\ln \hat{A}_{it} = \ln Y_{it} - \ln \hat{Y}_{it} \tag{3.14}$$

In the above equation $\ln \hat{Y}_{it}$ is the predicted level of output given logged levels of inputs and the coefficients estimated above. Once $\hat{A}_{it}$ has been estimated it is straightforward to calculate the growth rate of total factor productivity, $\frac{\dot{A}_{it}}{A_{it}}$. Once the growth rate of total factor productivity has been backed out, the aggregate rate of total factor productivity growth can be calculated as[2]

$$\frac{\dot{A}_{Total}}{A_{Total}} = \sum_j \frac{p_j Y_j}{\sum_k p_k Y_k^f} \frac{\dot{A}_j}{A_j} \tag{3.15}$$

where $\sum_k p_k Y_k^f$ is the sum of final demand (i.e. GDP) and $p_j Y_j$ is the total output of sector j. Because a share of the total output of a sector might be used as an intermediate input elsewhere, these weights sum to more than unity. Intuitively, sectors for which a large share of output is produced relative to GDP contribute more to total factor productivity growth as increases in productivity reduce unit costs in 'using' sectors, resulting in higher productivity throughout the economy. Given productivity estimates, I report the real GDP-weighted average contribution of each sector. Alternatively, this measures the counter-factual rate of GDP growth if the rate of productivity growth in all other sectors was zero.

The graphical results are in Appendix E. The results are presented in two parts. First, the average marginal contributions for each country/industry pair is given displayed

[2]This identity is derived algebraically in Hulten [41] and is a common procedure

as a bar chart. The value associated with each entry is $\frac{\dot{A}_j Y_j}{\sum_k Y_k}$, or the output growth rate of a given sector normalized by real GDP. Alternatively, this is the rate at which aggregate output would grow if output growth in all other sectors (not j) were equal to zero. This has the benefit of weighting productivity growth by the magnitude of a given sector, so that high productivity rates in small sectors are not over-emphasized. However, because it represents an average over the sample period the growth rates for each sector are regressed on a time trend and presented pairwise in the following tables. This information represents the average growth rate of total factor productivity over the sample period. This provides information about the trend of productivity growth which is hidden in the averages discussed above. The reader should be aware that a high rate of productivity growth need not imply that a sector will contribute significantly to the output of the economy. This will further depend on the size of the sector, in terms of output and the *level* of productivity, which may vary significantly across sectors.

In Belgium, output growth appears to have been driven almost exclusively by productivity increases in construction. However, this is due largely to a dramatic slowdowns in the productivity growth rate of the service and manufacturing sectors. Productivity growth in the manufacturing sector grew at an average of 1.8% over the first 6 years in the sample period, but at -3.1% for the final 5, which results in an average near zero. Information for the other sectors is summarized in the coefficient from a simple linear regression on a time trend, i.e. the average growth rate of total factor productivity for each sector. Upward trends are evident for all sectors other than manufacturing and social services, with relatively high rates of productivity growth in mining and gas and electricity transmission.

Output growth in the Czech Republic is led almost exclusively by the manufacturing sector. It is also one of the few sectors that displays positive productivity growth. Manufacturing in the Czech republic constitutes slightly more than 32% of output (cite OECD online) which is high relative to other countries in the sample, and output growth was strong through the sample period. Consistent with the service sector productivity hypothesis, productivity growth has been negative in the service sector, despite increases in output. Due to their small size, and low level of productivity it is not surprising that there is little to be gained in terms of output through productivity increases in the service sector.

Denmark presents a markedly different case. Estimates indicate that productivity growth has been negative for all sectors other than agriculture and gas and electricity distribution. However, increases in output are primarily driven by the varied service sectors in the economy. Both FIRE and construction contribute more to output growth than manufacturing, and wholesale only slightly less so. These estimates are contrary to the popular notion that productivity increases in the service sector are insignificant.

Output growth in Germany is driven primarily by productivity growth in manufacturing, wholesale and finance, insurance and real estate. Construction seems to be a significant detractor to output growth. Like Denmark, the results indicate that productivity growth has been on average negative over the sample period for most sectors, with positive productivity growth in excess of 1% occurring in only two sectors: mining, and gas and electricity distribution. Unfortunately, these sectors are too small for productivity growth to generate substantial changes in output, as indicated by their minuscule presence on the chart.

Finland's productivity growth is largely due to the telecommunications industry. Because of the presence of industry giants like Nokia, and its title as the first country to introduce a digital network for communications, there is little surprise that this is observed in the data. As expected, manufacturing demonstrates a significant contribution to output growth. The actual rate of productivity growth is remarkably high in both gas and electricity distribution (though like Germany, this sector is too small to account for much by way of output growth) and telecommunications.

Italy is unique in that it is one of the few countries where productivity growth in manufacturing plays a negative role in output growth. This is in part due to the fact that manufacturing in Italy actually contracted during the observation period, displaying virtually no change in real output between 1999 and 2005. FIRE is the only sector that experienced positive productivity growth and also generated the majority of output growth.

On an industry by industry basis productivity growth in Norway is consistently negative. However, output growth is being driven by a relatively even distribution across the 9 identified economic sectors. Combined, the service sectors account for the larges share of output growth, though manufacturing accounts for the single largest share. Norway is a bit of an outlier in that mining accounts for a much larger share of output growth than other countries in the sample. However, Norway's status as the eleventh largest exporter of petroleum (producing slightly less than the European Union as a whole) make this no surprise.

Finally, Sweden is consistent with the broad trend of the slowdown in productivity growth, and output growth is driven almost entirely by productivity increases in the manufacturing sector. Contributions from the FIRE and social services sectors are slight in comparison. This is perhaps the single result that is consistent with the prior of the productivity slowdown in the developed world being due to the increase in the economic output of a sector for which productivity growth is inherently slow, with the vast majority of output growth still being driven by productivity in the service sector.

As seen, the evidence on productivity growth is an intricate story, with dramatic variations both between and within countries. Generally, productivity growth is slowing in pace over the 11 year sample period, and displays vast differences between countries.

3.5.2 Aggregate productivity growth

The second result of the exercise is the comparison of estimates of aggregate total factor productivity using a standard least squares regression on aggregate variables, and the disaggregated method using the results obtained from robust estimation. The variation in productivity growth estimates suggest that bias in accounting may be significant.

To estimate total factor productivity from aggregate data, estimates are obtained from the linear regression

$$\ln \dot{Y}_{it} = \ln \dot{A}_{it} + \alpha \ln \dot{K}_{it} + \beta \ln \dot{L}_{it} \tag{3.16}$$

where (with an abuse of notation) $\dot{X}$ denotes the discrete time approximation of a rate of change, $\frac{X_t - X_{t-1}}{X_{t-1}}$. The regressors are constant price net capital stock and hours worked, both at the national level. Once the coefficient estimates are obtained, the estimate of total factor productivity growth can be calculated as

$$\ln \hat{\dot{A}}_{it} = \ln \dot{Y}_{it} - \ln \hat{\dot{Y}}_{it} \tag{3.17}$$

It is well recognized that this regression suffers from simultaneity, and therefore violates the assumptions necessary for linear estimation. However, when run on the full sample of data, the estimates for α and β are 0.34 and 0.68 respectively. This marks an insignificant departure from the standard assumed in the literature of $\alpha = 0.3$ and $\beta = 0.7$. These estimates of $\dot{A}$ along with the estimates of total factor productivity growth implied by 3.17 are shown against the growth rate of per capita GDP as given by the Penn World Tables. The Penn Tables report the growth rate of *per capita* gross domestic product, which is equivalent to *labor* productivity growth if a country is on a balanced growth path. The regression analysis carried out above calculates the growth rate of *total* factor productivity. The two are identified by the inverse of the coefficient on labor for a given regression, and the reported results are adjusted accordingly for comparison. A table of the results is located in Appendix D

The benefit of robust estimation relative to naive least squares using disaggregated data is generally quite evident. Compared to the simple least squares approach, the procedure carried out in this chapter provides estimates that are generally a closer approximation to the trends suggested by the Penn World Tables. Moreover, discrepancies on the order of 2% are not uncommon, suggesting that bias in the estimates is potentially very high.

An unfortunate by-product of the analysis is that the trend suggested by least squares using aggregate data is clearly the closest match to the Penn data. I can speculate that this may be due to the fact that drawing a comparison between the Penn data, which is real *per capita* income growth, and *productivity* growth requires that a country be on a balanced growth path, which is almost certainly not the case. Of course, measurement error likely plays a significant role in the results at hand, but whether it is sufficient to account for the estimated differences is unknown.

These results suggest considerable gains in correcting for the possible endogeneity of inputs in the regression framework outlined above. Some modifications might result in more robust approaches to the estimation. For example, it has been suggested that the error proxy term consist of a polynomial in multiple inputs, providing a more flexible means of conditioning the regression on the endogenous error component.

3.6. Conclusion

This chapter applies an alternative technique to the estimation of production functions with two purposes. The first is an exploration of the sector level rates of productivity growth in a sample of OECD countries. The information gleaned from this exercise reveals a remarkably heterogenous distribution of productivity across the different countries in the sample. While productivity growth tends to be concentrated in the manufacturing sector there are some notable exceptions, and evidence that the bulk of productivity growth is often disbursed across what are often termed 'service' sectors, though the patterns differ dramatically by country. This challenges the notion that the service sector is inherently a low-productivity growth sector, and emphasizes the need to measure productivity at disaggregated levels of output. The general lack of data for the majority of countries in the sample is an important reminder of the value of consistent data at the many levels of aggregation.

The second purpose is the compare estimates of productivity growth derived from the estimation performed in this chapter to both naive methods and some other estimates. With regard to this, this chapter performs at times well and at times demonstrates inconsistency with benchmark statistics. For a subset of the countries sampled the estimates are capable of matching a much higher degree of the variation in productivity estimates. For others it appears that naive least squares estimates perform better. These comparisons are presented with the caveat that comparing estimates of per capita income growth to factor productivity growth requires that the economy by on a *balanced* growth path, which casts some doubt on the validity of comparison.

Future research in the area calls for the inclusion of imported intermediate inputs in addition to domestic, and extension to the myriad frameworks capable of addressing productivity growth. These, in addition to the current paper have the potential to provide more rigorous insight and improved measurement to the important area of productivity analysis.

APPENDIX A

PRICE OF LAND

In equilibrium land is not traded, and cannot be produced. To determine the price of land I calculate the *shadow* price of land as follows: Suppose that households could accumulate land. The households utility maximization problem becomes

$$U_0 = \sum_{t=0}^{\infty} \beta^t N_t u(c_t, a_t) \tag{A.1}$$

subject to

$$N_t p_{c,t} c_t + N_t p_{a,t} a_t + p_{l,t}(L_{t+1} - L_t) \leq N_t w_t + r_{k_y,t} K_{y,t} + r_{k_a t} K_{a,t} + r_{l,t} L_t \tag{A.2}$$

Consider the households first order condition with respect to land:

$$\frac{\partial U_t}{\partial L_{t+1}} : -\beta^t \frac{p_{l,t}}{c_t p_{c,t}} + \beta^{t+1} \frac{r_{l,t+1} + p_{l,t+1}}{p_{c,t+1} c_{t+1}} = 0$$

This implies that the price of land in time period t is

$$p_{l,t} = p_{c,t} c_t \beta \frac{r_{l,t+1} + p_{l,t+1}}{p_{c,t+1} c_{t+1}}$$

which results in the forward solution

$$p_{l,t} = p_{c,t}c_t \sum_{i=1}^{\infty} \beta^i \frac{r_{l,t+i}}{p_{c,t+i}c_{t+i}} + \lim_{t\to\infty} \beta^t \frac{p_{l,t}}{p_{c,t}c_t}$$

Ruling out the possibility of bubbles in the price of land results in

$$p_{l,t} = p_{c,t}c_t \sum_{i=1}^{\infty} \beta^i \frac{r_{l,t+i}}{p_{c,t+i}c_{t+i}} \tag{A.3}$$

This equation can be interpreted as the present discounted value of the return from a unit of land relative to the value of consumption.

Noting that the return to a unit of land in time period t is $\frac{\phi\bar{a}N_t}{\bar{L}}$ and that the growth rate of consumption *per worker* is $(1+\gamma_b)$ along the balanced growth path, this reduces to

$$p_{l,t} = \frac{\phi\bar{a}N_t}{\bar{L}} \sum_{i=1}^{\infty} \left(\frac{\beta(1+\gamma_n)}{(1+\gamma_b)(1+\gamma_n)} \right)^i \tag{A.4}$$

or simply

$$p_{l,t} = N_t \left[\frac{\phi\bar{a}}{\bar{L}} \left(\frac{1+\gamma_b}{1+\gamma_b-\beta} \right) \right] \tag{A.5}$$

Intuitively, the price of land is proportional to the population. This follows as the amount of output that the agricultural sector must produce increases as the population grows. This results in larger factor payments to land, and thus an increase in its value as an asset.

However, because structural change implies that the economy is not on the balanced growth path, the above expression only applies when the economy has fully transitioned to the industrial economy, with a marginal share of employment and labor in the agricultural sector. In addition, because the shooting algorithm only generates the full equilibrium time path for all variables in the last time period, calculating A.5 prior to the end of the simulation is also incorrect. To solve this, the model is run initially for 1000 time periods, generating the equilibrium prices and quantities. Using this first run, agents calculate the price of land using equilibrium data. This ensures that agents are not using data 'off the equilibrium path' when forecasting the price of land. As expected, the time paths depart when the economy is undergoing structural change (initially) and as the simulation progresses because fewer future values of GDP are available. I then rerun the exercise for 250 periods, using the first 250 values for the price of land. This ensures that the margin of error is on the order of β^{750}, or $5.05e^{-14}$.

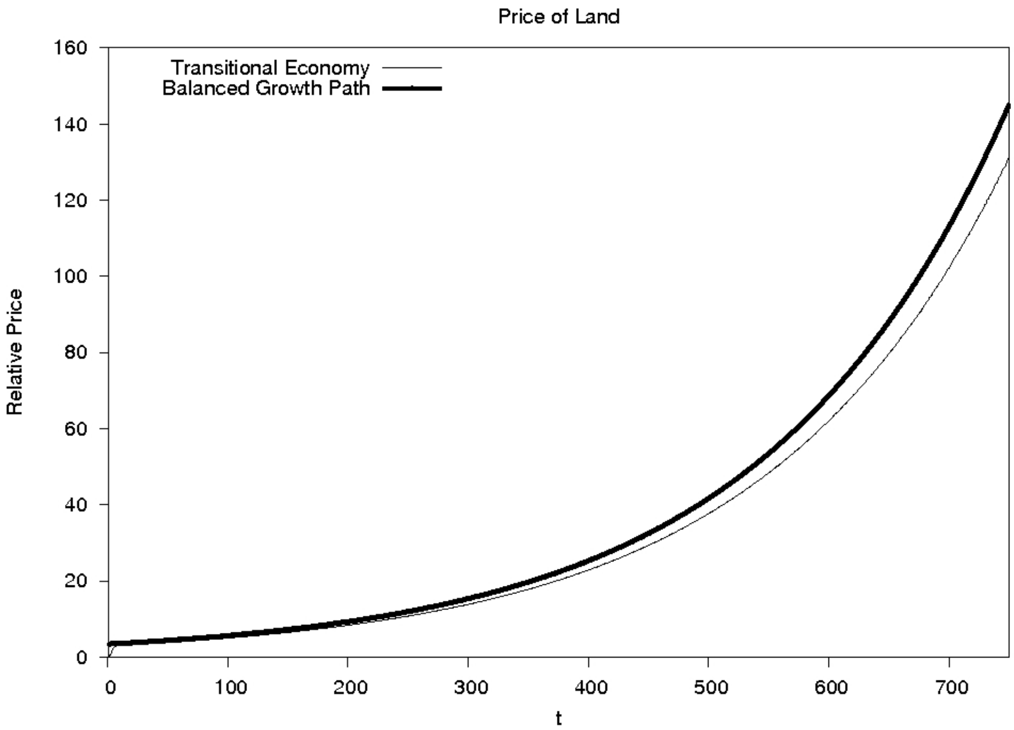


FIGURE 3. Price of Land

APPENDIX B

TIME PATHS

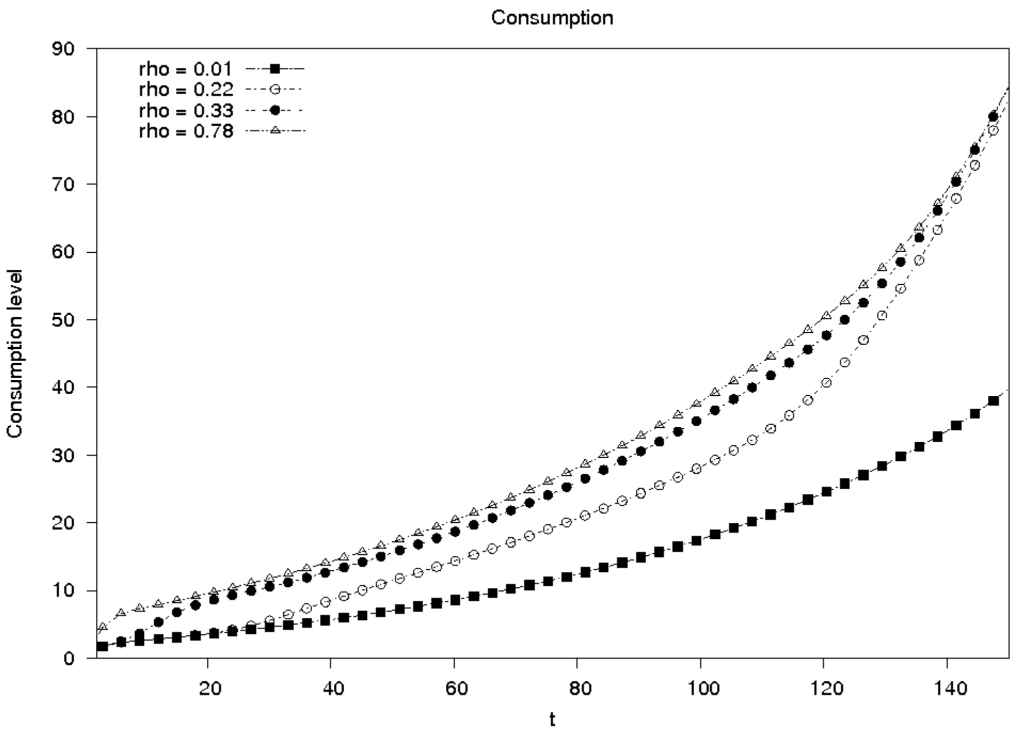


FIGURE 4. Consumption

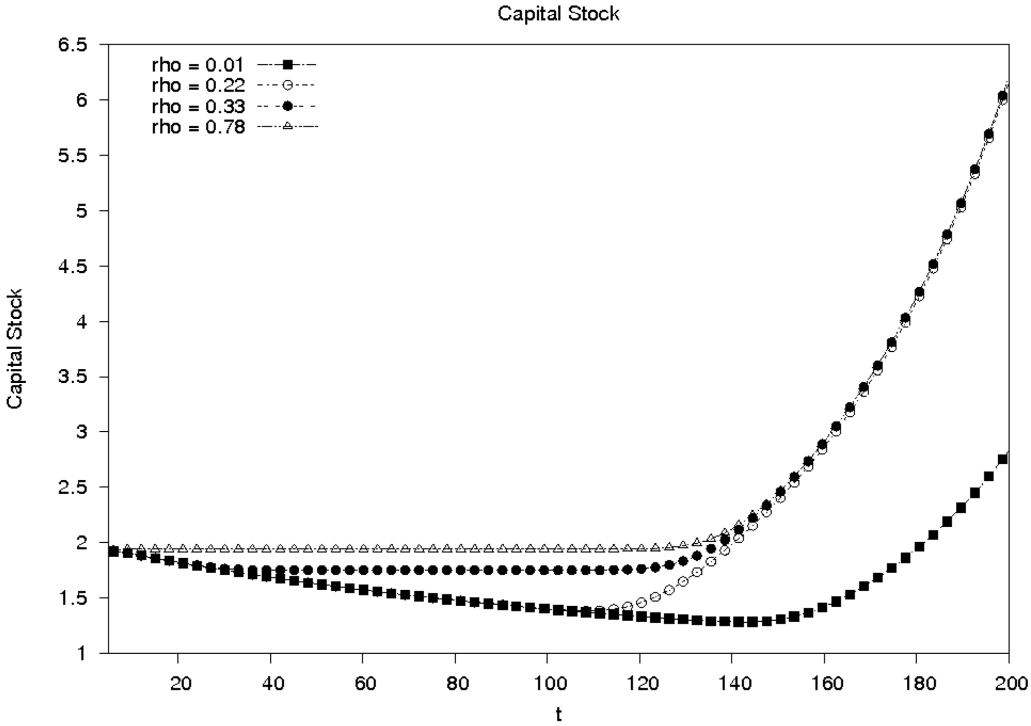


FIGURE 5. Aggregate capital stock

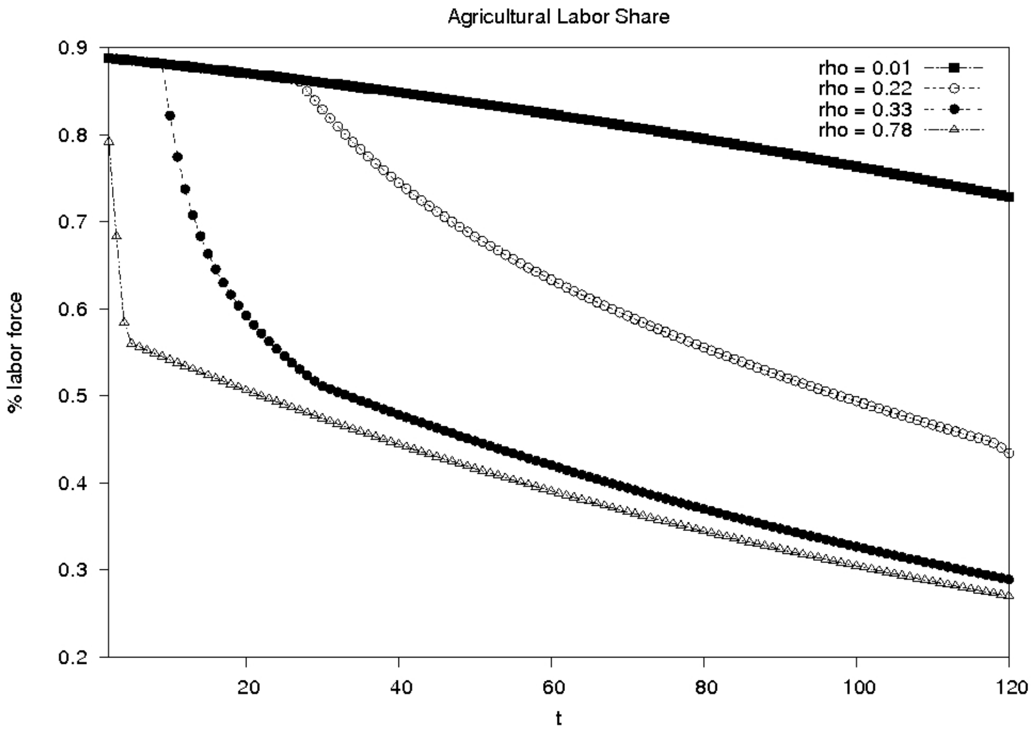


FIGURE 6. Agricultural share of labor force

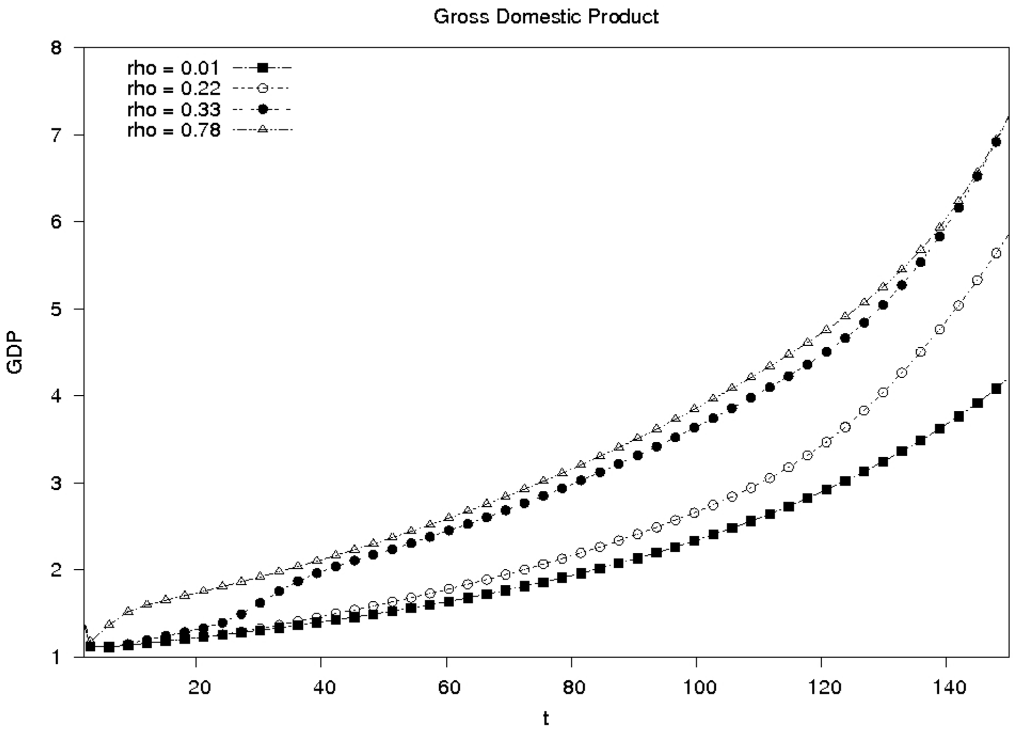


FIGURE 7. Gross Domestic Product

APPENDIX C

COUNTRY GROUPS

C.1. Low Income

Afghanistan, Albania, Bangladesh, Benin, Bolivia, Burundi, Cambodia, Cameroon,Ghana, Guyana, Haiti, Honduras, India, Kenya, Liberia, Kyrgyzstan, Malawi, Mali,Mauritania , Mongolia, Mozambique, Niger, Nepal, Pakistan, Philippines, Rwanda, Senegal, Sierra Leone, Sudan, Tajikistan, Togo, Uganda, Yemen, Zambia

C.2. Middle Income

Algeria, Argentina, Armenia, Belize, Brazil, Bulgaria, Colombia, Costa Rica, Croatia, Cuba, Ecuador, Egypt, El Salvador, Estonia, Fiji, Gabon, Guatemala, Indonesia, Iraq, Jamaica, Jordan, Kazakhstan, Latvia, Lithuania, Nicaragua, Mexico, Morocco, Panama, Paraguay, Peru, Poland, Romania, South Africa, Sri Lanka, Thailand, Tunisia, Turkey, Ukraine, Uruguay, Zimbabwe

C.3. High Income

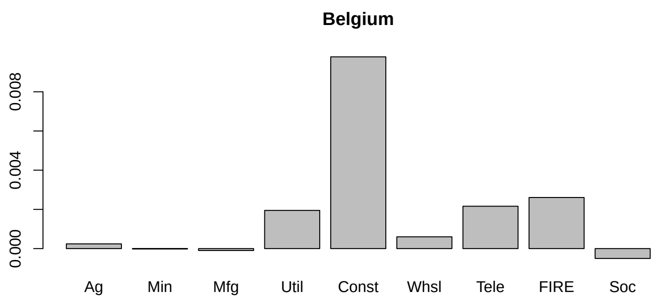
Australia, Austria, Bahrain, Barbados, Canada, Chile, Cyprus, Denmark, Finland, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Kuwait, Malaysia, Malta, Mauritius, Netherlands, New Zealand, Norway, Portugal, Qatar, Slovenia, Spain, Sweden, Taiwan, Saudi Arabia, Singapore, Venezuela

C.4. ISI

Mexico, Brazil, India, Argentina, South Korea, Pakistan

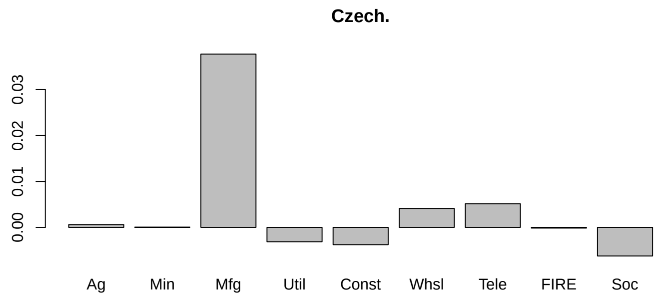
APPENDIX D

PRODUCTIVITY BY SECTOR



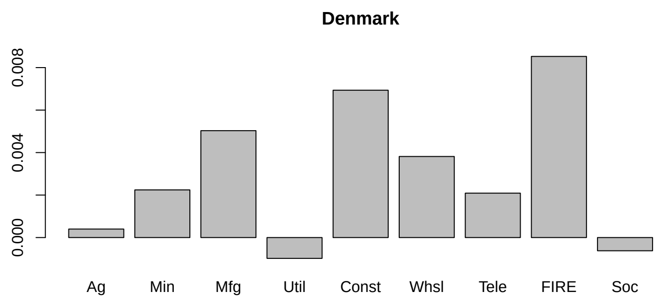
Sector	Coeff.
Agriculture	0.019
Mining	0.037
Manufacturing	-0.034
Gas/Elec	0.032
Construction	0.010
Wholesale	0.014
Transp./Tele.	0.016
FIRE	0.0035
Soc. Serv.	-0.006

TABLE 14. Belgium



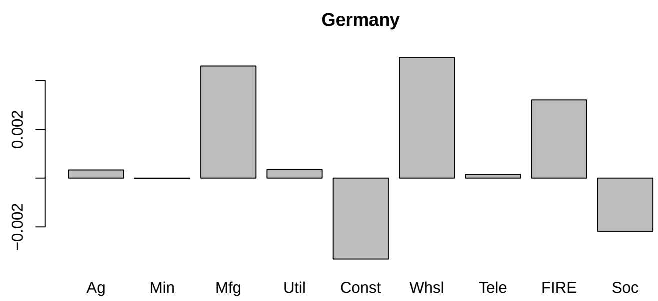
Sector	Coeff.
Agriculture	0.018
Mining	-0.018
Manufacturing	0.030
Gas/Elec	-0.003
Construction	-0.013
Wholesale	-0.004
Transp./Tele.	-0.012
FIRE	0.012
Soc. Serv.	0.000

TABLE 15. Czech Republic



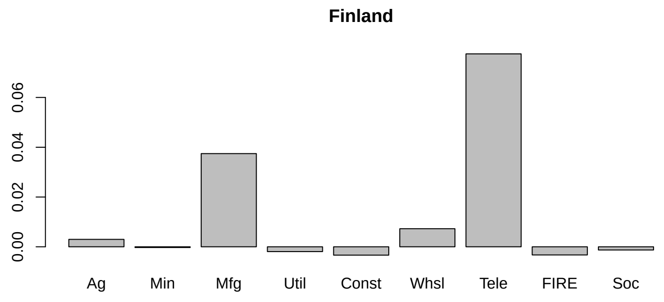
Sector	Coeff.
Agriculture	0.007
Mining	-0.015
Manufacturing	-0.004
Gas/Elec	0.010
Construction	-0.043
Wholesale	-0.000
Transp./Tele.	-0.010
FIRE	-0.002
Soc. Serv.	-0.004

TABLE 16. Denmark



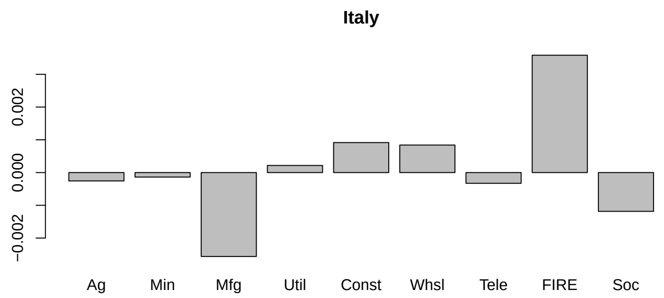
Sector	Coeff.
Agriculture	-0.001
Mining	0.015
Manufacturing	-0.005
Gas/Elec	0.010
Construction	-0.006
Wholesale	-0.008
Transp./Tele.	-0.001
FIRE	0.004
Soc. Serv.	0.002

TABLE 17. Germany



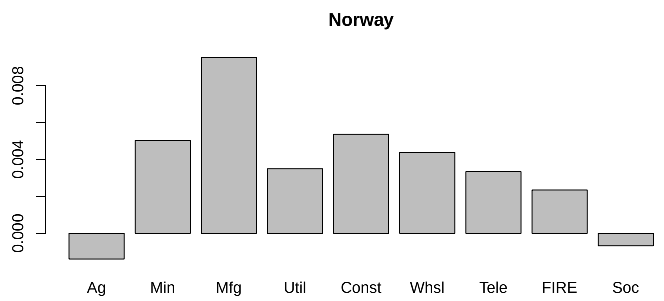
Sector	Coeff.
Agriculture	0.007
Mining	-0.003
Manufacturing	-0.015
Gas/Elec	0.054
Construction	-0.001
Wholesale	-0.005
Transp./Tele.	0.070
FIRE	-0.004
Soc. Serv.	-0.000

TABLE 18. Finland



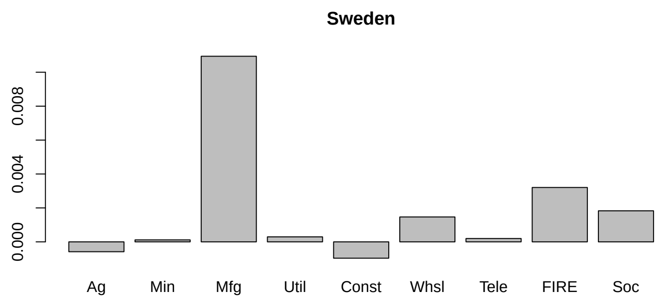
Sector	Coeff.
Agriculture	-0.001
Mining	-0.012
Manufacturing	-0.003
Gas/Elec	-0.012
Construction	0.003
Wholesale	-0.003
Transp./Tele.	-0.001
FIRE	0.001
Soc. Serv.	-0.002

TABLE 19. Italy



Sector	Coeff.
Agriculture	0.000
Mining	-0.000
Manufacturing	-0.005
Gas/Elec	-0.086
Construction	-0.004
Wholesale	-0.001
Transp./Tele.	-0.004
FIRE	-0.001
Soc. Serv.	-0.000

TABLE 20. Norway



Sector	Coeff.
Agriculture	-0.013
Mining	0.016
Manufacturing	-0.002
Gas/Elec	-0.000
Construction	-0.010
Wholesale	0.000
Transp./Tele.	-0.003
FIRE	-0.003
Soc. Serv.	-0.000

TABLE 21. Sweden

APPENDIX E

PRODUCTIVITY TRENDS

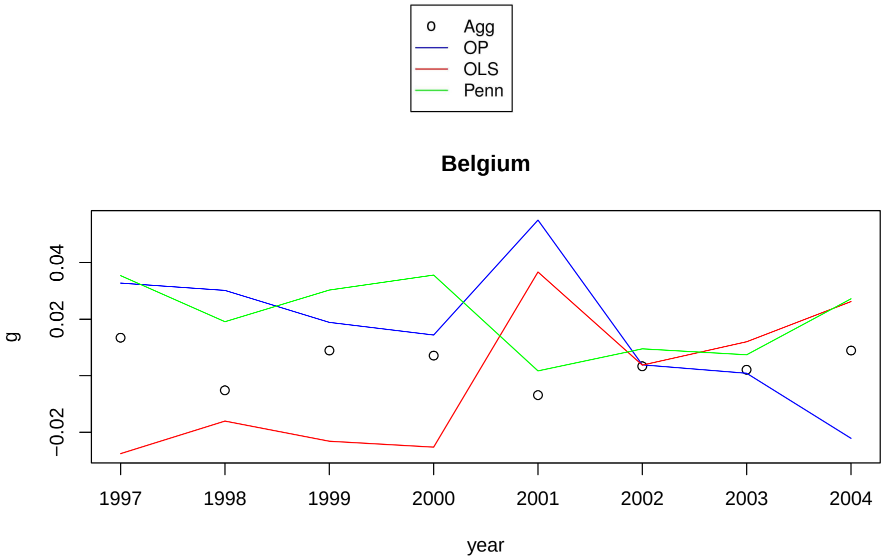


FIGURE 8. Belgium

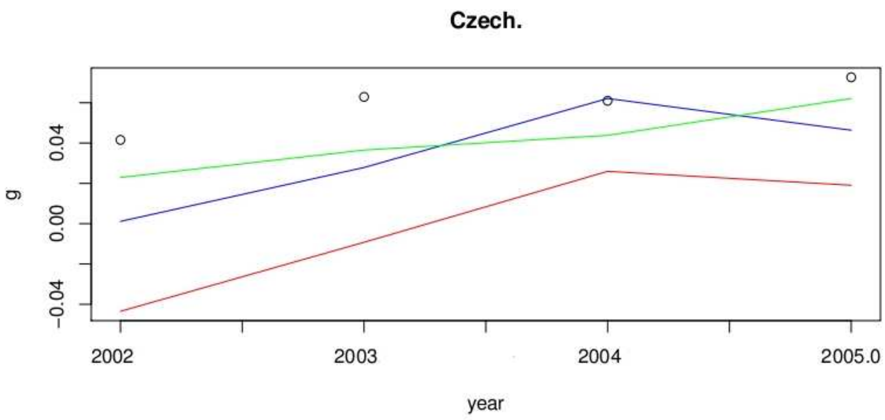


FIGURE 9. Czech Republic

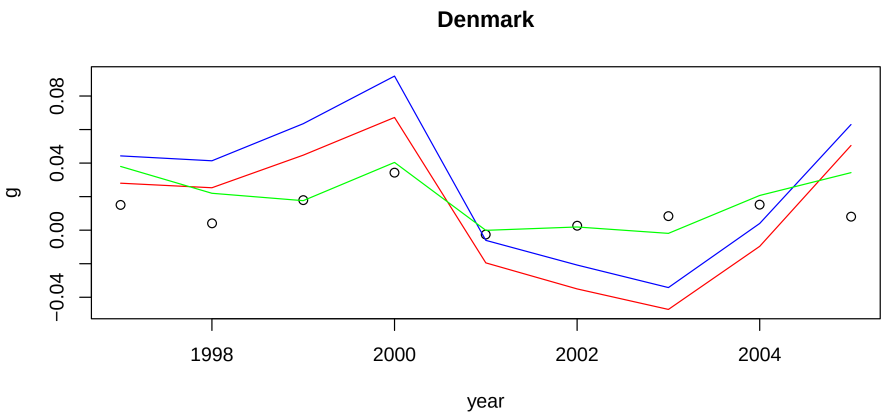


FIGURE 10. Denmark

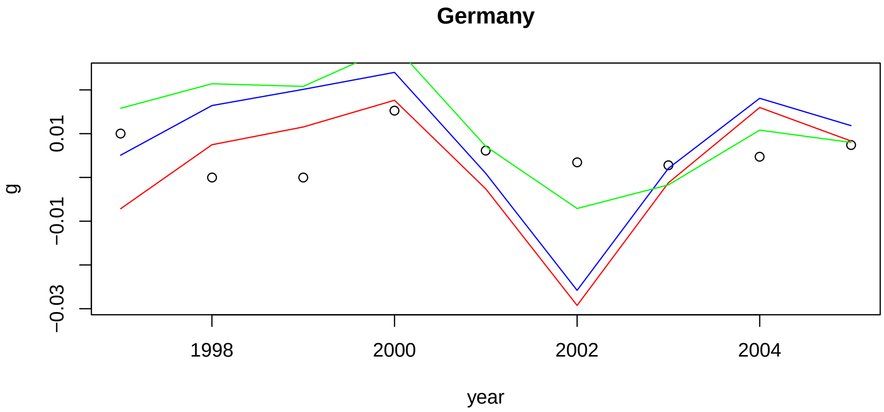


FIGURE 11. Germany

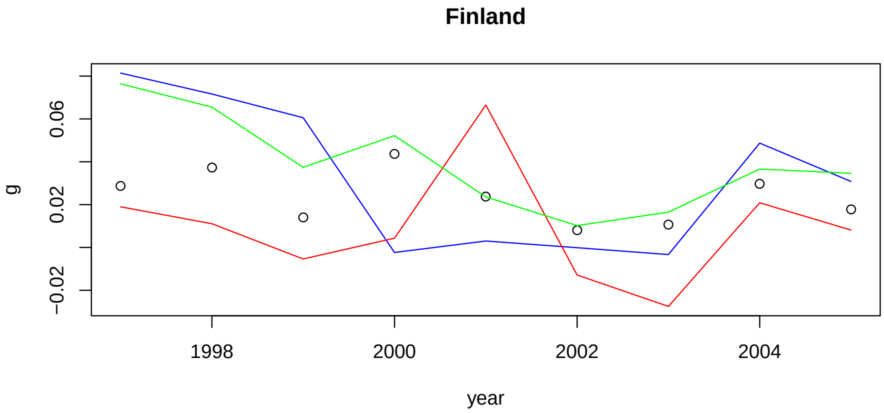


FIGURE 12. Finland

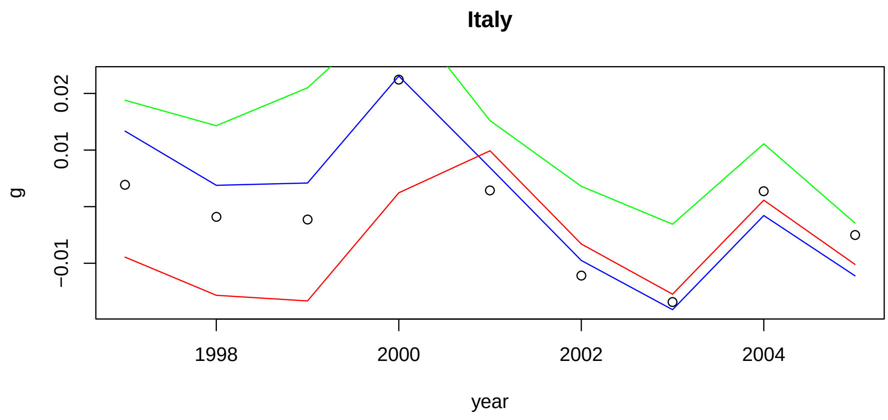


FIGURE 13. Italy

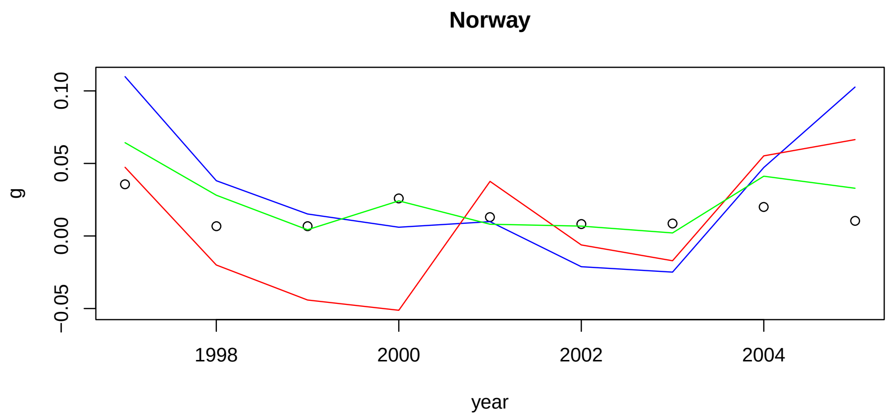


FIGURE 14. Norway

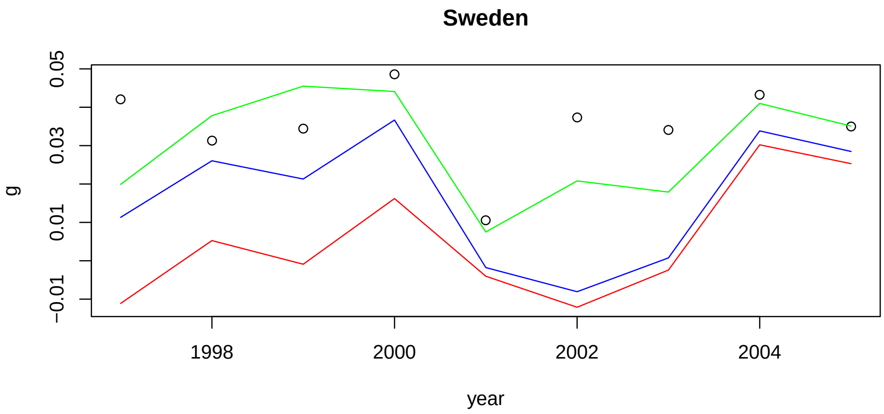


FIGURE 15. Sweden

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