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On Sources of Economic Growth and Comparative Advantage

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Abstract

This thesis considers sources of economic growth and comparative advantage. Parts I and II focus on basic research. They analyze the prospects of fostering technological progress, and hence growth, through policy-making in this area. Part III complements this analysis by examining the implications of a country's level of development for its competitiveness in international trade. These implications will feed back into the incentives to implement growth-oriented basic research policies. Our results follow.

Part I We identify potentialities for guiding policy in the area of basic research. We first provide an extended review of basic research and offer new insights on its linkages to key economic variables and economic growth. This guides us in identifying and discussing a series of emerging policy issues: (1) a country's openness as a key factor for optimal basic research investments, (2) the role of basic research in enabling a country to catch up with the world technological frontier, (3) the optimal mix of basic and applied research, (4) profound links between the manufacturing base and basic research, (5) limits on commercialization and patenting of basic research, and (6) the scope for targeting basic research.

Part II We examine the public provision and financing of basic research. Basic research is a public good that benefits innovating entrepreneurs, but its provision and financing also affect the entire economy – in particular, occupational choices of potential entrepreneurs, wages, dividends, and aggregate output. We show that the impact of basic research on the general economy rationalizes a taxation pecking order to finance basic research. More specifically, in a society with desirably dense entrepreneurial activity, a large share of funds for basic research should be financed by labor income taxation, while a minor share should be left to profit taxation. Such tax schemes will induce a significant proportion of agents to become entrepreneurs, thereby rationalizing substantial investments in basic research that fosters their innovation prospects. These entrepreneurial economies, however, may make a majority of workers worse off, giving rise to a conflict between efficiency and equality. We discuss ways of mitigating this conflict and thus strengthening the political support for growth policies.

Part III We analyze the interplay between product-intrinsic complexity and endogenously chosen product quality in international trade. Our work reveals a novel mechanism that can explain a rich set of empirical observations: (1) how specialization within products on quality can equalize comparative advantages across products, (2) why poor countries do not export a broad range of products nonetheless, and (3) why the share of products for which this is the case tends to be decreasing over time. Our theory motivates the use of a censored regression model to estimate the link between a country's GDP per capita and the quality of its exports. Following this empirical strategy, we find a much stronger relationship than when using OLS, in line with our theory.

Zusammenfassung

Die vorliegende Arbeit befasst sich mit Ursprüngen des Wachstums und der Wettbewerbsfähigkeit von Volkswirtschaften. Teile I und II legen ihren Fokus auf Grundlagenforschung. Sie untersuchen Möglichkeiten zur Förderung des technologischen Fortschritts, und somit des wirtschaftlichen Wachstums, mittels politischer Initiativen auf dem Gebiet der Grundlagenforschung. Teil III komplementiert diese Analysen, indem er untersucht, wie sich die Entwicklungsstufe eines Landes in seiner internationalen Wettbewerbsfähigkeit widerspiegelt. Die Auswirkungen auf die Wettbewerbsfähigkeit sind nicht zuletzt entscheidend für die Erfolgsaussichten einer Wachstumsförderung durch Grundlagenforschung. Im Folgenden werden die Ergebnisse der einzelnen Teile kurz zusammengefasst.

Teil I Wir ergründen Möglichkeiten der Politikberatung auf dem Gebiet der Grundlagenforschung. Wir beginnen mit einem systematischen Überblick über die Grundlagenforschung und ihre volkswirtschaftliche Bedeutung. Auf dieser Basis identifizieren und diskutieren wir wichtige politische Fragestellungen: (1) die optimalen Investitionen einer Volkswirtschaft in Grundlagenforschung in Abhängigkeit von ihrer Offenheit, (2) die Bedeutung der Grundlagenforschung für den Aufholprozess von Schwellenländern, (3) die optimale Verknüpfung von Grundlagenforschung mit angewandter Forschung, (4) der Zusammenhang zwischen Grundlagenforschung und der einheimischen Industrie, (5) Grenzen der Kommerzialisierung von Grundlagenforschung, (6) Möglichkeiten einer gezielten Ausrichtung von Grundlagenforschung auf einzelne Bereiche.

Teil II Wir analysieren die öffentliche Bereitstellung und Finanzierung von Grundlagenforschung. Grundlagenforschung ist ein öffentliches Gut, welches unmittelbar innovativen Unternehmern zugute kommt. Darüber hinausgehend hat die Bereitstellung und Finanzierung von Grundlagenforschung bedeutende Auswirkungen auf die gesamte Volkswirtschaft, insbesondere auf Unternehmertum, Löhne, Gewinne und den aggregierten Wohlstand. Wir zeigen, dass diese Auswirkungen eine hierarchische Steuerpolitik rechtfertigen. Wenn Unternehmertum aus gesamtgesellschaftlicher Sicht wünschenswert ist, dann sollte Grundlagenforschung – und die Staatsausgaben im Allgemeinen – zuvorderst über Steuern auf das Arbeitseinkommen und nur nachrangig über eine Besteuerung der Unternehmensgewinne finanziert werden. Diese Steuerpolitik fördert innovatives Unternehmertum zusätzlich und macht somit von seiner Komplementarität mit Grundlagenforschung Gebrauch. Derartige politische Massnahmen haben jedoch bedeutende Verteilungseffekte und sie können negative Auswirkungen auf eine Mehrzahl der Bevöl-

kerung haben. Wir diskutieren Möglichkeiten, diese Verteilungseffekte abzumildern und dadurch die politischen Erfolgsaussichten von Wachstumspolitik zu verbessern.

Teil III Wir analysieren das Zusammenspiel von Produktkomplexität und -qualität im Außenhandel. Wir argumentieren, dass die Komplexität den Produkten inhärent ist, während Unternehmen die Qualität ihrer Produkte selbst bestimmen können, in Abhängigkeit von der Wettbewerbsfähigkeit der Länder, in denen sie produzieren. Unsere Arbeit zeigt einen Mechanismus auf, der bislang in der Literatur unbeachtet blieb. Er kann wichtige empirische Befunde erklären: (1) wie Spezialisierung innerhalb von Produktkategorien auf Qualität komparative Vorteile ausgleichen kann, (2) weshalb dennoch Entwicklungsländer für viele Produkte nicht wettbewerbsfähig sind, (3) weshalb der Anteil der Produkte, für die das gilt, über die Zeit abnimmt. Unsere theoretischen Analysen führen zu einem Censored Regression Modell zur Schätzung des Zusammenhangs zwischen dem Pro-Kopf-Einkommen einer Volkswirtschaft und der Qualität ihrer Exporte. Das hier vorgeschlagene Schätzverfahren deutet auf einen weitaus stärkeren Zusammenhang als bisher auf Basis eines linearen Regressionsmodells angenommen. Diese Beobachtung ist im Einklang mit unserem theoretischen Modell.

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Introduction

Over the past 200 years, the world has seen unprecedented growth in standards of living, most remarkably reflected in the doubling of life expectancy and the tenfold increase in GDP per capita, on average.[1] The associated '*consequences for human welfare [...] are simply staggering*'[2], and we inevitably ask ourselves: Will it be possible to sustain such high growth in the future, and if so, what are appropriate policies to bring about such growth?

Technological progress has been a key driving force behind this development. We simply could not imagine the world as it is today without anesthesia, electricity, the green revolution, or semiconductor electronics. Improved technologies enable the production of more and higher quality output using the same inputs, and lead to the development of new products. We conjecture that future growth will be intimately linked to the further advancement of technology, at least from the perspective of industrialized countries. In Parts I and II of this thesis, we analyze the prospects of fostering such advancements through basic research policies.

Basic research aims at the advancement of knowledge without a particular application in view. New knowledge widens the scope for technological progress through applied research. For example, the green revolution is based on Nitrogen fixation and on Mendelian inheritance, the Global Positioning System (GPS) accounts for important relativity effects, and molecular medicine as well as potential gene therapies yet to be developed are rooted in the discovery of the DNA.[3] Hence innovation is grounded in past basic research, and basic research policies today will have profound consequences for the growth prospects far in the future.

Policy-making in the area of basic research is an intricate task as the corresponding effects on the overall economy are manifold and the individual effects often remain obscure. Moreover, governments cannot rely on market forces alone as basic research exhibits im-

[1] Cf. Riley (2001) and Bolt and van Zanden (2013).
[2] Lucas Jr. (1988, p. 5)
[3] These scientific discoveries in turn also benefited from prior research. Cf. Pray (2008) for a discussion of the discovery of the DNA structure, for example.

portant characteristics of a public good.[4] The ambition of Parts I and II of this thesis is to support the design of policies concerning basic research. In Part I, we start from the characterization of basic research and its impacts on the economy. We then identify and discuss a series of important basic research policy issues and highlight promising avenues for future economic research. In Part II, we put one specific policy issue under deep scrutiny: the role of basic research and tax policies in stimulating innovative entrepreneurship. We identify growth-oriented policies and discuss their distributional effects. Since the early 1980's, the Western world is faced with a decline in labor income shares, in particular of low-skill labor. It is of utmost importance to address these distributional effects, for reasons of justice, but also as they may undermine the political support for growth policies. Our work suggests that it may be possible to reconcile efficiency and equality, if the tax system allows for sufficient redistribution of the gains from innovation.

Basic research policies are often determined at the national level, and, hence, domestic effects are of particular interest. To account for these effects, it is important to understand the prospects of fostering domestic technological capabilities through basic research policies. However, as the world becomes more integrated, it is increasingly important to also understand how a country's technological capability translates into its ability to sustain a higher standard of living when faced with competition from the rest of the world.[5] The basic implication of the competitive fringe is straightforward. It was vividly summarized by Köhler (2005), the former President of the Federal Republic of Germany, at the peak of the debates on Germany being the '*Sick Man of Europe*'.[6] He claimed that in order to succeed on the world market, Germany would need to be '*as much better as it is more expensive*'.[7] Notwithstanding its intuitive appeal, this argument has not yet been fully developed theoretically. The objective of Part III is to take a further step in this direction.

In our model countries with a higher technological capability compete by producing higher quality versions of the same products. It is this quality differentiation that allows industrialized countries to sustain a high standard of living in the face of competition from low-cost countries. What is more, a higher technological capability enables a country to successfully compete for a broader range of products – including more complex products. The intuitive reason is that products such as nuclear reactors and high-tech machines are simply too difficult to produce in countries with low technological capabilities, even in their most basic, low-quality version.

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[4] Indeed, governments are strongly involved in funding and provision of basic research (cf. chapter 1).

[5] Today, the world share in GDP of exports in goods and services is around 30%, two and a half times as large as it used to be 50 years ago. *Source*: Own calculation based on World Bank (2013).

[6] Cf. http://www.economist.com/node/3352024 (retrieved on 20 February 2014).

[7] Own translation. The original quote is: '*Wir müssen um so viel besser sein, wie wir teurer sind*'.

In developing these arguments, we take a country's technological capability as given. With a view on our discussions in Parts I and II, it is interesting to assess how the benefits from a higher technological capability feed back into the incentives to invest in the built-up of such capabilities in the first place, e.g. via basic research. In concluding the dissertation, we touch upon some potential implications. We conjecture that countries at the technological frontier might have strong incentives to invest in strengthening their technological capabilities even further. On the contrary, the return to such investments may be low or even zero for countries with low technological capabilities, possibly giving rise to poverty traps. A comprehensive analysis of these issues is left for future research.

In the following, we provide a more detailed description of each part of the thesis.

Part I

Basic research policies are on the agenda of policy-makers in many parts of the world. In Part I, we seek to contribute to better informed policy decisions in future. We start in chapter 1 with a structured overview of the key characteristics of basic research and its links to the overall economy.[8] We outline the importance of basic research, both as a factor accounting for a non-trivial share of aggregate expenditures and as a key stimulus for growth and innovation. We argue that there is a strong case for both public funding and public provision of basic research.

On this basis, we identify and discuss six emerging policy issues in chapter 2:

- How do a country's openness and its distance to the world technological frontier affect its optimal level of basic research?
- What is the optimal mix between basic and applied research? What are the means to stimulate the latter?
- How do the manufacturing base and basic research reinforce each other?
- To what extent is upstream patenting of university research desirable?
- What are the effects of stronger incentives to commercialize public research?
- Should basic research be targeted – on sectors, disciplines, or technologies, for example?

For each of these issues, we present a review of the related theoretical and empirical literature. This adds up to a comprehensive overview of the current state of affairs. We combine this overview with ongoing policy debates and innovative perspectives on the

[8] This chapter incorporates findings of earlier research in this area at ETH Zurich. See e.g. Amon (2011) and Schneller (2011).

data. This provides us with new insights and allows us to identify fruitful avenues for future economic research.[9]

Part II

In Part II, we analyze how basic research and tax policies affect innovative entrepreneurship – and thus economic growth. Non-trivial interdependencies have to be considered. In particular, basic research is embryonic in nature and only impacts indirectly on the economy via applied research and commercialization. Hence innovative entrepreneurs are the main beneficiaries from basic research. At the same time, they are needed for these investments to become effective. Taxation not only provides the funds for basic research, it also impacts on the households' decision whether or not to become an entrepreneur.

We address these interdependencies in a general equilibrium framework. We show that the complementarity between basic research and entrepreneurship rationalizes a taxation pecking order. In particular, if basic research investments are large enough, entrepreneurship is socially desirable, and these public investments should be backed up by tax policies that further promote entrepreneurship, that is, by high labor income taxes and low profit taxes. This stimulus for entrepreneurship, in turn, increases the benefits from public investments in basic research.

However, such growth-oriented policies may harm workers, in particular if innovation is labor saving. In such circumstances, a conflict between efficiency and equality may arise. We address its bearing on the political viability of growth policies in a median-voter framework. We show that in societies with unequal distribution of shareholdings, the median voter may reject growth-oriented policies. Even if she supports some growth-oriented policies, she tends to invest too little in basic research, thus providing a rationale for the high rates of return to public investments in basic research that are typically observed in empirical studies. Interestingly, these inefficiencies are mitigated as upper bounds on taxation increase. With flexible tax bounds, tax incentives to entrepreneurs (efficiency) and redistribution of gains from innovation (equality) can be better aligned. Hence our work reveals potentially harmful effects from constitutional tax bounds. Such bounds may also harm firm-owners, the share of the population that they are often meant to protect.

The main part of the analysis is outlined in chapter 3.[10] We provide extensions and supplementary results in chapter 4.

[9] This part is based on joint research with Hans Gersbach.
[10] This chapter is based on a joint paper with Hans Gersbach and Maik Schneider.

Part III

Finally, we shift focus in Part III. While Parts I and II seek to provide guidance on how to best stimulate technological progress and growth, Part III takes the technological capability of countries as given, and asks how it translates into comparative advantages in international trade. We introduce a novel mechanism: the interplay of product-intrinsic complexity with endogenously chosen product quality. We show that this mechanism yields an upper triangular structure of specialization of countries on products, i.e. it can explain why industrialized countries are successfully exporting most of the products, while many developing countries are competitive for only a few, simple products.

The basic intuition is straightforward. Countries with high standards of living can compete for even the simplest products by producing high-quality versions of these products, allowing these countries to be 'as much better as they are more expensive'. While you can buy an analog watch for less than a Euro on the Internet, many Swiss watches are sold at a price of several thousand Euros, for instance. By contrast, developing countries cannot always compete by producing low-quality, low-cost versions of a product due to minimum-quality requirements. Even the most basic watch needs to measure time accurately. Such minimum-quality requirements can either be product intrinsic or be introduced by law. The crucial observation is that for complex products it is more difficult to comply with such requirements. Producing a functional air bed is certainly less of a challenge than producing an autopilot that can safely navigate you through the traffic snarl of Moscow. Hence these minimum quality requirements prevent developing countries from competing successfully for complex products.

This rationale has important consequences for empirical strategies to estimate the link between a country's GDP per capita and the quality of its exports. In particular, it motivates the use of a censored regression model. Following this empirical strategy, we find a much stronger link than when using OLS.

These insights are derived and outlined in chapter 5. In chapter 6, we corroborate our findings by showing that they also prevail in a variant of our theoretical set-up that incorporates trade in a homogeneous intermediate good. Here, we also touch upon a potential feedback from the derived pattern of international specialization on the incentives to invest in the built-up of technological capabilities. We suggest that there might be large gains from further strengthening the technological capabilities of countries already at the technological frontier. On the contrary, there might be poverty traps at the lower end of economic development, where the returns to investing in technological capabilities are low or even zero.

Part I.

Basic Research and Growth Policy: Update and Emerging Issues

1. Basic Research: Key Characteristics and Economic Concepts*

'Currently, we do not have the robust and reliable methodological tools needed to state with any certainty what the benefits of additional public support for science might be, other than suggesting that some support is necessary to ensure that there is a 'critical mass' of research activities.'

Salter and Martin (2001, p. 529)

1.1. Introduction

Motivation

The fact that it is very difficult to measure the social benefits of basic research is a serious obstacle to policy-making in this area.[1] Yet a thorough understanding of basic research and how it can affect the overall economy opens up potentialities for guiding policy. In particular, it can help to focus policy-makers on critical decisions and big-push experiments in the area of basic research. The identification of such potentialities is the aim of Part I of the thesis.

Informed basic research policy-making is highly relevant. In the course of the first two decades of the 21st century, governments all over the world have been, and still are, implementing major reforms in the area of basic research. South Korea and Singapore have

* This chapter is based on joint research with Hans Gersbach.

[1] In 2001 Salter and Martin presented a detailed review of the literature assessing the benefits of publicly funded basic research. They concluded that although the social benefits of such policies remain unclear, public support for basic research is needed. This view is also taken by Stephan (2012).

stepped up their basic research investments considerably, more than doubling their expenditures as a percentage of GDP from 2000 to 2009.[2] The European Council aims to increase total (public and private) R&D spending in the European Union to 3% of GDP by 2020.[3] With the ambition of increasing its pool of scientists with state-of-the-art training, Brazil has initiated a program to support scientists going abroad.[4] After having initiated big-push investments in basic research at the beginning of the 21st century, Ireland has installed a Research Prioritisation Steering Group to identify targets for future investments.[5] In 2013, Canada announced that it would be directing its National Research Council toward more applied research and transforming it into a *'business-driven, industry-relevant research and technology organization'*.[6] At a more general level, many developed economies aim at reindustrialization as a means of guaranteeing future economic growth and prosperity.[7] Emerging economies search for strategies to get them closer to the world technological frontier. As basic research provides the requisite knowledge base and helps to spur private innovation, it can – indeed must – play an important role in such endeavors.

We pursue an integrative approach, considering various facets of basic research and basic research policies. In particular, we first provide a structured overview of the key characteristics of basic research and its links to the economy. This overview then fuels the identification of a series of emerging policy issues. For each of the different policy issues addressed we provide an expanded review of the related theoretical and empirical literature. This adds up to a comprehensive overview of the current state of affairs. We combine these insights with new data and perspectives to study the relationship between basic research and key economic variables as well as measures of the knowledge base. This enables us to identify specific areas where the existing economic literature could and should be supplemented by further studies. The integrative approach proposed here can thus not only change the way we think about basic research and growth but also help identify opportunities for guiding policy in the area of basic research.

Basic research policy issues

We identify and discuss six emerging basic research policy issues. Some of these issues relate directly to the previously mentioned policy reforms and their implementation. Oth-

[2] *Source*: Own calculations, based on OECD (2012a). The data was downloaded in June 2013.
[3] Cf. General Secretariat of the European Council (2010).
[4] Cf. Brazilian Secretariat for Social Communication (2011).
[5] Cf. Research Prioritisation Project Steering Group, Ireland (2012).
[6] Goodyear (2013).
[7] Cf. Obama (2013) and European Commission (2012b), for example.

ers may broaden the scope for policy-making in the future. In either case, an in-depth understanding of these issues implies potential for guiding policy-makers in the future and focusing their attention on critical decisions in this area. We summarize the policy issues in the following questions:

– What determines the optimal level of basic research investment? We focus on two specific determinants:
  - How does a country's openness affect the socially optimal amount of basic research?
  - How do optimal basic research investments depend on the current distance of a country from the world technological frontier? Can large basic research investments help narrow the distance rapidly?

– What is the optimal mix between basic and applied research? How can applied research be stimulated most effectively?

– How do the manufacturing base and basic research reinforce each other? How is basic research related to technological capabilities?

– To what extent is the upstream patenting of university research desirable?

– What are the effects of stronger incentives to commercialize public (basic) research?

– Should basic research be targeted or concentrated (on sectors, disciplines, or technologies) and if so, how much? What procedures should be used to decide on the level of funding and the allocation of the funds for basic research?

Foundations and organization of Part I

To address these issues, we need a thorough understanding of basic research and of the reasons why governments play the central role in its funding and provision. Accordingly, in chapter 1 – before we address each of the six policy issues in turn – we define basic research, discuss its key characteristics (section 1.2), and highlight its importance in terms of resources employed, funding modes, and aligned benefits (section 1.3). This yields different possible conceptualizations of basic research reflected in different assumptions made in theoretical models (section 1.4). We conclude this chapter with the rationales for both public funding and public provision of basic research (section 1.5).

After having laid out these foundations in the first chapter, we address the six policy issues previously referred to in chapter 2. Section 2.8 of chapter 2 concludes.

1.2. Definition of basic research – key characteristics

The OECD (2002b, p. 30) classifies research and development (R&D) activities under three main categories: basic research, applied research, and experimental development. It defines basic research as '*experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.*'[8] According to this definition, basic research in general does not provide (commercializable) solutions for specific practical problems, but rather provides the knowledge base needed to tackle these problems.

Here we are mainly interested in basic research policies and their implications for innovation and economic growth. We therefore follow the most of the economic literature on basic research in subsuming experimental development under applied research.[9] Unlike basic research, applied research sets out to *'[...] provide [...] complete answers'* to important practical problems (Bush, 1945, p. 13), thus directly contributing to the development and improvement of specific production technologies or products.

In line with the definitions above, the following key characteristics are typically attributed to basic research:[10]

Embryonic	Basic research outcomes are embryonic in the sense that they are early-stage inventions with little or no commercial use in view.
Cumulative	Basic research builds on and further develops the insights provided by prior (basic) research.
Time lags	The generation of new knowledge within the sphere of basic research and its reflection in new and refined products or processes involve major time lags.
Uncertainty	Basic research outcomes are highly uncertain.

[8] Note, however, that this is not the case with basic research in the so-called *Pasteur's Quadrant* (cf., for example, Nelson, 2004). *Pasteur's Quadrant* is a term introduced by Stokes (1997) to characterize basic research with immediate commercial use in view.

[9] This main classification goes back to Bush (1945), at least. Cf. Akcigit et al. (2013), Cozzi and Galli (2009), and Gersbach et al. (2013) for recent examples of economic literature classifying research into basic research and applied research.

[10] Cf. Amon (2011) for a discussion of these characteristics.

Hierarchy Basic and applied research typically have a hierarchical order, with the former preparing the ground for the latter.

Two-way spillovers Not only does applied research benefit from basic research, applied research also stimulates basic research. Thus basic and applied research spur each other on.

1.3. Significance of basic research

To further motivate our careful scrutiny of basic research, we begin our analysis with a brief survey of the data and literature on the significance of basic research. We first consider the *input* side, briefly summarizing the key patterns of basic research investment found in the data. We then turn to the *output* associated with these investments. Basic research is viewed as a major driving force for innovation and hence for economic growth. We briefly discuss the various channels through which basic research impacts the economy, along with the literature that assesses the benefits accruing from it.[11]

1.3.1. Investments into basic research

A quick glance at research and development investment immediately reveals that R&D is not only important because of its potential benefits but also as a factor accounting for a non-trivial share of aggregate expenditures. On a global scale, USD 1.4 trillion annually is plowed into R&D at present (Economist, 2013a). These investments are not distributed evenly across countries. In 2008, 25% of global R&D investments were undertaken by the US, the world's largest individual investor in R&D, and another 10% by Japan, the second-largest investor. Yet these shares are slowly falling over time, indicating that R&D investments are increasingly spread across the world.[12]

For a better comparison of (basic) research investments across countries, Table 1.1 outlines R&D expenditures as a percentage of GDP along with the share of these funds channeled into basic research for a selection of OECD countries plus Singapore, China,

[11] Basic research has beneficial effects beyond those typically reflected in measurable economic aggregates. As an example, innovations in healthcare or clean-tech may have extensive positive effects on the well-being of citizens in general that are hard to quantify. Similarly, answers to fundamental questions about humankind, the earth, or nature, as well as advances in the humanities may provide intangible satisfaction. In principle, conceptual work on basic research, as reported in section 1.4.2, may also reflect these broader benefits.

[12] Shares are based on investments in PPP. *Source*: Own calculations, based on World Bank (2013). The data was downloaded in June 2013.

Table 1.1.: R&D expenditures of countries[a]

	Gross domestic expenditures on R&D as a percentage of GDP		Basic research expenditures as a percentage of total R&D expenditures		Applied research expenditures as a percentage of total R&D expenditures[b]	
	2000	2009	2000	2009	2000	2009
Argentina	0.44	0.60	27.75	29.80	72.25	70.20
Australia	1.47	2.26[c]	25.81	20.07[c]	74.19	79.93[c]
China	0.90	1.70	5.22	4.66	94.78	95.34
Czech Republic	1.17	1.47	23.34	27.10	76.66	72.90
France	2.15	2.27	23.60	26.08	76.40	73.92
Hungary	0.81	1.17	24.24	20.62	75.76	79.38
Ireland	1.10[d]	1.76	15.84[d]	22.90	84.16[d]	77.10
Israel	4.29	4.49	17.16	13.70	82.84	86.30
Japan	3.00	3.36	12.38	12.46	87.62	87.54
Korea	2.30	3.56	12.61	18.06	87.39	81.94
Portugal	0.73	1.64	22.85	18.93	77.15	81.07
Singapore	1.85	2.24	11.75	20.28	88.25	79.72
Slovak Republic	0.65	0.48	22.77	40.80	77.23	59.20
South Africa	0.73[e]	0.87	27.75[e]	23.26	72.25[e]	76.74
Switzerland	2.47	2.87[c]	27.96	26.78[c]	72.04	73.22[c]
United States	2.71	2.91	15.95	18.75	84.05	81.25
Average	1.67	2.10	19.81	21.52	80.19	78.48

[a] *Source*: Own calculations, based on OECD (2012a). The data was downloaded in June 2013. This table is a slightly updated version of the table presented in Gersbach et al. (2013).
[b] The OECD categorizes R&D into 'basic research', 'applied research', 'experimental development' and 'not elsewhere classified'. We summarize the last three items under 'applied research'.
[c] Data from 2008.
[d] Data from 2002.
[e] Data from 2001.

one African country (South Africa), and one Latin American country (Argentina), for which the OECD reports data.[13] This comparison reveals that both the United States and Japan are also among the countries with the highest R&D investments relative to GDP. In addition, three main patterns are observable from Table 1.1: First, industrialized countries tend to spend a higher share of their GDP on R&D than emerging countries. Second, the share of aggregate income channeled into R&D tends to increase over time.[14] Third, roughly one fifth of total R&D expenditures are spent on basic research. As the share of basic research in total R&D is slightly increasing on average, the share of GDP spent on basic research has increased over time.[15]

[13] As pointed out by Dougherty et al. (2007), R&D expenditures over GDP provide a measure for a society's burden of investing in R&D. R&D-specific purchasing power parities are useful in comparing effective R&D investments across different countries. There is little such data available. Throughout Part I we

There is little data available on the funding of basic research. Gersbach et al. (2013) analyze data from the OECD Main Science and Technology Indicators to find that for a selection of 15 countries, the average share of basic research performed in the government and higher education sector was more than 75% in 2009. Gersbach et al. (2014) point out that the OECD Main Science and Technology Indicators reveal that around 80% of the total research performed in these 'public' sectors is also funded by the government.[16] Together, these findings suggest that a major share of basic research investments is publicly funded.

This suggestive evidence is broadly in line with the patterns observed directly from US data. Table 1.2 shows basic research expenditures by sector of performance and by source of funds for 2009. According to this table, around $2/3$ of total US basic research is performed either by the federal government or by universities and colleges. The same holds true with regard to the funding of basic research, whereas only around $1/5$ is funded by the business sector.[17] Furthermore, by far the main part of basic research performed by either the federal government or by universities and colleges is also funded by these two sectors, thus supporting the line of reasoning applied above to the OECD data for a broader range of countries. The National Science Board (2012, Table 4-3) also shows that, as opposed to basic research, applied research and development are mainly performed in the business sector (roughly 82%) and also funded by it (roughly 70%).

thus refer to R&D expenditures over GDP as a measure of the R&D intensity of different countries.

[14] Note that for the selection of countries considered in Table 1.1, all countries except the Slovak Republic increased their R&D spending as a percentage of GDP from 2000 to 2009. A similar pattern is observable over a longer time horizon and/or a broader selection of countries. Most of the 41 countries included in the OECD Main Science and Technology Indicators increased the share of their GDP spent on R&D over the time-span for which there is data available. The only exceptions are Luxembourg, which basically kept its R&D investment intensity constant, the UK, and a selection of former member states of the Warsaw Pact, including Russia.

[15] For the selection of 35 countries for which the OECD Main Science and Technology Indicators report data on basic research expenditures as a percentage of GDP, only Chile, Germany, Israel, The Netherlands, New Zealand, Slovenia, South Africa, Sweden, and Switzerland (slightly) decreased the share of their GDP spent on basic research over the maximal time-span for which there is data available. For most of these countries, this maximal time-span for data on basic research is relatively short. If we limit our attention to countries for which there is data available from the 1980s to today, then the tendency becomes more pronounced: All of these 12 countries, including the US and Japan, increased the share of their GDP spent on basic research substantially over the period considered, with the relative increase ranging from 27% in the case of Russia to as much as 536% in the case of Portugal, albeit starting from a low level.

[16] Gersbach et al. (2014) is included in this thesis as chapter 3.

[17] US-based evidence may be considered conservative in the sense that US basic research tends to be less public in international comparison (Cozzi and Galli, 2009). Note, however, that some US universities and colleges are in part privately funded.

Table 1.2.: US basic research expenditures by performing sector and source of funds[a]

Performing sector	Source of funds ($millions, 2009) Total	Business	Federal govern-ment	Universities & colleges	Other non-profit	% of total BR performed
Total	75,970	16,486	40,451	10,800	8,233	100
Business	14,784	13,444	1,340	-[b]	-[b]	19.5[c]
Federal government	11,373	-[b]	11,373	-[b]	-[b]	15.0[c]
Universities & colleges	40,544	2,344	24,242	10,800	3,158	53.4[c]
Other non-profit	9,269	698	3,496	-[b]	5,075	12.2[c]
% of total BR funded	100	21.7[c]	53.2[c]	14.2[c]	10.8[c]	

[a] *Source*: National Science Board (2012), Table 4-3.
[b] Small to negligible amount, included in other sectors.
[c] Figures do not add to 100 because of rounding differences.

Alongside the overall patterns, Table 1.1 reveals some spectacular developments in specific countries. Singapore and South Korea, for example, more than doubled their basic research investments as a percentage of GDP from 2000 to 2009.[18] Such major policy changes will be taken up in section 2.2.

1.3.2. Importance of basic research for innovation and growth

It is generally believed that in aggregate the effects of (public) basic research on economic innovation and growth are positive and significant.[19,20] The inherent and deep measurement problems notwithstanding, a large body of the literature supports this view. The public-goods nature of basic research as outlined in the seminal work of Nelson (1959) and Arrow (1962) suggests that social rates of return to basic research are higher than

[18] Note, however, that, in the case of South Korea, there is a break in the series in 2007. Data prior to 2007 does not include investments in the humanities and social sciences.

[19] For these benefits to materialize, the innovation system arguably relies on a well-run state (cf., for example, Economist, 2013b).

[20] As pointed out by Salter and Martin (2001), much of the literature on basic research uses different terminologies such as ‘science’, ‘academic / university research’, or ‘public research’. Moreover, as we will set out in detail in section 1.5, there are two main dimensions of public engagement in basic research: public funding and public provision. The distinction between these concepts is not always strict in the literature. Considering the overlap between these terms, we will mostly subsume all of them under ‘public basic research’ and use ‘basic research’ if we are not focusing on the involvement of the public sector.

private rates of return. Accordingly, early empirical studies concentrated on the assessment of the social rate of return, which was generally found to be high.[21] Some studies also tried to estimate the implications of public basic research for productivity and GDP growth. The effects identified are also substantial.[22]

These aggregate empirical studies have been criticized mainly on two grounds. First, the empirical strategies were questioned.[23] Second, they do not provide insights with regard to the different channels linking basic research to economic innovation and growth. These questions were addressed in more detailed empirical studies based on citations of scientific publications in patents, for example, in surveys among R&D managers, and in detailed case studies tracing the inputs of preceding basic research in the process of major innovations. Generally, these studies also support the importance of basic research for growth and innovation. In addition, they suggest that the benefits of basic research for innovation are diverse, indirect, and often involve major time lags. Based on an in-depth review of the existing literature, Salter and Martin (2001) propose to cluster these manifold benefits in six different groups. Schneller (2011) adopts their classification of benefits and extends their review to the more recent literature. These diverse benefits are key in understanding the different economic views on basic research and the approaches to modeling basic research, as well as the policy issues involved. Hence let us now summarize each of these categories. The interested reader is referred to the work of Salter and Martin (2001) and Schneller (2011) for further details on the underlying literature.

Knowledge base

Basic research is generally understood to increase the knowledge base, comprising, for example, ideas, technologies, theories, and prototypes. The knowledge base can then be taken up in applied research aimed at developing new and refined products or processes. This channel from basic research to innovation was the main subject of the early literature

[21] Salter and Martin (2001) provide a summary table of estimated rates of return to publicly funded R&D, mostly in the agricultural sector. Most of these estimated rates of return were around 30% or higher. In a more recent study, Toole (2012) considers the impact of publicly funded basic research on the pharmaceutical industry. His analyses suggest that public basic research significantly spurs innovation, with the rate of return to these public investments being as high as 43%. Cf. also Hall et al. (2009) for a survey of the literature measuring the returns to R&D in general.

[22] Martin (1998) estimates that in 1993, approximately 2% of Canadian GDP were attributable to university R&D performed in previous years. Guellec and Van Pottelsberghe de la Potterie (2004) analyze a panel of 16 OECD countries and find that research performed in the public sector has a large impact on productivity growth. Cf. also the discussion in section 2.4.

[23] Main criticisms involve potential errors in the measurement of R&D inputs and the resulting outputs, the reliance on simplified production functions, and the possibility of reversed causality (cf. Griliches, 1998; Salter and Martin, 2001; Cockburn and Henderson, 2001; Hall et al., 2009).

on basic research.[24] It was addressed and analyzed in many studies.[25]

Skilled graduates

Graduate students who have recently been trained in university research help firms in accessing the knowledge base generated by basic research.[26] It may thus be seen as a transmission channel for the benefits addressed above. However, graduate training in university research also develops skills in complex problem-solving that are relevant for private innovation beyond their importance for accessing the knowledge base. Moreover, skilled graduates are important drivers of innovative entrepreneurship.[27]

Instrumentation and methodologies

As a byproduct of basic research, new instrumentation and techniques are often developed, which are needed to tackle the fundamental problems under scrutiny. Industrial surveys typically point to the high relevance of new problem-solving techniques for private innovation.[28]

Scientific networks

Advances in technological and scientific knowledge also increase the *burden of knowledge*.[29] It follows that *'increasingly, knowledge and intelligence are organised in social ways, rather than being accessed on an individual basis'* (Salter and Martin, 2001, p. 524). Hence having access to these scientific networks is of primary importance for private, science-based innovation. Public basic research can provide firms with access to these networks. Indeed, empirical studies suggest that the proximity to universities has

[24] Cf., for example, Nelson (1959) and Arrow (1962).

[25] Cf. Narin et al. (1997) for a leading example of a patent-citation study showing that patents frequently refer to scientific publications. Mansfield (1995), Cohen et al. (2002), and Monjon and Waelbroeck (2003), for example, address the importance of knowledge generated from basic research in surveys among industrial firms. Arundel and Geuna (2004) argue that these studies typically point to a low importance of basic research as a direct external source of information used in innovation. However, this does not preclude a more indirect and time-lagged link from basic research to innovation.

[26] Cf., for example, Cohen et al. (2002) and Arundel and Geuna (2004).

[27] Arvanitis and Stucki (2012) show for the case of Switzerland that innovative activities of a start-up depend critically on the founders' university education and their prior work experience in R&D.

[28] Cf., for example, Arundel et al. (1995) and Cohen et al. (2002).

[29] The term *burden of knowledge* captures the fact that individuals have to approach the knowledge frontier, before they can engage in state-of-the-art research. Jones (2009, p. 284) summarizes the idea in a nice figurative way: *'... if one is to stand on the shoulders of giants, one must first climb up their backs, and the greater the body of knowledge, the harder this climb becomes.'*

a positive effect on innovation, and surveys point to the importance of networking with university staff to foster innovation.[30]

Problem-solving capacity

Basic research enhances the overall ability to tackle and solve complex problems. Obviously, this ability largely draws on the knowledge base of the economy, the trained graduates, existing instrumentation and methodologies, and scientific networks. Hence it is closely linked to the four benefit categories discussed above. Yet Salter and Martin (2001) include it as a separate category, mainly because of the importance attributed to it by industrial R&D managers.

New firms

Salter and Martin (2001) identify the creation of new firms as a last category of benefits from basic research, although they point out that evidence about this benefit was mixed. The more recent literature seems to justify inclusion. Schneller (2011) reviews some empirical studies that suggest that basic research does indeed have a positive local effect on the creation and growth of new firms.

As we have seen, some of the categories considered here overlap, and some benefits are accounted for in various ways. The characteristics of basic research and the different channels through which it impacts on the economy make it particularly difficult to pin down more precisely how much value added or how much total factor productivity growth can be achieved by additional investments in basic research. These difficulties are intrinsic to basic research. While new possibilities of collecting and analyzing large data may overcome some of them, policy-makers have to choose basic research policies under significant uncertainties with regard to their effects. Nevertheless, as we will argue in chapter 2, much can be gained by focusing policy planning on critical issues and known determinants.

[30] Cf. Jaffe et al. (1993) and Cohen et al. (2002), for example.

1.4. The economics of basic research

1.4.1. Economic views on basic research

From our discussion in the previous section we observe that the benefits from basic research are manifold. Depending on the weighting attached to these benefits, we can conceptualize basic research in different economic terms. We distinguish five possible perspectives.[31]

Basic research as a global public good

As basic research expands the knowledge base of the economy, including new instrumentation and methodologies, it can be seen as a global public good. This was a predominant view in the early literature.[32] According to this view, the output of basic research is non-excludable and non-rivalrous. Knowledge spillovers and limited patentability prevent firms from fully appropriating the gains from basic research. Moreover, Nelson (1959) argues that as basic research is non-rivalrous, its outcomes should be fully and freely disseminated in the social optimum.

Basic research as a local public good

Basic research has important local effects. Among other things, it provides firms with trained scientists and problem-solvers. It also provides them with access to the scientific network, thus fostering their overall problem-solving capacity. Such positive regional effects of public basic research were also identified in empirical studies showing that it fosters the innovation potential and the growth of local firms.[33] Hence basic research may also be seen as a local public good.[34]

Basic research as a local public good with cross-country spillovers

This perspective is a combination of the global and the local public good interpretation of basic research. If all the previously addressed benefits are present, this view may in-

[31] A first outline of these views is given in Gersbach (2007).
[32] Cf. Nelson (1959) and Arrow (1962), for example.
[33] Cf. Jaffe et al. (1993), Anselin et al. (1997), and Audretsch and Lehmann (2004), for example.
[34] Obviously, non-rivalry and non-excludability are no longer strictly satisfied with regard to the benefits considered here, notably in connection with the supply of skilled graduates.

deed be appropriate. The international spillovers may be direct through publicly available knowledge, the build-up of scientific networks, or the migration of trained scientists, for example. Alternatively, these spillovers may occur indirectly through trade or foreign direct investments.

Basic research as a private good

A firm's own basic research can foster its absorptive capacity, that is provide it with direct access to the knowledge base. Cohen and Levinthal (1989), Rosenberg (1990), and Callon (1994) developed this line of reasoning, arguing that such direct access motivates private investment in basic research. This absorptive capacity is both rivalrous and excludable, so it is a private good. If we wanted to push this interpretation to its limits, we could define basic research as a private good.[35] Similarly, the positive effects on the creation and growth of new firms previously described potentially give rise to excludable benefits from basic research.

Basic research as the first step in the innovation process

If we leave aside the distinctions made so far and focus on the overall characteristics of basic research instead, we may, quite generally, think of basic research as being the first step in the innovation process. This perspective is found in many conceptual studies on basic research and innovation.[36] It is also at the heart of the theoretical work of Grossman and Shapiro (1987), Aghion and Howitt (1996), Cozzi and Galli (2009), and Gersbach et al. (2010b), for example.

1.4.2. Modeling basic research

Economists have taken various approaches to modeling basic research. What these approaches have in common is that basic research contributes to the development of more and/or higher-quality blueprints for production, depending on whether these models are in the tradition of Romer (1990) or of Aghion and Howitt (1992). They differ with regard to the characteristics of basic research they emphasize. We distinguish four conceptually

[35] Kealey (1996) actually pushed this line of reasoning to the point where basic research is a byproduct of private investment in access to knowledge. He postulates that governments should follow a laissez-faire strategy regarding research policies.

[36] Cf. Bush (1945) and the linear model of innovation, for example.

different ways of modeling basic research.[37] We start from our review of the benefits from basic research, which suggests that the outcomes of basic research need to be further processed to become effective for economic innovation and growth. Accordingly, we concentrate on those approaches that take into account both basic research and applied research by private firms.

Basic research as a stimulus for the innovation rate of private firms

A first approach towards modeling basic research is to treat it as a stimulus for the rate of innovation achieved by private firms. This stimulus may either be direct or indirect via some measure of the knowledge base. In the light of the discussion on the benefits associated with basic research, this approach may be seen as a reduced form that mainly captures the positive effects of basic research on the knowledge base and the problem-solving capacities of firms. In Nelson's words (1959, p. 300): *'The greater the underlying knowledge, the lower the expected cost of making any particular invention.'*

In the model presented by Gersbach et al. (2013), current public basic research improves the probability that domestic firms will either catch up with or leapfrog to the world technological frontier. Basic research is undirected and it is a national public good, i.e. public basic research affects domestic firms equally across all sectors. A similar approach is presented in Gersbach et al. (2014), who examine the entrepreneurs' decision to innovate in the context of a closed economy. Depending on the exact functional forms, basic research may or may not be a necessary condition for innovation in these models.

Models accounting – among other things – for indirect stimuli via the knowledge base have, for example, been presented by Parker (1999), Morales (2004), and Gersbach et al. (2010b). In these models, however, the indirect stimuli from basic research point in different directions. Morales (2004) follows a *burden of knowledge* rationale.[38] In his model, the aggregate knowledge base in the economy, as determined by past public and private basic and applied research, decreases the productivity of future research. By contrast, Parker (1999) and Gersbach et al. (2010b) argue that positive spillover effects from basic to applied research imply that the productivity of applied research increases with the knowledge base.[39] The key difference between models of direct and indirect stimuli for

[37] Obviously, these distinctions are not strict, and many authors actually unify several of these approaches in their work. We introduce these distinctions because they allow a better understanding of how the different characteristics of basic research may be reflected in economic theory.

[38] Cf. footnote 29 for a brief discussion of the *burden of knowledge*.

[39] Parker (1999) actually considers private and public research and distinguishes the stock of knowledge available in both research sectors. As public research does not affect market production directly, we treat it as basic research, classifying private research as applied research. More generally, Parker (1999) and

the rate of innovation is that in the latter, past investments also matter, whereas in the former they do not.[40]

Basic research as a stimulus for the quality of innovations by private firms

An alternative approach is to let basic research affect the quality of innovations by private firms. This reflects the idea that basic research expands the knowledge base, including instrumentation and methodologies. New fundamental insights from basic research may form the basis for high-quality innovations.

Some authors introduced this mechanism in growth models based on creative destruction. Basic research is assumed to have a positive impact on the size of innovation steps undertaken by private firms. This effect may or may not be sector-specific and it may or may not show some persistence. Akcigit et al. (2013), for example, focus on sector-specific effects. In their model, sector-specific knowledge from basic research increases the size of the innovation steps associated with subsequent applied research in the same sector. This positive effect lasts for a stochastic period of time. Akcigit et al. (2013) also allow for cross-sectoral spillovers, with new knowledge in one sector potentially affecting the size of innovation steps in other sectors. They distinguish private basic research from public basic research insofar as the former directly leads to an innovation, whereas the latter needs to be commercialized via applied research first. They argue that this distinction captures the *ivory tower* nature of public research.

The mechanism introduced by Morales (2004) is not sector-specific. The previously mentioned aggregate knowledge base in the economy determines the economy's technological frontier. Any successful innovator will jump to this frontier. As opposed to the mechanism in Akcigit et al. (2013), its counterpart in Morales (2004) is short-lived. The current state of knowledge can only give rise to a single quality jump in each lagging sector.[41]

Aghion and Howitt (1996) introduce a quality-enhancing effect from basic research into a model of expanding varieties.[42] In their model, the economy's technological frontier is

Gersbach et al. (2010b) introduce spillovers from basic to applied research and vice versa. They follow a *standing on the shoulders of giants* rationale: In their models, the current level of technology – the stock variable associated with applied research – and of the knowledge base – the stock variable associated with basic research – have a positive impact on the productivity of both applied and basic research.

[40] In the model presented by Gersbach et al. (2013), past investments in basic research have an indirect effect on innovation in the current period, as they impact on the distribution of distance from the world technological frontier across economic sectors.

[41] Note, however, that the basic and applied research needed to jump to the knowledge frontier pushes this frontier further ahead.

[42] Aghion and Howitt (1996) distinguish research from development. For the purpose of our discussions here, we consider the former to be basic research and the latter to be applied research.

constituted by both applied and basic research in the past. At any point in time, this technological frontier determines the quality of new vintages originating from basic research. Subsequently these can be commercialized via applied research.

Basic research as the first stage in the innovation process

In the spirit of Grossman and Shapiro (1987), some authors explicitly model basic research as the first stage in the innovation process. In particular, Cozzi and Galli follow this approach in several of their papers.[43] In their models, innovation is a two-stage process. In the first stage, sector-specific (directed) basic research is used to develop a basic 'half-idea' that can then be used in applied research to develop a product of higher quality.

Gersbach et al. (2010b) introduce a similar mechanism into their model. They consider undirected basic research. In their model, basic research produces ideas. Each idea forms part of the knowledge base and can be taken up in directed applied research, which, if successful, will increase the variety of products available in the economy. There is a fixed correspondence from ideas to possible innovations. Gersbach et al. (2010b) argue that this mechanism captures the hierarchy between basic and applied research. In their model, as in the models presented by Cozzi and Galli, basic research determines the innovation possibility set of applied research.

In the model proposed by Aghion and Howitt (1996), basic research is also undirected and prepares the ground for subsequent applied research, which can develop new product varieties. Aghion and Howitt (1996), however, do not assume a fixed correspondence between basic and applied research. In their model, any item of fundamental knowledge deriving from basic research can, in principle, be translated into infinitely many new product varieties by increasing applied research efforts – albeit with decreasing returns.

Basic and applied research as complementary factors

A final, though less common, approach to modeling the benefits from basic research is to consider basic and applied research as complementary inputs into a single R&D process. This approach may be most suitable for modeling private basic research. In the light of the above discussion, it appears to mainly capture the benefit of obtaining access to scientific networks and of increasing the absorptive capacity of the researching firm, thus

[43] Cf. e.g. Cozzi and Galli (2009), Cozzi and Galli (2013), and Cozzi and Galli (2014). While Cozzi and Galli (2009) concentrate on public basic research, Cozzi and Galli (2014) analyze the optimal patent policy in an economy with private basic research. Cozzi and Galli (2013) analyze the trade-offs between these policy schemes.

increasing the productivity of its applied research. Morales (2004) proposes a mechanism in this spirit. In his model, firms combine applied and private basic research to maximize their return from research.

1.5. Basic research and the public sector

From our discussion in section 1.3.1 we observe that the public sector is a major player in basic research, both in terms of funding and performance. Accordingly, we can distinguish two fundamental dimensions of public engagement in basic research. Table 1.3 gives a stylized representation of these dimensions, along with the resulting policy options.

Table 1.3.: Dimensions of public basic research

		Organizational form	
		Private	**Public**
Funding	**Private**	Industrial research	Industrial funding of research at universities / PROs[a]
	Public	Subsidies for private research	Publicly funded research at universities / PROs[a]

[a] PRO stands for *Public Research Organization*.

All of these stylized policy options can be encountered in reality. Obviously, mixed forms also exist, both in terms of funding and of organizational form, such as joint research centers, for instance. Yet such a categorization is helpful in reviewing the economic literature on the role of the public sector in basic research.

The case for the public funding of basic research is well established in the literature. The classical argument dates back to the seminal work of Nelson (1959) and Arrow (1962) and is based on a lack of appropriability of the returns from basic research. Put simply, as the benefits from basic research are typically diverse, uncertain, and lagging over time, they cannot all accrue within a single firm. What is more, improved patentability of innovations from basic research alone cannot give rise to socially optimal outcomes. Any strengthening of upstream patent rights comes at the cost of an *anticommons effect*.[44] In this regard, Nelson (1959) argues that as the knowledge from basic research is a public good, it should be fully and freely disseminated.[45]

[44] Cf. also the discussion in section 2.5.
[45] Cf. also Mowery et al. (2001) and Nelson (2004), for example.

As set out above, some authors have questioned the public-goods nature of basic research, in particular its non-rivalry.[46] These authors argue that to be able to apply existing scientific knowledge in applied research, firms need to invest in complementary absorptive capacities via private basic research. Yet, due to the non-rivalry of knowledge from basic research, any such knowledge should still be fully and freely disseminated, at least among those firms that have the necessary absorptive capacities. Hence there is still a case for public funding. More generally, public funding for basic research can also be supported on the grounds of an *evolutionary approach* to the economics of basic research. This approach assumes a more integrative perspective on basic research and the innovation system. Basic research arguably generates diverse benefits, which partly accrue in the form of tacit knowledge embodied in individual researchers or research networks.[47] According to Salter and Martin (2001), these benefits allow a new rationale for the public funding of basic research.

As Aghion et al. (2008) point out, while the classical public-good argument supports the public funding of basic research, it does not clarify why basic research should be organized in public universities rather than by subsidizing private firms doing basic research. This facet of public engagement in basic research has been given less attention in the literature. Yet several arguments in favor of public engagement have been put forward. Aghion et al. (2008) argue that, concerning the organizational form of research, the fundamental trade-off is one of creative control versus focus. While private firms can dictate the lines of research to the scientists they employ, scientists working in academia have creative control over their work. They argue further that scientists value creative control, implying that private firms have to pay a wage premium when compared to academia. They develop a model based on this rationale, showing that early-stage research, which is far from being commercialized and, hence, has a relatively low expected value as of today, should be performed in academia.[48]

Akcigit et al. (2013) present a different rationale for public basic research. They develop a model with public and private basic research. Both public and private basic research are sector-specific and have positive spillovers on subsequent applied research within the same sector. However, while private basic research, if successful, immediately gives rise to innovation, public basic research does not, due to its *ivory tower* property. In their model, the lack of appropriability results in underinvestment in private basic research. Akcigit et al. (2013) argue that a type-dependent research subsidy to the private sector to

[46] Cf. the discussion in section 1.4.1.
[47] Cf. the discussion in section 1.3.2 for further details.
[48] Aghion et al. (2008) do not take a stand on whether this research should be located at public or private universities.

alleviate the under-investment problem may not be feasible, due to asymmetric information and the resulting moral hazard problem. As a consequence, they propose a uniform subsidy for the private sector combined with public basic research as a feasible policy solution. This policy choice yields the highest social welfare, in particular when combined with intellectual property rights for public basic research, which, so they argue, mitigates its *ivory tower* property.

Public provision of basic research may also be justified, in the spirit of Nelson (1959), on the grounds that it enables a better diffusion of the associated knowledge. Irrespective of their funding sources, private firms typically have little incentive to disseminate their insights from basic research. A classical argument in favor of patents takes up this concern, arguing that patents force firms to disclose their research.[49]

Arguments of a more qualitative nature for pursuing basic research in academia were proposed by Callon (1994) and Salter and Martin (2001). Callon (1994) argues that public engagement in science is needed to counteract the path-dependency and convergence inherent in private-sector innovation. Put differently, public basic research is needed as a source of new networks and technological opportunities that preserve variety and flexibility in the economy. Salter and Martin (2001) identify the supply of trained researchers to private firms as a major benefit from basic research.[50] They conclude that basic research and the education of graduate students need to be closely integrated.[51]

[49] Note, however, that university researchers also sometimes refrain from disclosing commercially valuable research, due to lack of interest or lack of awareness, for example. Cf. the discussion in sections 2.5 and 2.6.

[50] Cf. section 1.3.2.

[51] Cf. also Rosenberg and Nelson (1994) and Howitt (2013).

2. Basic Research Policies*

2.1. Introduction

Our discussion in the previous chapter makes a strong case in favor of public funding and public provision of basic research. In what follows, we take this as read, turning our attention now to the design of basic research policies in the quest for guidance on how much, how, and where to spend the public funds, and on how to optimally combine such investments with complementary policies. We address a series of different policy questions directly connected to basic research. For each of them, we briefly characterize the main trade-offs involved, as far as applicable, and summarize the insights offered by the existing economic literature. We also highlight potential avenues for economic research in this area.

2.2. How much basic research?

The obvious first – and very important – policy question concerns the optimal amount that should be spent on basic research. Many studies approached this question by estimating the private and social rates of return to basic research.[1] But although these estimates generally indicate high returns to basic research, they cannot provide a basis for concrete policy actions, as Salter and Martin (2001) point out. A complementary approach is to break down this issue and to identify factors for optimal basic research investment. We follow this approach and consider two specific determinants: openness and distance from the world technological frontier.

* This chapter is based on joint research with Hans Gersbach.

[1] Cf. Salter and Martin (2001), Schneller (2011), and the discussion in section 1.3.2.

Openness

In an international context, building up the knowledge base through basic research has various effects. New knowledge generated domestically by basic research can spill over to foreign countries, either directly or indirectly via exports or foreign direct investments. Innovating countries can benefit from these spillovers if domestic firms earn monopoly profits in foreign markets. Conversely, countries can try to free ride on basic research investments from the rest of the world, potentially at the cost of losing domestic monopoly profits if innovative foreign firms enter the market. The spillovers to and from a country depend on the country's openness. Hence openness is a critical factor for basic research investment. Given the opposing effects involved, the interaction between openness and basic research investment is a priori unclear and deserves further scrutiny.

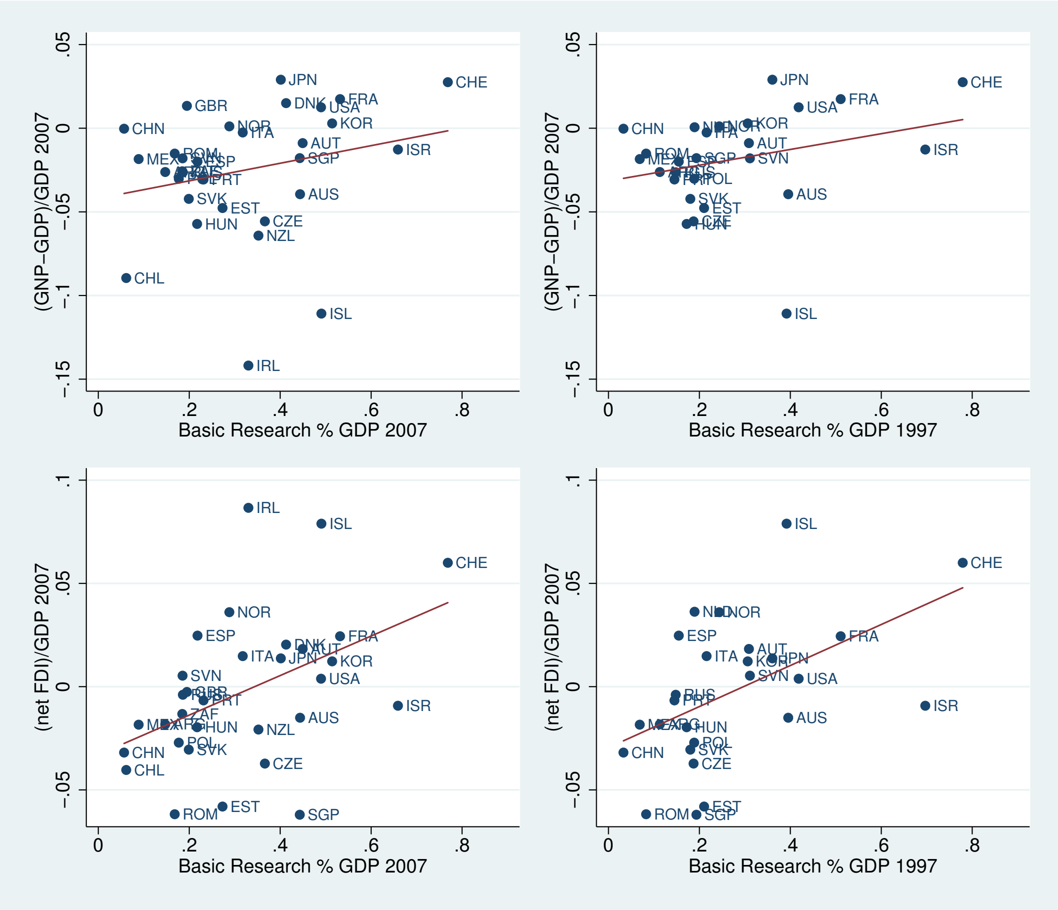
We address the connection between openness and basic research investment from two different angles: FDI/trade and researcher mobility. We start with the former. Figure 2.1 plots two indicators of how successful domestic firms are in investing abroad against current and lagged basic research intensities: the difference between GNP and GDP over GDP and net FDI over GDP. While the former reflects cumulated past investment, the latter reflects current investment. Based on the reasoning discussed above, we would expect these measures to be positively correlated with (lagged) basic research investments. This is exactly what we observe.[2,3] Obviously, these simple correlations are preliminary and in particular do not enable us to identify causal relationships. Yet they still highlight the importance of a better understanding of the underlying forces.

Gersbach et al. (2013) address these issues from a theoretical point of view. They analyze optimal basic research investments in an open economy model where foreign firms can enter technologically lagging domestic sectors. The entrance of foreign firms has two opposing effects. First, these firms operate at the world technological frontier, thus having a positive effect on productivity. Second, their profits do not accrue for the domestic population. The government can invest in basic research to improve the probability of successful innovation by domestic firms, thus enabling those firms to catch up with the

[2] The correlation coefficients are 0.24 (GNP(t)-GDP(t), BR(t)), 0.29 (GNP(t)-GDP(t), BR(t-10)), 0.46 (FDI(t), BR(t)), and 0.51 (FDI(t), BR(t-10)). 2007 was considered because data on foreign direct investments are only available from 2005 onwards. These data may have been influenced by the great recession that started in late 2007. Results are essentially the same when considering 3-year centered moving averages in 2006. Note, however, that basic research investments over GDP exhibit a relatively low time variance.

[3] As originally pointed out by Pearson (1896), correlations between ratios with common denominators may be spurious. This is, however, less of a concern if the hypothesis is phrased in terms of ratios (Kuh and Meyer, 1955), which is arguably the case here. We are interested in the relationship between (lagged) basic research intensities and different measures for the net success of domestic firms investing abroad. These measures are naturally also expressed relative to GDP.

Figure 2.1.: Basic research and net income from abroad



Source: Own illustration, based on data taken from OECD (2012a) and from World Bank (2013). The data was downloaded in June 2013. Values on both axes refer to 5-year centered moving averages.

world technological frontier. Gersbach et al. (2013) show that if innovation steps are small, the more open countries are, the more they should invest in basic research. For large innovation steps the opposite holds true.

By analyzing the equilibrium in a two-country set-up, Gersbach and Schneider (2013) explicitly take into account the interdependencies of national investment decisions in basic research. They show that in a decentralized equilibrium some countries – in particular small open economies – may overinvest in basic research compared to basic research policies coordinated among countries. Yet total global investment in basic research tends to be below the social optimum. Hence Gersbach and Schneider (2013) provide a rationale for both the relatively high investment in basic research by technologically advanced small open economies such as Switzerland and South Korea, and for international coordination within, say, the EU or at CERN.[4]

[4] Such coordination can also be justified by the large lump-sum investments necessary to perform basic research in some areas.

Cross-country spillovers also exist with respect to more local benefits from basic research. Large multinational companies can – and actually do – locate research and development centers in the vicinity of publicly funded scientific centers abroad.[5] In addition, researchers tend to be mobile, thus enabling firms to hire researchers trained abroad through foreign basic research investments.[6]

More generally, the mobility of researchers is an important factor for basic research policies. It has an impact on the supply of skilled graduates, or problem-solvers, one of the major benefits deriving from public basic research identified by Salter and Martin (2001). Moreover, this mobility affects the domestic knowledge base, insofar as this knowledge base takes the form of the tacit knowledge of individual researchers. One might ask whether public basic research is needed to prevent – or at least mitigate – a 'brain drain', presumably involving the most talented researchers. Or conversely, can countries that invest heavily in basic research attract skilled researchers from abroad, thereby strengthening their domestic talent-pool? What are the long-run prospects of training foreign researchers? Do they return to their home countries upon graduating and if so, what are the underlying forces prompting them to do so? Empirical evidence underlines the importance of such effects for basic research policies. Today, around 45% of PhD students in the US and 60% of PostDocs are temporary residents. These shares have sharply increased over time, starting from a level of around 20% (PhD) and 40% (PostDocs) in 1980 (Stephan, 2012).[7] At the same time, there are large cross-country differences. Franzoni et al. (2012) surveyed the corresponding authors of articles published in 2009 to find that, in a sample of 16 countries, Switzerland's research community exhibited the highest mobility. It had the highest share of immigrants among its researchers (56.7%) and the second-highest share of emigrants (33.1%).[8] In contrast, Japan had a very low share of immigrants (5%) and emigrants (3.1%). The US had many immigrants (38.4%), but few emigrants (5%), unlike India with 0.8% immigrants and 39.8% emigrants.

Stephan (2012) discusses some patterns underlying these data, in particular those underlying the internationalization of PhD students in the US. When choosing their graduate school, students tend to imitate other students from their country, and they tend to be attracted by faculty of the same ethnicity. A majority of PhD students stay in the US

[5] Cf. the discussion in Dasgupta and David (1994). A more recent example is Google's decision to establish a development center in Zurich, which was partly motivated by the possibility of drawing upon technical knowledge from researchers trained in Zurich and elsewhere in Europe (http://www.swissinfo.ch/eng/archive/Zoogler_revolution_gains_momentum.html?cid=982694, retrieved on 8 April 2014).

[6] Cf. Franzoni et al. (2012), for example.

[7] Cf. also Hunter et al. (2009), for example.

[8] Immigrants and emigrants are identified based on a comparison of the country of residence at the age of 18 and the country of residence at the time of the survey.

upon graduating, albeit with important cross-country differences. While more than 80% of the Chinese and the Indian PhD students are still in the US five years after graduating, less than half of the students from South Korea, Taiwan, Mexico, and Chile have stayed there. Staying rates seem to be influenced by economic conditions in the home country and by fellowship programs supporting such research visits to the US. Addressing the determinants and effects of migration by researchers and their interplay with domestic basic research investment in greater depth is a promising avenue for economic research and may be expected to guide policy-making in this area.[9]

Distance from frontier

Science and technological progress is a cumulative process in which every advance is rooted in the knowledge base developed by prior research.[10] Hence it seems natural that a stock of scientific and technological expertise is needed to conduct – and benefit from – state-of-the-art basic research. It is therefore no surprise that basic research is mainly performed by industrialized economies that are at – or close to – the world technological frontier.[11] Moreover, as Figure 2.2 illustrates, on balance, the closer countries are to the world technological frontier, the more they tend to invest in basic research.[12] The simple rationale for this is developed in Gersbach et al. (2010a). In a small open economy model with creative destruction, the closer a country is to the world technological frontier, the more it should invest in basic research. The main intuition is that the closer an economy is to the world technological frontier, the more effective basic research becomes in deterring technologically advanced foreign firms from entry, and, conversely, the more effective it is in supporting domestic firms operating on the world market.

However, the general pattern masks important differences in the way countries with similar stages of economic development select their basic research policies. Figure 2.3 plots basic research expenditures and the status of economic development for a selection of eight countries from 1995 to 2010. These countries exhibit very different patterns with regard to basic research investments over the process of economic development. The Czech Republic and South Korea were significantly catching up with the world techno-

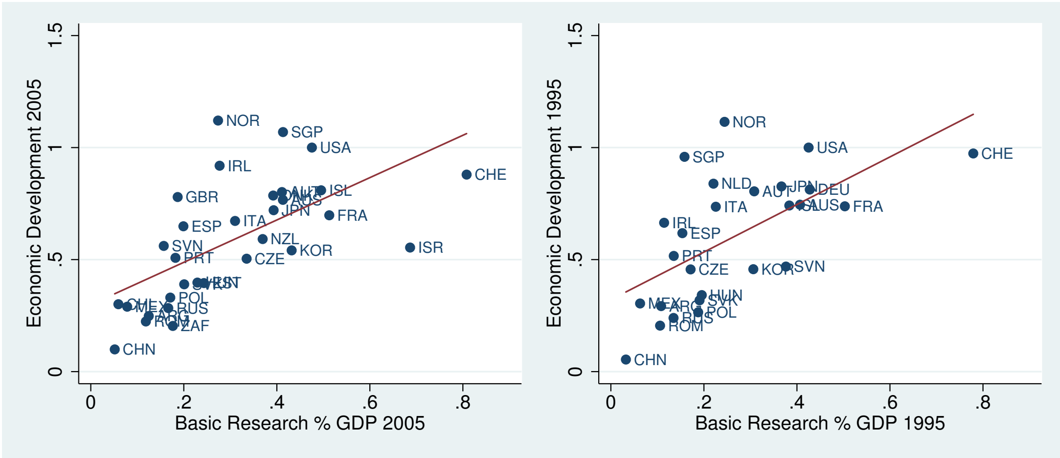
[9] A variety of countries actively set up policies in this area. Brazil, for example, launched a large-scale initiative to support students and scientists going abroad (Brazilian Secretariat for Social Communication, 2011).

[10] Cf. Scotchmer (1991), Scotchmer (2004), and Nelson (2004), for example.

[11] Cf. section 1.3.1.

[12] The ratio of GDP per capita in PPP over US GDP per capita in PPP is used as a proxy for the status of economic development (cf., for example, Acemoglu et al., 2006; Gersbach et al., 2013). To smooth short-term fluctuations, centered 5-year moving averages are considered. The correlation coefficients are 0.62 (2005) and 0.61 (1995).

Figure 2.2.: Basic research and economic development – overview



Source: Own illustration, based on data taken from OECD (2012a) and from World Bank (2013). The data was downloaded in June 2013. Values on both axes refer to 5-year centered moving averages. 'Economic Development' is defined as $\frac{\text{GDP per capita in PPP}}{\text{US GDP per capita in PPP}}$.

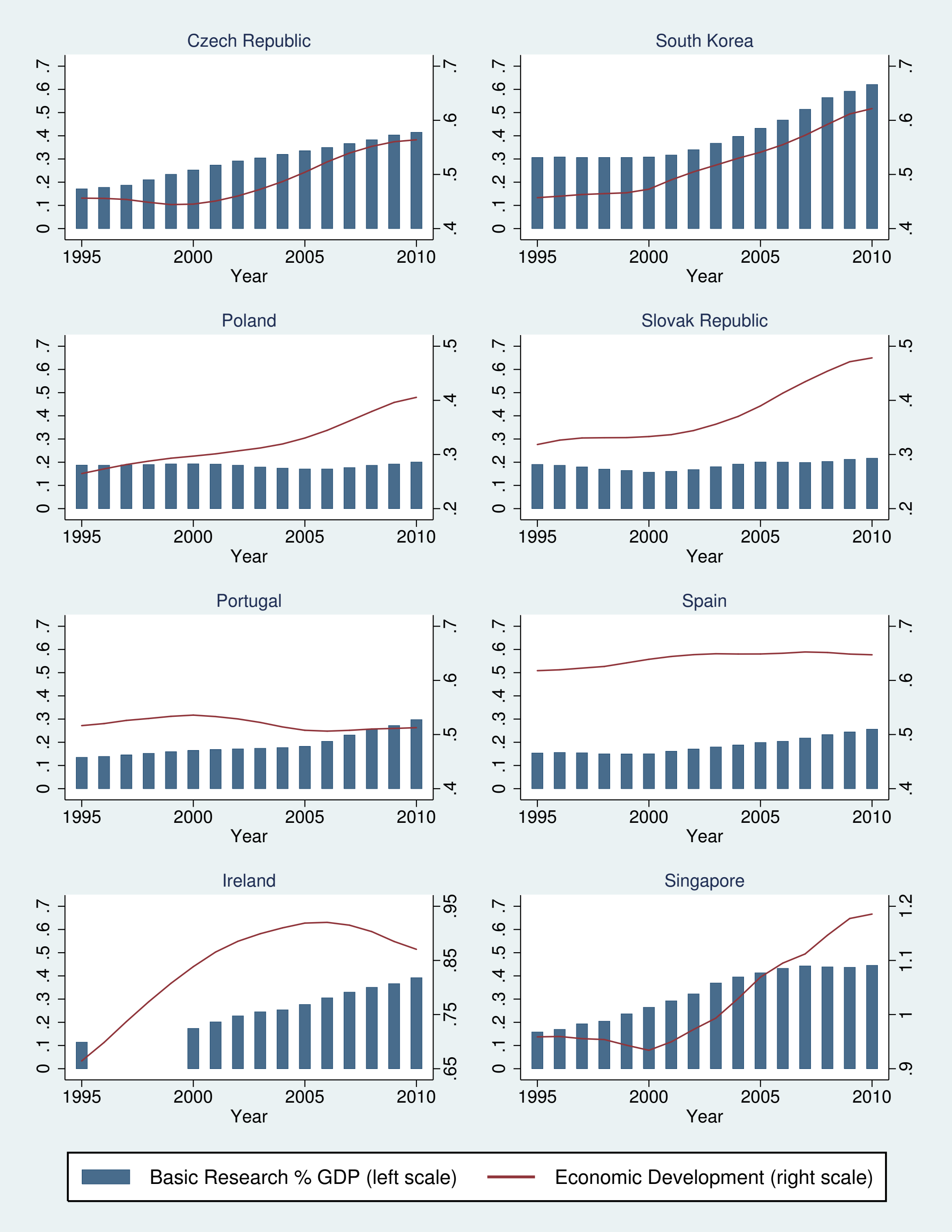
logical frontier. In parallel, they heavily increased their investments in basic research. By contrast, Poland and the Slovak Republic kept a more or less constant, and relatively low, level of basic research in the course of their development, starting, however, from a slightly lower level of economic development than the Czech Republic and South Korea. At the same time, Portugal and Spain invested little in basic research, only increasing these investments slightly towards the end of the period considered. They stagnated at levels of economic development roughly comparable to Czech Republic and South Korea in 2010. Finally, Ireland and Singapore reached relatively high levels of economic development with comparatively little investment in basic research and then initiated strategic *big-push* investments in basic research with the goal of establishing globally competitive and innovative knowledge economies.[13] While Singapore managed to sharply increase its standard of living in comparison to the US since 2000, the development of Ireland is hump-shaped, and its GDP per capita, relative to US GDP per capita, was only slightly higher in 2010 than in 2000.[14,15]

[13] Cf. Irish Council for Science, Technology and Innovation (1999) and RIE Secretariat (2011).

[14] Note, however, that Ireland was hit particularly severely by the great recession that started in late 2007. Still, Singapore has seemingly been more successful with its *big-push* policies than Ireland. This conjecture is also supported by looking at a more direct measure of the respective productive capacities, as proposed by Hidalgo and Hausmann (2009) and Hausmann et al. (2011) (cf. the discussion in section 2.4 for further details on this measure). In the period from 1997 to 1999, the three years prior to and including the launch of its *big-push* policies, Ireland was, on average, ranked 12.3 in the proposed country ranking of economic complexity. This average rank dropped to 16.7 for the period 2006 to 2008. By contrast, from 1989 to 1991, the three years prior to and including the launch of its *big-push* policies, Singapore had an average rank of 19.7, and managed to reach an average rank of 10.7 for the period 2006 to 2008 (country rankings were downloaded from http://atlas.media.mit.edu/rankings/country in June 2013).

[15] The basic research data considered in Figure 2.3 include both public and private basic research. For a better view of the importance of government policies for these developments, it would be interesting

Figure 2.3.: Basic research and economic development – country patterns



Source: Own illustration, based on data taken from OECD (2012a) and from World Bank (2013). The data was downloaded in June 2013. Values refer to 5-year centered moving averages. 'Economic Development' is defined as $\frac{\text{GDP per capita in PPP}}{\text{US GDP per capita in PPP}}$.

to consider public basic research only. For the selection of countries considered, there is little data on the share of basic research investments funded by the government. However, with the exception of South Korea, where more than 50% of basic research is performed by private firms, the reasoning outlined in section 1.3 also applies to the selection of countries considered here. It suggests that public investments account for the main part of total basic research investments. As an alternative, we can

These findings indicate that policy-makers are facing some critical decisions with regard to basic research policies over the course of economic development:

– What is the optimal mix of investment in innovation and in the adoption of existing technologies (imitation) for countries at different stages of their economic development? What does this imply for basic research policies?

  - Can countries imitate without themselves investing in the knowledge base? Or can basic research engineer rapid growth through imitation?
  - Is it possible for emerging economies to take over technological leadership in certain sectors?
  - If so, what is the role of domestic basic research in the transition from imitation to innovation? Should the domestic knowledge base be established gradually, evolving in tandem with the overall economy? Or can *big-push* policies in basic research effectively engineer a rapid build-up of the knowledge base at later stages of the economic development?

These – and related – questions have been given little attention in the literature so far.[16] Yet they are of first-order relevance for growth policies in industrialized and emerging economies, and a thorough understanding of the main mechanisms involved remains an important task for growth theorists.

2.3. Basic and applied research

Basic research is embryonic in nature. It mainly impacts the economy indirectly, via applied research and development by innovating firms. How to combine these two factors

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consider government-financed gross domestic expenditures on R&D (GERD) as a percentage of GDP, as reported by OECD (2012a). For the selection of countries considered, these public investments in all categories of research and development follow a pattern over time that is similar to the ones shown in Figure 2.3 for basic research. The main difference is that the public investments in R&D tend to be higher than total basic research investments in the economy. This indicates that the governments significantly fund applied research and/or experimental development in addition to basic research.

[16] Some authors have analyzed convergence to the world technological frontier in macroeconomic models. These models, however, do not address the importance of basic research for convergence. Howitt (2000) presents a model where countries grow through investments in physical capital and productivity-enhancing R&D. Countries converge to a constant productivity level relative to the world technological frontier, depending on the exogenous savings rate, research subsidies, and research effectiveness. Howitt (2000), however, does not focus on optimal policies. Acemoglu et al. (2006) present a model where countries switch from investment (imitation) to innovation as they approach the world technological frontier. Without a switch in growth strategies, the countries are stuck in a non-convergence trap. In their model there are cross-country technological spillovers, and innovation is driven by entrepreneurial selection.

optimally, both with regard to policy targets and adequate policy measures, is thus a core issue.[17]

Basic and applied research in the growth process

Gersbach et al. (2010b) analyze the interplay between basic and applied research in a dynamic closed economy model. In this model, basic research expands the knowledge base, i.e. it generates new ideas, theories, and prototypes needed for private firms to develop blueprints for new product varieties. Whenever there are unused prototypes, firms will find it beneficial to commercialize them in applied research. Hence basic research is a necessary and sufficient condition for long-run economic growth. Depending on whether or not the economy operates at its knowledge frontier, long-run growth is either solely driven by basic research investments or it can be further stimulated by subsidizing applied research.

Stimulating applied research

The government can stimulate applied research in several ways. First, it can support private applied research by investing in basic research. As discussed in detail in section 1.3.2 and above, basic research expands the knowledge base, generates new instruments and methodologies, and generally fosters an economy's problem-solving capacity, among others. Hence it improves the prospects of success for innovating firms. However, basic research also ties up research capacities that are then no longer available for applied research. Spinesi (2013) discusses the crowding-out of private applied research by public basic research. He presents a model in which – quite intuitively – the more productive public basic research is in terms of knowledge creation and the higher the spillovers to applied research, the more likely public basic research is to stimulate private applied research.

Second, applied research can be supported either by directing public research more toward applied research or by subsidizing private applied research. We will address the former in our discussion of efforts for improving the commercialization of public basic research (section 2.6). Subsidization of private applied research is widely used by policy-makers. These subsidies have been examined in several empirical studies, notably the extent to

[17] Based on a comparison of Canada with the US, Howitt (2013) stresses the importance of this policy issue. He provides data indicating that while Canada invests more in university research relative to GDP, the share of business R&D in GDP is significantly higher in the US. Howitt (2013) suggests that this discrepancy in private applied research may partially explain why Canadian universities perform less well in technology transfer than their US counterparts.

which they crowd out private funding for applied research. While David et al. (2000) review the available empirical evidence, suggesting that it is not conclusive with regard to the net effect of research subsidies, more recent evidence seems to support the view that such policies have at least some positive effects.[18]

Third, applied research is shaped by tax policies. While research subsidies reduce the cost of applied research, tax policies impact on the (expected) net returns on these investments. In addition, they have an indirect effect on applied research by shaping the opportunity costs of becoming an (innovating) entrepreneur. Gersbach et al. (2014) analyze the interplay of basic research investments and tax policies in a general equilibrium framework.[19] They show that the complementarity between basic research policies and innovative entrepreneurship rationalizes a pecking order of taxation: the more entrepreneurs perform applied research and take up the knowledge created by basic research, the more investments in basic research can benefit the economy. Accordingly, these investments should be financed through high labor income and low profit taxes, thereby stimulating this take-up.[20]

In most theoretical models on basic research and applied research, firms are (implicitly) incentivized to invest in applied research via intellectual property rights.[21] Patents provide firms with temporally and geographically bounded monopolies, allowing them to earn monopoly profits in return for disclosing their invention. An extensive literature analyzes optimal patent design, a review of which is beyond the scope of our work here. We thus limit our attention to patent policies directly concerning basic research and discuss this literature in section 2.5. There we also refer to surveys of the literature on intellectual property rights.

Finally, policies tailored to manufacturing may be used to foster private applied research. As we will see in the next section, the manufacturing industry is responsible for the main part of business R&D, which suggests that it might be possible to stimulate the latter by

[18] Hall and Maffioli (2008) survey evidence from Latin American Technology Development Funds to conclude that research subsidies increase R&D intensity and firm growth, but have little or no significant impact on innovation (patents, new product sales, or productivity). Hussinger (2008) presents evidence from the German manufacturing industry also suggesting that research subsidies have a positive effect on research intensity and, in addition, on new product sales. Czarnitzki et al. (2011) find positive effects of R&D tax credits on product innovation for Canada. Cappelen et al. (2012) find similar effects for Norway at the firm level but not at the market level.

[19] This paper is included in this thesis as chapter 3.

[20] Such growth policies can, however, harm workers with little capital income, in particular if innovation is (partly) labor-saving. Gersbach et al. (2014) show that this can give rise to political conflicts. A resolution of these conflicts may be possible if the tax system allows for both appropriate incentives to perform applied research and sufficient redistribution of the gains from innovation.

[21] In these models, patents enable innovators to earn positive profits, as in the seminal endogenous growth models by Romer (1990) and Aghion and Howitt (1992).

policies supporting the manufacturing industry. Beyond performing applied research, the manufacturing industry may matter more generally for basic research, as it implements product and process innovations and can inspire subsequent research. We will thus now address the connection between basic research and the manufacturing industry in more detail.[22]

2.4. Basic research and the manufacturing base

After the great recession that started in late 2007, the policy-makers of many Western countries are seeking a reindustrialization of their economies with the ambition of fostering future economic growth and prosperity.[23] At the heart of such attempts is the connection between basic research and the manufacturing base. On the one hand, one might ask whether more investment in basic research is needed to rebuild and maintain a strong manufacturing base in western economies. On the other hand, a strong manufacturing base may be needed for basic research to become fully effective and thus to maintain an innovative knowledge economy.

Let us further approach this relationship by raising more detailed questions. Recall that basic research mainly impacts the economy indirectly via applied research by private firms and that there are two-way spillovers between basic and applied research. Moreover, note that manufacturing accounts for the main part of business R&D spending (McKinsey Global Institute, 2012). Does this imply that innovative economies require a strong manufacturing base, both as a consumer and as an inspirer of basic research? Can higher investments in basic research stimulate the manufacturing base? Or can or should countries specialize as scientific and innovative hubs, with manufacturing potentially off-shored? Taking this further still, can gains from innovation give rise to ‘Dutch-disease-like ef-

[22] We limit our attention to the manufacturing industries as, in part, these industries have strong links with basic research and as they feature prominently in policy debates after the great recession. However, our considerations may also apply to other industries that display strong links to (public) basic research, such as the IT sector. Some of the most prominent anecdotal evidence on how basic research matters for innovation is from the IT sector (cf. e.g. Economist, 2013b), and the ‘electronics’ industry, for example, accounts for a significant share of university patents (cf. footnote 47). Obviously there is a significant overlap between the IT sector and the manufacturing industries. To the extent to which this is true, our subsequent discussions also apply directly to the IT industries. This is not the case for software, knowledge management, and dotcom businesses, for example. Subjecting the links from basic research to these industries to careful scrutiny is a further promising avenue for economic research. Such work could conceivably be interesting for manufacturing industries as well. The McKinsey Global Institute (2012), for example, argues that manufacturing industries increasingly add value through high-end services, as opposed to pure manufacturing, and that the use of big data and the management of complexity are important drivers of the future success of these industries.

[23] Cf., for example, Obama (2013) and European Commission (2012b).

fects', actually preventing economies that are at the world technological frontier from being competitive in a variety of (low-tech) manufacturing industries?

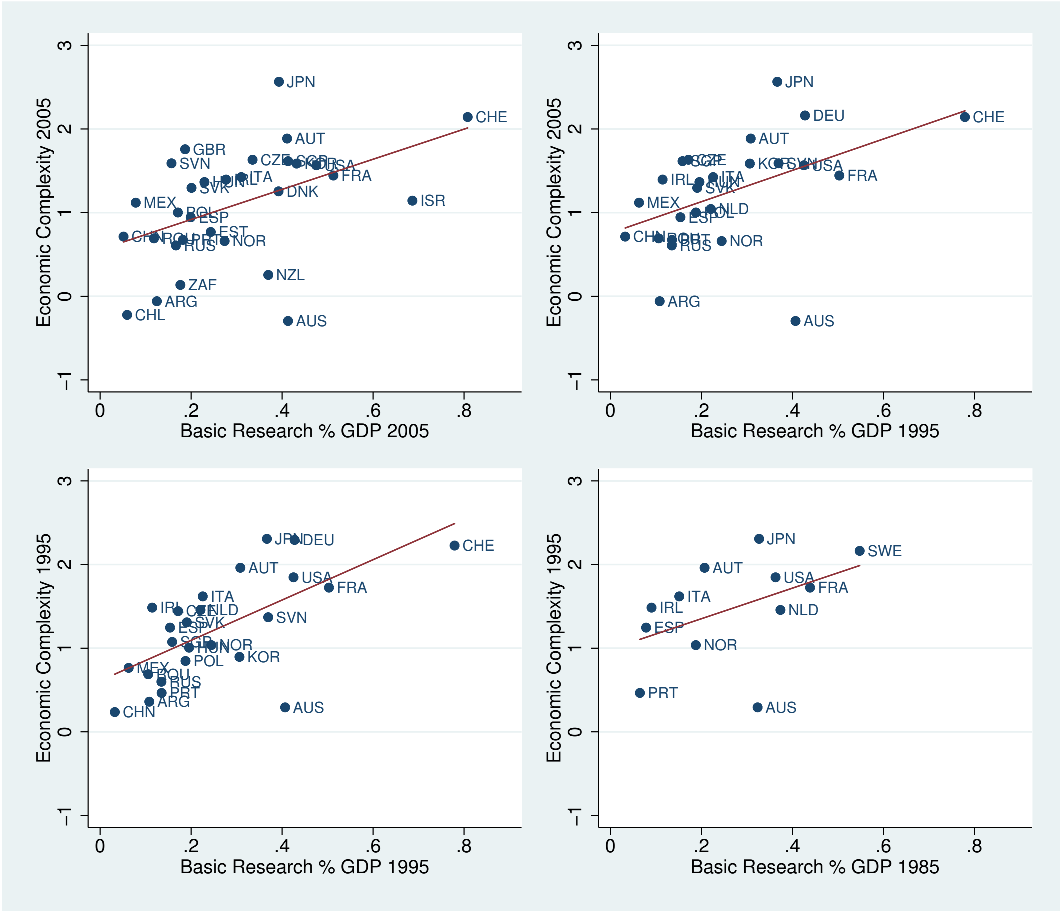
Pisano and Shih (2012) suggest that the manufacturing base is an important element in a country's innovation system. They argue that firms should locally integrate R&D and production, notably in immature industries and in industries with low *modularity*, i.e. in industries where product characteristics and production processes are intimately linked. The McKinsey Global Institute (2012) presents survey-based evidence in support of these conjectures. Their work suggests that the benefits aligned to a local integration of R&D and production are larger for more complex and R&D-intensive industries. They further divide manufacturing into five sectors. Based on this clustering, local manufacturing seems to be of particular relevance for innovation in the 'global innovation for local markets' sector (including industries such as 'chemicals', 'pharmaceuticals', and '(electrical) machinery') and the 'global technologies / innovators' sector (including industries such as 'semiconductors', 'electronics', and 'medical, precision, and optical equipment'). These industries are characterized by innovation- and/or quality-based competition and high R&D intensity. Following the innovation process further up and considering the local effects of basic research, this points to potentially significant benefits from liaising basic research with a strong manufacturing base, especially in these high-tech industries.

The gains from basic research for (manufacturing) industries have been analyzed in several empirical studies. In an early attempt, Mansfield (1980) and Link (1981) found a significant positive effect of private basic research investments on productivity in manufacturing industries. Their results were corroborated by Griliches (1986) and Czarnitzki and Thorwarth (2012), for example. Both studies also find a premium for basic over applied research, where Czarnitzki and Thorwarth (2012) show that this premium is higher for high-tech industries than low-tech industries, thus endorsing the above reasoning. Adams (1990) analyzes the impact of capitalized measures of university research on productivity growth in manufacturing industries. He finds strong positive – albeit lagging – effects. Guellec and Van Pottelsberghe de la Potterie (2004) and Luintel and Khan (2011) present cross-country studies taking into account public and private investments in research, indicating positive aggregate effects of public research on productivity.

These studies are based on simplified production functions, and the underlying empirical strategies have been criticized on various grounds.[24] Figure 2.4 takes a different approach. It plots countries' basic research intensity against a measure of economic complexity, as proposed by Hidalgo and Hausmann (2009) and Hausmann et al. (2011). This measure is based on a binary trade matrix, indicating for every country those products for which it

[24] Cf. footnote 23 in chapter 1.

Figure 2.4.: Basic research and economic complexity



Source: Own illustration based on data taken from http://atlas.media.mit.edu/rankings and from OECD (2012a). The data was downloaded in June 2013. Values on both axes refer to 5-year centered moving averages. 'Economic Complexity' is the index value as downloaded from http://atlas.media.mit.edu/rankings.

has a revealed comparative advantage.[25] Broadly speaking, a country has a high value of economic complexity if it is a strong exporter of complex products, i.e. products exported by a few highly developed economies. Hidalgo and Hausmann (2009) and Hausmann et al. (2011) demonstrate that their measure has several favorable properties.[26]

The economic complexity index is based solely on the international trade of physical goods. Hence it either reflects the strength of an economy's manufacturing base or its potential for offshoring production and refining domestically. Considering both contemporaneous and 10-year-lagging investments, Figure 2.4 shows that basic research investments are strongly positively correlated with this measure.[27] Obviously, these simple

[25] Hidalgo and Hausmann (2009) and Hausmann et al. (2011) propose assessing revealed comparative advantages using the measure originally developed by Balassa (1965).

[26] Among others, it is strongly positively correlated with GDP per capita and it has some predictive power for future economic growth. A new variant of this methodology, which might capture the underlying idea even better, has been proposed by Tacchella et al. (2012).

[27] The correlation coefficients are 0.47 (2005) and 0.65 (1995) if current basic research investments are

correlations are preliminary. Considering the previously stated opposing interpretations of the link between economic complexity and the manufacturing base, they are not sufficient to answer the questions raised above. They are, however, a promising starting point for a more detailed examination of this mutual interdependency.

2.5. Intellectual property rights for basic research

The protection of intellectual property rights (IPR) is another policy area of immediate relevance for basic research. As the literature exploring the optimal design of IPR is extensive, a detailed review is beyond the scope of our work here. We briefly review the literature on two policy issues that are of primary importance here, that is (a) patent protection for upstream innovations and (b) university patenting.[28] Classical arguments in favor of patents suggest that they provide private firms with incentives to invent *and* to disclose these inventions (Eisenberg, 1989).[29] Hence patent protection for upstream innovations may be used as a (partial) substitute for the public funding of basic research. University patenting, on the other hand, is of primary importance for the cost and benefits associated with public basic research.

Patent protection for upstream innovations

A classical argument in favor of patents on upstream innovations refers to their importance for downstream R&D. Kitch (1977) made this point quite some time ago. He argues that embryonic inventions may require exclusive patents to provide firms with the incentives necessary for investment in commercialization.[30] He further suggests that upstream patent rights enable their owner to coordinate cumulative research, thus improving the efficiency of these investments.[31] And he points to the fact that patents facilitate contracting, thus

considered, and 0.47 (2005) and 0.46 (1995) if 10-year-lagging basic research investments are considered.

[28] The interested reader is referred to the reviews of World Intellectual Property Organization (2011) and Hall and Harhoff (2012), for example. Thursby and Thursby (2008) and Montobbio (2009) review the literature specifically addressing the impact of university patenting.

[29] These benefits are, however, disputed in the literature. Cf. Levin et al. (1987) and Cohen et al. (2000), for example, for studies questioning the efficiency of patents in overcoming the appropriability problem, and the discussions on disclosure of research outcomes in patents in Eisenberg (1989) and Boldrin and Levine (2013).

[30] However, whenever downstream inventions can be patented, the need for upstream patents based on this line of reasoning is less evident (cf., for example, Kitch, 1977; Mazzoleni, 2006; Hellmann, 2007).

[31] By contrast, Merges and Nelson (1990) argue that competitive forces are preferable to coordination by an upstream monopolist.

raising the potential for joint and/or cumulative innovation efforts.[32]

These arguments notwithstanding, the increased patenting of outcomes from basic research has raised concerns in the literature. One major misgiving is that it might impede rather than stimulate downstream innovation as a consequence of the *anticommons effect*. In its most general form, the anticommons effect refers to the observation that any privatization of upstream innovations is costly, as non-rivalrous scientific knowledge should be fully and freely disseminated.[33]

Different facets of such anticommons effects have been identified. Scotchmer (1991), for instance, argues that upstream patents impose a tax on downstream innovation, thus potentially preventing investment in socially beneficial projects. Hence, with private investment in upstream innovation, patent policies need to trade off incentives for upstream innovation against incentives for downstream innovation.[34] Merges and Nelson (1990) argue that because benefits from upstream innovations are diverse and uncertain, and because the cognitive capabilities of corporations are bounded, (exclusive) licensing of basic research innovations typically results in missed opportunities. Murray and Stern (2007) analyze patent/paper pairs to find that upon granting a patent, the citations of the associated paper drop significantly, thus suggesting that patents do hinder the diffusion of the underlying knowledge, even within the sphere of basic research.

Referring to the biomedical industry, Heller and Eisenberg (1998) argue that additional problems arise if upstream patent rights are fragmented. In that case, transaction costs may be prohibitively high, leading to a *tragedy of the anticommons*. Shapiro (2001) takes up this idea and argues that similar problems related to *patent thickets* arise in other industries such as the semiconductor industry or the software industry. He argues that the market structure resembles one with complementary monopolies, as originally studied by Cournot (1838), and that hence upstream patent holders may charge inefficiently high license fees, even in the absence of transaction costs. What is worse, Shapiro (2001) points to the fact that *hold-up* problems might prevent downstream manufacturers from innovating in the first place, especially when facing uncertainty over patent eligibility and patentability.[35] The relevance of patent thickets is supported by theoretical and empirical

[32] Cf. also Arora et al. (2001), who argue that intellectual property rights might also facilitate the cross-firm transfer of complementary tacit knowledge.

[33] Cf. the discussion in section 1.5.

[34] These trade-offs involved in cumulative innovation processes have received much attention in the literature (cf. Scotchmer, 1991; Chang, 1995; Green and Scotchmer, 1995; Hopenhayn et al., 2006; Cozzi and Galli, 2014).

[35] Several authors express concern about an increase in patenting uncertainty. Boldrin and Levine (2013), for example, argue that the legal system has caused an increase in uncertainty. Hall et al. (2013) point to the fact that the number of patents pending has sharply increased. They also refer to several other studies expressing concern about increased uncertainty.

work.[36] These patents on upstream innovations do not necessarily refer to basic research, and, as a matter of fact, they frequently do not.[37] Still, the difficulties associated with upstream patenting provide additional support for at least some sort of public funding for basic research, as discussed in section 1.5.

University patenting

Most industrialized countries have strengthened university patenting in the past. The Bayh-Dole Act of 1980, allowing US universities to acquire patent rights over innovations from federally funded research, is a milestone in this regard. In the sequel, the Bayh-Dole Act was backed up by further policy changes and court decisions in the US and inspired policy changes in other industrialized economies.[38]

As pointed out by Verspagen (2006), university patents are paradoxical insofar as publicly funded research (patronage) is generally seen as an alternative to patents for resolving the appropriability problem inherent in scientific knowledge.[39] Indeed, Thursby and Thursby (2008) argue that university patents are not needed for university invention and disclosure per se. They are mainly justified as a means of fostering the commercialization of university inventions.[40] Patents incentivize university researchers in a different way from the academic community, notably if they enable researchers to participate in licensing revenues as under the Bayh-Dole Act. Proponents of university patenting argue that these incentives help to move *'nascent discoveries out of the 'ivory tower' and into commercial practice'* (Murray and Stern, 2007, p. 649). For example, they may induce university researchers to contribute their tacit knowledge to applied research and development.[41] On a similar note, these incentives may also direct researchers towards less fascinating ba-

[36] Lerner and Tirole (2004), Boldrin and Levine (2005), Llanes and Trento (2011), and Llanes and Trento (2012), for example, present theoretical models analyzing patent thickets. Empirical studies suggest that patent thickets can have adverse effects on innovation and market entry, among other impacts (cf. the discussion of this literature in Hall et al. (2013) for further details). The evidence available for university research, however, suggests that patent thickets seem to be less severe in this sector (cf. Huys et al., 2009; Walsh et al., 2012).

[37] Cf. the discussion of the origins of patent thickets in Hall et al. (2013) and the discussion of industry effects in Boldrin and Levine (2013), for example.

[38] Cf. Rai (1999), for example, for a review of US developments, and OECD (2003) and Mowery et al. (2004) for reviews of related policy changes in other countries.

[39] Cf. also Mowery et al. (2001).

[40] Arguments originally supporting the introduction of the Bayh-Dole Act generally centered on the importance of upstream patenting in incentivizing private downstream innovation in the spirit of Kitch (1977) (cf. e.g. Mowery et al., 2004; Cohen, 2004).

[41] Thursby and Thursby (2002) suggest several reasons why additional incentives are needed. In particular, they argue that researchers may dislike being involved in commercialization because of delay-of-publication clauses in licensing agreements, or because they are unwilling to spend their time on applied research. Cf. also the discussion in Howitt (2013).

sic research that has potentially high commercial value.[42] More generally, patents may help to bridge the university/industry gap by strengthening the awareness of university researchers for the commercial value of their work.[43]

However, opponents of university patenting fear that these incentives may undermine the Mertonian norms of science and believe that as soon as patenting is permitted the requirements for *universalism*, *communism*, *disinterestedness*, and *organized skepticism* are endangered.[44] This concern has some merit: in particular, patents arguably undermine the culture of open science.[45] Moreover, when universities strive to maximize *'expected revenues from intellectual property'* (Nelson, 2004, p. 469), they may shift the focus of their research from basic toward more applied research.[46]

While technology transfer offices have sharply increased their activities since the Bayh-Dole Act, the empirical evidence on the effects of an increase in university patenting is mixed at best, and the associated costs and benefits are still an open issue for future work in this area.[47] As Montobbio (2009, p. 194) puts it: *'We do not know whether scientists are shifting their resources toward other unpatented activities and we do not know whether the very productive scientists who patent and publish are, because of the patents, publishing at a suboptimal rate.'*

[42] Cf. also Aghion et al. (2008), for example, on the valuation of creative control by university researchers.

[43] Cf. Verspagen (2006), for example.

[44] Cf. Merton (1942).

[45] Cf., for example, Rai (1999), Krimsky (2003), Nelson (2004), and Verspagen (2006). Verspagen (2006) argues that this might happen either directly (because research cannot be published prior to patent application) or indirectly (because scientists may behave competitively rather than cooperatively when striving for patenting).

[46] Cf. Mowery et al. (2001), Thursby and Thursby (2002), and McManis and Noh (2012).

[47] In the US, disclosure of inventions to technology transfer offices as well as university patenting and licensing have sharply increased over the last few decades (cf., for example, Thursby and Thursby, 2008). Evidence for Europe is limited, but developments, though less pronounced, tend to point in the same direction (Geuna and Nesta, 2006; Montobbio, 2009). These patterns are, however, centered on a few industries, such as biomedicine, chemicals, and electronics, in particular, and they are only partly attributable to changes in IPR (cf., for example, Henderson et al., 1998; Mowery et al., 2001). Furthermore, the existing evidence does not allow conclusions on the importance of university patents for this development (cf. Thursby and Thursby, 2008; Verspagen, 2006). Geuna and Nesta (2006), Thursby and Thursby (2008), and Montobbio (2009) review the empirical evidence on the potential cost of university patenting. They find some evidence pointing to an increase in secrecy in university research. Referring to the biomedical industry, Cockburn and Henderson (2001) suggest that an increase in secrecy might harm the efficiency of innovation systems. However, the causal impact of university patenting on these trends is unclear (cf. also McManis and Noh, 2012). With respect to the research agenda, these authors find little support for the view that university patenting has compromised basic research, e.g. by shifting research toward more applied work. Thursby et al. (2007) present a model suggesting that while patenting increases the applied-to-basic research ratio, the increase in applied research tends to be compensated by a decrease in leisure time rather than in terms of time spent on basic research.

2.6. Commercializing basic research

Notwithstanding the strengthening of university patenting and technology transfer activities, a significant share of university inventions still remain in the *ivory tower*. Technology transfer offices estimate that possibly less than half of the commercially valuable university inventions are actually reported to them.[48] Hence the improved commercialization of publicly funded basic research remains an important policy issue and *'it is hard to find a policy document from government, business or university sources that does not call for greater, wider or deeper 'interactions' between private business firms and the universities'* (David and Metcalfe, 2007, p. 22).

To the extent to which such policies improve the knowledge transfer to the business sector, they should have positive effects on economic growth and innovation. However, these endeavors may result in a shift of public research towards *Pasteur's Quadrant* or even beyond it.[49] This may either happen unintentionally, when researchers react to incentives for an improved commercialization of their research,[50] or it may be effectuated purposefully by governments as a means of increasing the commercial gains from publicly funded research.[51] In this regard, Canada announced in May 2013 that it intended to direct its National Research Council toward more applied research and to transform the Council into a *'business-driven, industry-relevant research and technology organization'* (Goodyear, 2013). This shift in prioritisation of publicly funded research followed a key recommendation of the Jenkins Report (Independent Panel on Federal Support to Research and Development, Canada, 2011). It is, however, in contrast with earlier recommendations for public research policies. The OECD (2002a), for example, advocates greater priority for more long-term oriented, basic research as a basis for sustainable economic growth.[52]

It is of utmost importance for the long-term growth perspectives of developed and emerging countries to explore both the potential and, even more, the socially desirable limits on the commercialization of basic research. Yet the latter issue has been given little attention in the literature so far. As Thursby and Thursby (2008, p. 224) conclude with regard to the literature on university patenting: *'The overarching issue that is largely ignored*

[48] Cf. Thursby and Thursby (2008).
[49] Cf. footnote 8 in chapter 1 for a brief discussion of the term *Pasteur's Quadrant*.
[50] Cf. the discussion in section 2.5.
[51] Turning university research more toward applied research bears the potential of increasing its immediate commercial value. In addition, Arvanitis et al. (2008) suggest that university departments with a focus on applied research are more intimately involved in the commercialization of their work.
[52] The reorganization of the National Research Council, however, need not necessarily imply a reorientation of public research toward more applied research. Howitt (2013), for example, argues that public basic research may best be shifted toward universities. In such case, he suggests, the National Research Council may be transformed into something like a federal technology transfer office.

in this work is whether increased commercialization of university inventions is socially desirable.'

We highlight three key arguments why such limits exist and should be taken into account by policy-makers. First, a stronger emphasis on research promising high commercial value at first sight may not yield the intended effects. Howitt (2013) points to the fact that both the universities and the individual scientists that are the most successful in technology transfer tend to be the ones that excel on academic grounds. These scientists tend to be motivated by research interests and by scientific prestige rather than commercial gains from their work. Moreover, Howitt (2013) argues that firms attempting to commercialize the gains from public basic research prefer to tie in with the universities that lead the field on academic grounds. Together, these considerations suggest that scientific excellence is key for large commercial gains from public investments in basic research. Considering this, countries should promote curiosity-driven, truly fundamental research.

Second, with the hierarchical order between basic and applied research in mind, there are socially desirable limits on the commercialization of university inventions, as identified in Gersbach et al. (2010b). If incentives for commercialization are too strong, the knowledge base would eventually be compromised, thus reducing the potential for developing new and refined products or processes in applied research. This would ultimately have a negative effect on the rate of innovation.[53] As a polar case, consider the scenario where basic research determines long-term growth, so that more applied research is only beneficial for growth within the boundaries set by basic research.[54] Then a significant redirection of basic research in favor of applied research, which relies on the knowledge base, would reduce the rate of innovation, at least in the long run.

Third, even if a stronger emphasis on commercialization of university research increased the commercial gains while the knowledge base was not compromised directly, such policies may have adverse effects in the long run. Geuna and Nesta (2006) stress that the distribution of university licensing income is highly skewed, implying that a stronger reliance on commercial gains may undermine the plurality of the university system. With serendipity being an important factor for scientific progress (Nelson, 2004), this may harm the effectiveness of the national research system.

Overall, the above reasoning suggests that, while a stronger focus on the commercial-

[53] If the knowledge base is a global public good, this logic primarily concerns aggregate levels of innovation and may apply less to single countries. Individual countries can, in principle, free ride and primarily try to commercialize the existing knowledge base. Yet, at an aggregate level, this will eventually cause underinvestment in knowledge creation. In addition, to the extent to which local basic research matters for private innovation, focusing strongly on the commercialization of university invention may be undesirable, even from a single country's perspective (cf. sections 1.3.2 and 1.4.1).

[54] Cf. the discussion in section 2.3.

ization of publicly funded research may be beneficial in the short run, it could imply less innovation and less economic growth in the long run. Further research is needed to substantiate this conjecture.

2.7. Allocating basic research funds

Considering the substantial public investments in basic research, a further immediate policy issue is how to allocate these funds. More particularly, we need to ask where to allocate these funds, on what grounds, and who should be responsible for the decisions underlying allocation.

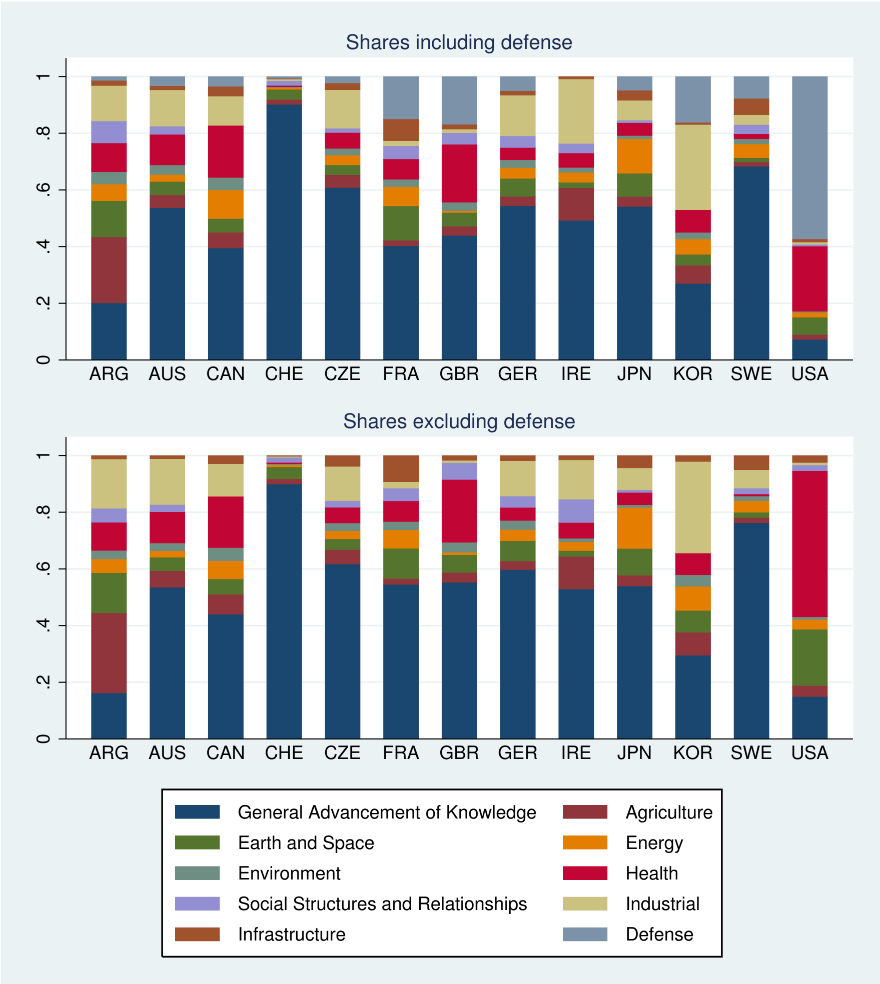
Targeting basic reserch

We first address the question whether or not public funds for basic research should be targeted. Should they, for instance, be channeled into dealing with specific socio-economic needs, into economic sectors, or fields of science? And if so, why? To help lagging industries reach the world technological frontier? To support domestic industries that are particularly active in applied research? Or to establish scientific centers of excellence? On the other hand, any such targeting may undermine serendipity and interdisciplinary spillovers. Do these offsetting effects justify spreading basic research funds across fields of science? A deeper understanding of these costs and benefits is critical for informed policy-making in this area.

Cohen et al. (2002) present survey-based evidence highlighting the relevance of these policy issues. In particular, they identify the fields of science drawn upon for a selection of industries. Their evidence confirms the basic intuition that first, fields of science significantly differ in their overall direct relevance for the private sector; and second, that the importance of any given field of science varies significantly across industries. These findings provide means for targeting basic research investment to the needs of specific industries, if desired.

Figure 2.5 shows data further emphasizing the importance of these policy issues from a different perspective. It considers a selection of 13 countries and compares proportions of public resources for research by socio-economic objective. The chart suggests that countries differ widely in their concentration of public funds for research, with Switzerland and the US representing the polar cases. While Switzerland devotes almost 90% of these funds to the 'General Advancement of Knowledge', the US spend almost 60% on

Figure 2.5.: Government budget obligations or outlays for R&D by socio-economic objective, 2008

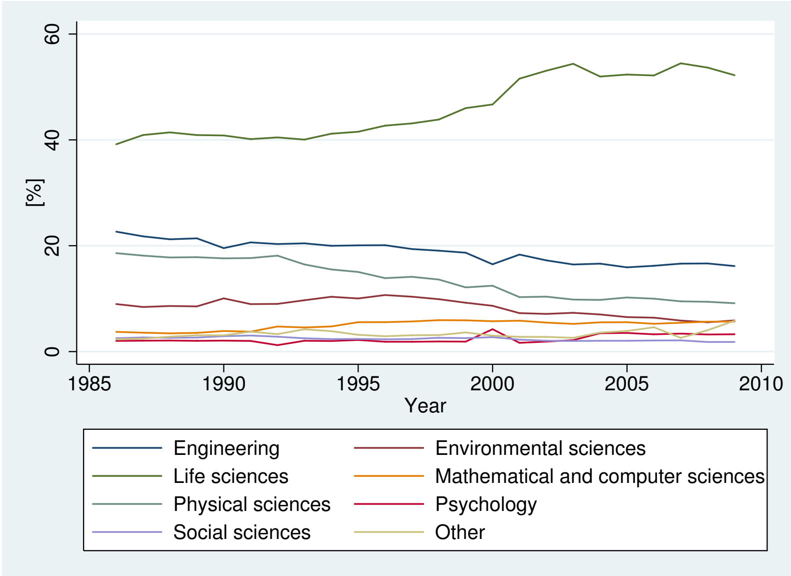


Source: Own illustration, based on OECD (2012b). The data was downloaded in June 2013 and was grouped as follows:

- *General Advancement of Knowledge* := 'General advancement of knowledge : R&D financed from General University Funds (GUF)' + 'General advancement of knowledge : R&D financed from other sources than GUF';
- *Agriculture* := 'Agriculture';
- *Earth and Space* := 'Exploration and exploitation of the earth' + 'Exploration and exploitation of space';
- *Energy* := 'Energy';
- *Environment* := 'Environment';
- *Health* := 'Health';
- *Social Structures and Relationships* := 'Education' + 'Culture, recreation religion and mass media' + 'Political and social systems, structures and processes';
- *Industrial* := 'Industrial production and technology';
- *Infrastructure* := 'Transport, telecommunication and other infrastructures';
- *Defense* := 'Defence'.

The data for Argentina, Australia, Canada, Switzerland, Japan, and the United States refers to the corresponding federal or central government only. Canada and South Korea do not report information on what we define as 'Social Structures and Relationships'. In the case of South Korea, these data are included in our 'General Advancement of Knowledge' aggregate.

Figure 2.6.: Share of US federal obligations for research by field of science



Source: Own illustration, based on National Science Board (2010) and National Science Board (2012). The data was downloaded from http://www.nsf.gov/statistics/seind10/appendix.htm and http://www.nsf.gov/statistics/seind12/appendix.htm, respectively, in March 2013.

defense-oriented research (upper graph). Within civil R&D, the US concentrate more than 70% of total funds on healthcare-oriented research and on the exploration of the earth and space (lower graph). As Figure 2.6 shows, the strong concentration of research funds in the US also applies to fields of science, with a focus on the life sciences. Moreover, this concentration has been increasing over time. This targeting of public basic research has important implications. It is reflected, for instance, in university patenting and publications.[55]

An in-depth understanding of the forces and agents shaping these patterns could provide helpful guidance for basic research policies. These issues are particularly important at the moment, as several countries are initiating policies similar to those of the US. The European Commission seeks to achieve reindustrialization by concentrating investment on ‘advanced manufacturing technologies for clean production’, ‘key enable technologies’, ‘bio-based product markets’, ‘sustainable industrial policy, construction and raw materials’, ‘clean vehicles and vessels’, and ‘smart grids’ (European Commission, 2012b). Such strategies would necessarily involve a significant amount of targeted basic research. Ireland has implemented a Research Prioritisation Steering Group, which has identified 14 priority areas for Ireland’s science, technology, and innovation strategy (Research Priori-

[55] In 1998, 41% of US university patents were in one of three areas of biomedical research (Geuna and Nesta, 2006). Similarly, US publications are concentrated in biomedical and clinical research (UNESCO, 2010).

tisation Project Steering Group, Ireland, 2012).[56]

Despite its relevance, the concentration of research funds has been given little attention in the literature so far. Nelson (2004) provides historical explanations for the strong concentration of research expenditure found in the US. He argues that such concentration was inspired by experience from World War II. During that time, publicly funded research made important contributions to the development of new weapons and to the improvement of healthcare. He also points to the fact that today, most funds are provided by mission-oriented agencies. These explanations, however, do not provide insights on the desirability of this strategy today. Polanyi (1962) argues that an *invisible hand* guarantees the efficient coordination of research efforts, and that any kind of directive by central authorities would impede this coordination process. Geuna and Nesta (2006) promote diverse public research, because it is impossible to identify fruitful avenues for research ex-ante. Callon (1994) suggests that diverse public research is needed to counteract specialization tendencies inherent in private markets. Schneller (2011, chapter 5) establishes conditions under which targeting basic research on specific sectors may be beneficial or may merely improve production in some sectors at the cost of compromising production in others. While these arguments are a first step, whether and how basic research expenditure should be targeted remains an important issue for future economic studies.

Allocation procedures

We next address the underlying decision mechanisms. Who should decide whether and where to distribute the funds? Dasgupta and David (1994) summarize the public debate that took place in the US in the early nineties. This debate called for stronger state control over the allocation of these funds. This was motivated by the fear that the *republic of science* might divert funds into purely curiosity-driven research and *big-science* enterprises. More generally, scientists may be expected to be biased toward their lines of research. Politicians, on the other hand, are also prone to be guided by factors other than social interest. Stephan (2012) presents a political-economy explanation for the strong US focus on healthcare-related research. Investments in health sciences are easy to justify in general. Interest groups lobby heavily to support research for specific diseases. Moreover, decision-makers are fairly old on average and are thus potentially guided by personal interests. Furthermore, politicians (or bureaucrats) have inferior knowledge of the potential gains from different lines of research compared to the scientists who are di-

[56] These areas were identified on the basis of the competitiveness of Irish companies, the complementarity with private (applied) research, the existing scientific expertise, and relevance. They represent socio-economic needs and do not necessarily imply a concentration toward specific fields of science.

rectly involved. These arguments point to important shortcomings in state control over these decisions. Hence any decision mechanism will inevitably have to trade off different costs and benefits, and further guidance is needed on how to weigh them.

If we go one step further, the allocation of basic research funds also encompasses the allocation to institutions and individual researchers. Stephan (2012) distinguishes and discusses five different allocation mechanisms: block grants, peer reviews, departmental assessments, earmarked funds, and prizes. Many European countries have a long tradition of allocating funds as block grants, thus liberating institutions and researchers from the obligation to raise funds for their research. In the US, by contrast, faculty members rely more on research grants, and 6 out of every 10 dollars from federal funds are allocated based on peer reviews (Stephan, 2012). While block grants and earmarked funds allow for long-term-oriented, fundamental, and highly uncertain research, i.e. more basic research, and may thus foster serendipity, they may at the same time lack accountability. Several countries have therefore switched to systems that put stronger emphasis on past performance and peer reviews, at the potential cost of increasing risk aversion among researchers and discriminating against young researchers (Stephan, 2012). These mechanisms may also undermine the diversity of researchers, which is identified by Acemoglu (2011) as a means of counteracting tendencies of the market economy to specialize inefficiently. Again, the various costs and benefits involved have to be carefully weighed against each other.

These costs and benefits may well vary across lines of research. One plausible conjecture is that the more research is slanted toward *Pasteur's Quadrant* (i.e. the more it has a specific practical use in view), the more funding can optimally be based on grants and peer reviews. However, when it comes to truly fundamental basic research partly relying on serendipity, such grant-based funding may well undermine the diversity and risk-taking needed in the research process. Then block grants may be preferable, as they enable individual researchers to exploit their superior knowledge and pursue those lines of research they deem best.

2.8. Conclusion

In Part I of the thesis we have argued that basic research is not only a key driver of modern economic growth, but is also an area in which policy-makers have ample room to make decisions that can foster the long-term well-being of their citizens. It is evident that policy decisions in the area of basic research have to be taken under conditions of major uncertainty. Technological progress can be fostered but not fully described ex ante in any detail or even guaranteed. It is thus of the greatest value to focus policy-makers on critical decisions and to combine conceptual reasoning and empirical evidence to take such decisions on the basis of the best information and reasoning possible. Our work attempts to contribute to the knowledge base for such decisions and to identify the most pressing issues for which uncertainty could – and should – be reduced.

In Part II of the thesis we will take one step further by scrutinizing one specific basic research policy issue: the interplay of basic research and tax policy in stimulating innovative entrepreneurship.

Part II.

Taxation, Innovation, and Entrepreneurship

3. Foundations and Key Results*

3.1. Introduction

The contribution of innovative entrepreneurship to the well-being of societies has been a constant concern for policy-makers and is at the center of policy debates on how to induce growth in the Eurozone (Economist, 2012). In Part II of the thesis, we will be examining two key drivers that shape entrepreneurial activities in societies and that are prominent in academic and policy debates: basic research and taxation.[1]

Basic research is a sophisticated public good. The main beneficiaries are innovating entrepreneurs: basic research improves their chances of developing new varieties or new, less cost-intensive production technologies.[2] At the same time, these innovating entrepreneurs are needed for basic research investments to become effective: basic research is embryonic in nature and only impacts indirectly on the economy via applied research and commercialization. In this part of the thesis we ask how much of this public good should be provided and how it should be financed. We further inquire whether optimal policies can be politically implemented.

Providing and financing basic research is an intricate task. Taxation will not only help to fund these investments, it will also impact on the entire economy through a variety of feedback effects. In particular, basic research investments and tax policies jointly impact on:

- the occupational choice of individuals to become entrepreneurs;
- wages earned by workers;

* This chapter is based on a joint paper with Hans Gersbach and Maik Schneider.

[1] Cf. European Commission (2008), European Commission (2013), and General Secretariat of the European Council (2010), for example. With the ambition to stimulate innovation and growth, the European Union is aiming towards directing 3% of GDP to R&D by 2020, 1/3 of which is supposed to be publicly funded (basic) research. The Netherlands, for example, have strengthened tax incentives for entrepreneurship and innovation (Government of the Netherlands, 2010).

[2] The positive effect of basic research on applied research has been the subject of several studies (cf. Gersbach et al. (2010b) for a discussion of the literature). Link and Rees (1990) and Acs et al. (1994) provide evidence suggesting that small firms may benefit particularly strongly from university R&D.

– dividends paid to shareholders by final-good producers;

– aggregate output.

We address these interdependencies in a general equilibrium framework. We develop a simple model of creative destruction where a final consumption good is produced using labor and a continuum of indivisible intermediate goods as inputs. Agents can either work in the final-goods sector, in the intermediate-goods sector, or they can become entrepreneurs or basic researchers. Entrepreneurs can benefit from basic research provided by the government and invest in applied research to develop labor-saving technologies for intermediates. Successful entrepreneurs will earn monopoly profits. In addition, entrepreneurship has immaterial costs (such as entrepreneurial effort cost) and benefits (such as initiative and social status). Potential entrepreneurs weigh these costs and benefits against the labor income lost when deciding on whether or not to become entrepreneurs. The government finances its basic research investments using a combination of labor income, profit, and (potentially) lump-sum taxes. This financing decision also affects the occupational choice made by potential entrepreneurs and hence impacts on the effectiveness of basic research investments.

Results and implications

Our first main insight is that financing basic research – a public good that impacts the economy indirectly through various channels – rationalizes a taxation pecking order. In particular, when innovations can potentially lead to labor savings that exceed labor used for entrepreneurial activities and basic research, it is desirable to have an innovative economy with dense entrepreneurial activities and basic research (called an *entrepreneurial economy*). In an entrepreneurial economy, a large share of funds for basic research should be financed by labor income taxation, while a minor share should be left to profit taxation. The fact that tax rates on one source of income (here labor) are higher than tax rates on another source (here profits) is called a *taxation pecking order*. The pecking order – primarily reliant on labor income taxes – ultimately arises from the complementarity of basic research investments and tax policies: the taxation pecking order induces a significant share of agents to become entrepreneurs, thereby increasing the benefits from investments in basic research.

However, labor-saving innovations lead to declining real wages so optimal policies in an entrepreneurial economy will harm workers with little shareholdings. These distributional effects can give rise to a conflict between efficiency and equality that will undermine political support for growth policies. To examine this conflict, we assume a political economy perspective and analyze growth policies in a median voter framework. We show that if shareholdings are skewed to the right the median voter may reject any growth-stimulating entrepreneurial policies. Then the society is 'trapped' in a *stagnant economy*. Furthermore, even if the median voter supports a growth-stimulating entrepreneurial economy, her preferred basic research investments and tax policy will both still be inefficient vis-à-vis the social optimum. Basic research investments tend to be too low, thus providing a rationale for the surprisingly high rates of return to public investments in (basic) research typically found in empirical studies.[3] Interestingly, these inefficiencies are mitigated as upper bounds on taxation increase. Then tax incentives to entrepreneurs (efficiency) and the redistribution of gains from innovation (equality) can be better aligned. Larger upper bounds on taxation allow for more redistribution to the median voter, thus potentially satisfying equity concerns and making growth policies politically feasible. At the same time, larger upper bounds on tax rates allow more flexibility in the relationship between tax rates on labor income and profits, which is decisive for entrepreneurship and innovation and hence for efficiency concerns.

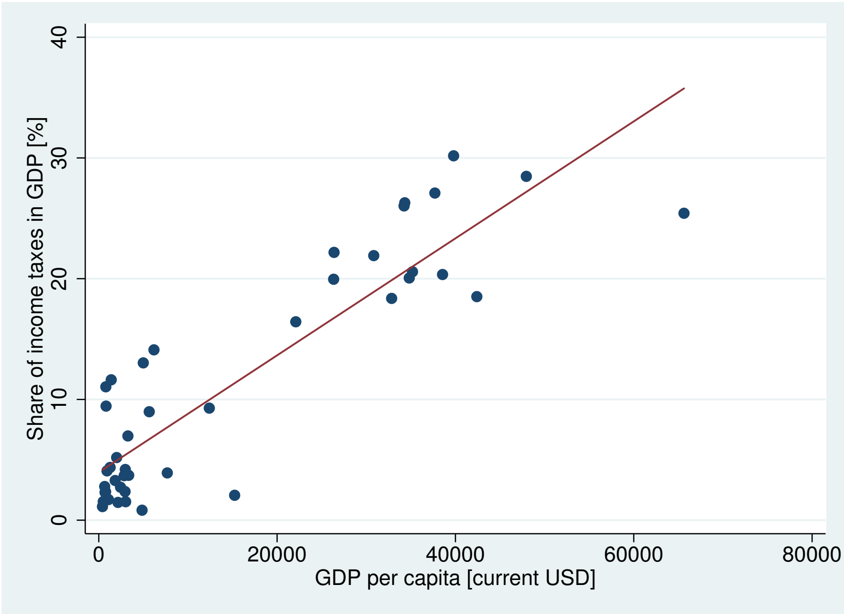
The insights above may have implications for two determinants of the boundaries of tax rates: constitutional bounds and fiscal capacity. Constitutional bounds to taxation are sometimes proposed as a means of protecting investors from excessive indirect expropriation via tax policies.[4] We show that while low upper tax bounds do indeed protect firm-owners if growth policies are given, they may actually harm firm-owners if these growth policies are subject to the political process. Then low upper bounds on taxation may undermine the political support for growth policies, and the society may be 'trapped' in a stagnant economy with little entrepreneurship and low profits. Indeed, we will argue that in a constitutional design phase behind the veil of ignorance bounds on taxation are likely to be rejected.

Alternatively, tax bounds may implicitly arise from fiscal capacity, '*economic institutions inherited from the past*' (Besley and Persson, 2009, p. 1219) that determine the government's ability to collect taxes. Figure 3.1 plots fiscal capacity against GDP per capita for a cross-section of countries, where following Besley and Persson (2009) we have used

[3] Cf. Salter and Martin (2001) for an overview of such studies and Toole (2012) for a more recent example.

[4] The Swiss constitution, for example, introduces restrictive bounds on direct taxes at the federal level: '*The Confederation may levy a direct tax: a. of a maximum of 11.5 per cent on the income of private individuals; b. of a maximum of 8.5 per cent of the net profit of legal entities*' (Article 128.1, Federal Constitution of the Swiss Confederation). Tax provisions are also repeatedly at the center of constitutional court rulings, and in many countries there are at least implicit tax bounds. The French constitutional court, for example, has stated that a total tax burden of 90.5% would not be admissible (cf. Conseil Constitutionnel de la République Française, 2013). Supermajority rules for tax increases are an alternative to bounds on tax rates. Several US states, for example, have such provisions, and they have also been proposed at the federal level in the past (cf., for example, National Conference of State Legislatures, 2010; Gradstein, 1999).

Figure 3.1.: Fiscal capacity and GDP per capita



Source: The data on the share of income taxes in GDP is taken from Besley and Persson (2009) and refers to averages from 1975 onwards. The data on GDP per capita is taken from World Bank (2013) and refers to 5-year centered moving averages in 2005. Countries with a share of oil revenues in GDP of more than 50% have been excluded from the sample. The data was downloaded in July 2013.

income taxes over GDP as a proxy for fiscal capacity. This plot indicates a strong positive relationship between fiscal capacity and GDP per capita. We provide a political economy rationale explaining why weak fiscal institutions may harm growth prospects. In a nutshell, weak fiscal institutions do not allow for sufficient redistribution to let a critical mass of the population participate in gains from growth-stimulating policies. Accordingly, they may undermine the political support needed for the implementation of such policies.[5]

This chapter is organized as follows: section 3.2 situates our work in the literature. Sections 3.3 and 3.4 outline the model and derive the equilibrium for given tax policies and basic research investments. In section 3.5 we analyze aggregate-consumption-optimal policies. Section 3.6 presents an analysis of the political economy of financing basic research. Section 3.7 concludes. We provide several robustness checks for our pecking order result and some additional details on the political economy of financing basic research in the appendix. Also, all the proofs are to be found in the appendix. Finally, we will discuss some extensions and provide corroborative results in chapter 4.

[5] Weak fiscal institutions are typically associated with developing countries, which are also the main focus of Besley and Persson (2009). However, industrialized economies may also suffer from weak fiscal institutions. As an example, the European Commission (2012a, p. 12) advances the view that '*currently Greece suffers from a lack of capacity to [...] collect taxes*'. While it is certainly concerned about rebalancing Greek public finances, it is also concerned about the '*fairness of the tax system*' (p. 11) and about ensuring that the '*burden of adjustment is fairly distributed*' (p. 13).

3.2. Literature

Our work is related to several important strands in the literature.

Rationale for public funding of basic research

The case for the public funding of basic research is well established in the literature, at least since the seminal paper of Nelson (1959). He identifies fundamental conflicts between providing basic research and the interests of profit-making firms in a competitive economy. First, the provision of basic research has significant positive external effects that cannot be internalized by private firms. Basic research should not be directed toward particular technologies, and the resulting scientific knowledge typically has practical value in many fields. As a consequence, technological specialization and a lack of patentability frequently prevent private firms from exploiting all the potential benefits from undirected basic research. Additionally, Nelson argues that due to its non-rivalry, full and free dissemination of scientific knowledge would be socially desirable. Second, Nelson argues that the long lag between basic research and its reflection in marketable products may prevent short-sighted firms from investing. Thirdly, he points out that the high uncertainty involved in the process may induce private provision of basic research below the socially optimal level. The more basic the research is the more severe these three problems become, so they represent a special motivation for the public provision of basic research.

The case for publicly funded basic research has further been substantiated by several other authors. In terms of market failure, Arrow (1962), for example, points out that invention, which he defines as the production of knowledge, is prone to three classical pitfalls: indivisibility, inappropriability, and uncertainty. Much like Nelson (1959), he argues that these problems result in underinvestment in research on the free market and that this problem is the more severe, the more basic the research is. Kay and Smith (1985) stress the enormous benefits from basic research and argue that public provision is necessary due to the public-good nature of basic research. They also out a case for the domestic provision of basic research rather than free-riding on basic research performed by other countries.

Beginning in the late 1980s, some authors question the public-goods nature of scientific knowledge. In particular, the view that existing knowledge is non-rival has been criticized. The argument advanced is that the utilization of specialized knowledge requires significant investments in complementary research capabilities. This may motivate private provision of basic research (see, for example, Cohen and Levinthal, 1989; Rosenberg, 1990; Callon, 1994). However, these authors do not question the public provision of basic research. Callon points out that public commitment in the field of science is needed in order to preserve variety and flexibility in the economy. Salter and Martin (2001) argue that a more evolutionary approach to the economics of basic research which acknowledges the diverse benefits above and beyond the generation of new knowledge allows for a new rationale for the public funding of basic research.

In summary, there is a strong case for publicly funded research, in particular basic research. This rationale is borne out by the empirical evidence. Gersbach et al. (2013) report data showing that for a selection of 15 countries the average share of basic research performed in the government and higher-education sector was approximately 75% in 2009. The OECD research and development statistics tell us that across OECD member countries around 80% of total research performed in the government or higher-education sector is also funded by the government.[6] Taken together, these findings suggest that a major share of basic research investments are indeed publicly funded. This evidence is also in line with US data on the source of funds for basic research, as reported in National Science Board (2012, Table 4-3).[7]

Effects of basic research and financing

Our main question is how optimally chosen basic research expenditures should be financed. Our work is thus related to the literature on financing productive government expenditures. In his seminal paper, Barro (1990) examines the case of productive government expenditures as a flow variable. Futagami et al. (1993) develop the case of productive government expenditures representing investments in a stock. These authors generate investment-based endogenous growth models where the individual firm faces constant returns to scale with respect to both private capital and the public services provided by the government. According to the comprehensive survey by Irmen and Kuehnel (2009), this applies more generally to the main body of the literature on productive government expenditures and economic growth. By contrast, our model is rooted in the tradition of R&D-based endogenous growth models, notably those that explicitly take into account the hierarchical order of basic and applied research (see, for example, Arnold, 1997; Morales, 2004; Gersbach et al., 2010b). In these models, basic research has no productive use in

[6] The data was downloaded from OECD (2012c) in April 2014 and refers to centered 5-year moving averages for 2007. For each country, the share of public funding in the government and higher-education sector has been computed as follows: $\frac{\text{sub-total government funding in higher-education sector + sub-total government funding in government sector}}{\text{total funding higher-education sector + total funding government sector}}$. The average of these shares across all OECD member countries works out at slightly below 80%.

[7] Cf. section 1.3.

itself but rather fuels into the productivity of the applied research sector, where knowledge is transformed into blueprints for new or improved products. In our case, basic research affects the innovation probability of entrepreneurs engaging in applied research. Using more public funds for basic research improves the chances of success for private entrepreneurs at the cost of diverting resources away from intermediate- and final-good production.

This implies that financing basic research has to fulfill a second important role. Suppose basic research is financed via a combination of labor income, profit, and lump-sum taxes. The relative size of labor to profit taxes affects the trade-off faced by potential entrepreneurs between being employed in the labor market and becoming an entrepreneur. Hence it influences the number of innovating entrepreneurs in our economy. To sum up, a socially efficient financing scheme for basic research must simultaneously provide the funds for these investments and must induce a socially desirable share of agents to become entrepreneurs.

Optimal taxation in an economy with entrepreneurship

We want to analyze the optimal mix of basic research and tax policies. Accordingly, our work is also related to the literature on optimal income taxation in the tradition of Mirrlees (1971). At the heart of our model is the occupational choice by (potential) entrepreneurs. Boadway et al. (1991) present a model with heterogeneous agents who can chose between becoming entrepreneurs or workers. While they restrict tax rates to make them the same for both types of labor, in our model the government can distinguish between taxes on profits and taxes on labor income.[8] Kanbur (1981) considers a model with an endogenous occupational choice on the part of homogeneous agents between becoming a worker earning a safe wage and an entrepreneur earning risky profits. While he considers entrepreneurial risk-taking under occupation-dependent taxation, he does not derive optimal tax policies. In this regard, his work is close in nature to calibrated dynamic general equilibrium models used to assess the effects of stylized tax reforms (see, for example, Meh, 2005; Cagetti and De Nardi, 2009).

Moresi (1998) and Scheuer (2013) analyze optimal tax policies in models of asymmetric information with occupational choice, where the government faces a trade-off between

[8] Allen (1982) had previously presented a model with two types of workers, skilled and unskilled, who can choose between two types of labor. In his model, however, workers perfectly select into these types of labor on the basis of their skill-group. In that sense, his model is closer in nature to Feldstein (1973) and Stiglitz (1982), who consider optimal taxation with two types of workers but no occupational choice. All of these papers also consider one tax instrument only.

efficiency and equality.[9] The distinctive feature of our model is that we analyze optimal tax policies and the investment of tax revenues in basic research. This means that the government can simultaneously affect the share of entrepreneurs in an economy and their innovativeness. We show that in such circumstances efficient policies make use of a taxation pecking order. Notably, in our model investments in basic research that allow for efficiency gains in aggregate should be accompanied by low profit taxes and high labor income taxes.

Political economics of tax policies

In our model productive government investments in basic research foster labor-saving technological innovation. In general equilibrium, innovation has a positive effect on profits but a negative effect on wages. These distributional effects are further accentuated by the taxation pecking order, giving rise to trade-offs between efficiency and equality that are similar to the ones considered in the literature on optimal taxation. We address these distributional effects from a political economy perspective when analyzing growth-stimulating policies in a median voter framework. Hence our work is also related to the literature on the political economics of tax policies.

Romer (1975), Roberts (1977), and Meltzer and Richard (1981) analyze majority voting on linear income taxes. Their work is a classical benchmark suggesting that if income distribution is skewed to the right voting will result in inefficiently high tax rates.[10] In our model the median voter's preferred policy may not maximize aggregate output, either on the extensive or on the intensive margin. On the one hand, if bounds on taxation are too restrictive, then the median voter will prefer a stagnant economy to growth-stimulating policies, and her preferred choice is inefficient on the extensive margin. On the other hand, if the median voter prefers some kind of growth-stimulating entrepreneurial economy, then her policy choice is inefficient on the intensive margin. The voter will generally prefer to have profit taxes that are too high and basic research investments that are too low vis-à-vis the social optimum. The fundamental trade-offs guiding the median voter's preferred policy choice are more intricate when we compare them to the case of linear income taxation. A higher tax on profits increases the redistribution of profits to workers at the

[9] Haufler et al. (2012), for example, take a different viewpoint on optimal tax policies with entrepreneurship. They consider a model where entrepreneurs engage in risky innovation and endogenously choose the quality (riskiness) of their project. Gains from innovation are subject to different tax treatments, depending on whether the entrepreneur has entered the market or sold his project to an incumbent. Optimal tax policies then trade off the gains from increased competition via market-entry against the losses of reduced entrepreneurial risk-taking due to lost tax deductions in the case of failure.

[10] Cf. Persson and Tabellini (2002) for a discussion and Traxler (2012) for a more recent example from the related literature.

expense of lowering the tax base – in our case via lower entrepreneurship. In addition, however, we allow for output-stimulating investments in basic research that increase the tax base and consider labor-saving innovation, implying that a larger tax base for profit taxes has a negative impact on the median voter's labor income.

Persson and Tabellini (1994) and Alesina and Rodrik (1994) were among the first to assess the implications of these inefficiencies for long-run economic growth by incorporating politico-economic equilibria into endogenous growth models. According to their models, increased inequality compromises long-run growth perspectives via stronger redistributive taxation. Both papers present empirical evidence supporting this main finding. We consider an R&D-based growth model as opposed to an investment-based growth model. As in Alesina and Rodrik (1994), the government can engage in productive government expenditures which, however, only affect the economy indirectly via innovating entrepreneurs. We show that in our model greater inequality also hinders growth-stimulating policies. However, this conflict of interests between growth policies and redistribution can be resolved if (constitutional) tax bounds are sufficiently flexible. The intuition is that tax policies impact indirectly on economic growth via the occupational choice of potential entrepreneurs, which is shaped by relative, rather than by absolute tax rates.

Given that (constitutional) tax bounds are center stage in our political economy section, our work also relates to the literature on constitutional design for tax policies. In their pioneering work in this area, Brennan and Buchanan (1977) assume that constitutional design takes place behind a veil of ignorance about future income. The constitutional limits on taxation should optimally be designed as an obstacle for a Leviathan-type government that maximizes revenues within these limits. Gradstein (1999) presents a model where supermajority requirements for tax policies can serve as a precommitment device for a government with time-inconsistent preferences. The implications of our model point to the opposite. As we show, constitutional tax bounds that are too small can prevent growth-stimulating policies from being supported by the median voter. Under certain conditions, this implies that households will reject any tax bound when voting behind the veil of ignorance in a constitutional design phase.

An alternative view on the bounds of taxation operative in our model is to interpret them as a reduced form for state capacity in the spirit of Acemoglu (2005) and Besley and Persson (2009). While, in the latter, fiscal capacity affects growth indirectly via its complementarity with other state capacities, in the former fiscal capacity directly influences growth as a determinant of the extent of distortionary taxation and productive investments by self-interested governments. We provide an alternative political economy rationale explaining why fiscal capacities may fundamentally affect growth: weak fiscal capacities do not allow for sufficient redistribution of gains from innovation and hence undermine political support for it.

3.3. The model

The economy is populated by a continuum of measure $\bar{L} > 1$ of households deriving utility $u(c) = c$ from a final consumption good. Each household either inelastically supplies one unit of homogeneous labor or chooses to become an entrepreneur, as shown below. Households are indexed by k ($k \in [0, \bar{L}]$).

3.3.1. Production

The final good, y, is produced with a continuum of intermediate goods $x(i)$ ($i \in [0, 1]$). The production technology is given by:

$$y = L_y^{1-\alpha} \int_0^1 x(i)^\alpha \, di \; , \tag{3.1}$$

where L_y denotes the labor employed in final-good production and where $0 < \alpha < 1$. The final good is only used for consumption, hence in equilibrium the output of the final good equals aggregate consumption C, i.e. $C = y$.

We assume that intermediate goods x are indivisible, i.e. $x(i)$ is either 1 or 0.[11] The final good is chosen as the numéraire with its price normalized to 1. Firms in the final-good sector operate under perfect competition. They take the price $p(i)$ of intermediate goods as given. In the following, we work with a representative final-good firm maximizing its profits π_y:

$$\pi_y = y - \int_0^1 p(i) x(i) \, di - w L_y \tag{3.2}$$

[11] As we explain later, we consider the case of labor-saving technological progress in the intermediate-good sector. With indivisible intermediate goods, labor saved in intermediates production is not taken up elsewhere in the economy at constant wages. This can give rise to a stark conflict of interest between equality and efficiency and hence to political conflicts in our economy. We discuss these in detail in section 3.6. Three remarks are in order at this stage: first, our finding of the optimality of a taxation pecking order relies neither on labor-saving technological innovation nor on the indivisibility of intermediates. It follows rather from the complementarity of basic research and the occupational choice of potential entrepreneurs. Second, we believe that the conflict between equality and efficiency in our economy is broadly in line with the decreasing shares of labor income in aggregate income, in particular for low-skilled labor, that can be observed in the EU and the US (cf. footnote 32). And third, while the indivisibility of intermediates can accentuate the equality-efficiency trade-off in our economy, it is not necessary for such effects to arise (cf. footnote 33).

by choosing the quantities $x(i) \in \{0, 1\}$ and the amount of labor L_y. The variable w denotes the wage prevailing in the market for labor. If the final-good producer chooses $x(i) = 1$ for all i, the demand for labor in final-good production will be:

$$L_y = \left(\frac{1-\alpha}{w}\right)^{\frac{1}{\alpha}}. \tag{3.3}$$

3.3.2. Behavior of intermediate-good producers

Each intermediate good can be produced by a given standard technology using $m > 0$ units of labor. Hence, marginal production costs when using the standard technology are mw. We assume that the standard technology is freely available. If an entrepreneur engages in research and development and successfully innovates, the labor input per unit of the intermediate declines by a factor γ ($\gamma < 1$), leading to marginal production costs of γmw. The innovating entrepreneur obtains a monopoly and offers his product at a price equal to the marginal cost of potential competitors, mw, thereby gaining profit $\pi_{xm} = (1-\gamma)mw$. If no innovation takes place, Bertrand competition yields an equilibrium price of mw as well, implying zero profits for all producers of the intermediate good under consideration.

3.3.3. Innovation

There is a measure 1 of individuals $[0, 1] \subset [0, \bar{L}]$ who are potential entrepreneurs. Individuals face different costs and benefits when deciding to become an entrepreneur. Specifically, we assume that agents are ordered in $[0, 1]$ according to their immaterial utilities from entrepreneurial activities and where individual k faces the utility factor $\lambda_k = (1-k)b$ ($k \in [0, 1]$, b being a positive parameter). This factor rescales the profit earned from entrepreneurial activities to take into account immaterial costs (such as cost from exerting effort as an entrepreneur or utility cost from entrepreneurial risk-taking that are not reflected in the utility from consumption) and immaterial benefits (such as excitement, initiative, or social status) associated with entrepreneurial activity.[12,13] Agents with a higher index k have lower utility factors. A utility factor $\lambda_k < 1$ represents net immaterial cost of being an entrepreneur, while factor $\lambda_k > 1$ represents net immaterial benefits.[14] For individuals

[12] We use a multiplicative rather than an additive form to capture costs and benefits from entrepreneurship. A detailed rationale will be provided in footnote 23.

[13] Cf. footnote 24 for a discussion on how differences in risk-attitudes may give rise to occupational choice effects similar to the ones arising from our immaterial benefit factor λ_k.

[14] Our concept of immaterial utilities associated with being an entrepreneur is in line with empirical evidence (cf. Douglas and Shepherd, 2000; Hamilton, 2000; Praag and Versloot, 2007; Benz and Frey,

k with $\lambda_k = 1$, and thus $k^{crit} = \max\left\{1 - \frac{1}{b}, 0\right\}$, immaterial costs and benefits associated with entrepreneurial activities cancel out. If b is small and hence k^{crit} is small or even zero, the society is characterized by a population of potential entrepreneurs for whom effort costs matter most. If b is large and hence k^{crit} is large, the potential entrepreneurs enjoy being one compared to a worker. We assume that λ_k is private information and hence only observed by agent k.[15]

The chances of entrepreneurs of successfully innovating can be fostered by basic research. Basic research generates knowledge that can be taken up by entrepreneurs and transformed into innovations that improve their production process. Specifically, suppose that the government employs L_B $(0 \leq L_B \leq \bar{L})$ researchers in basic research. Then the probability that an entrepreneur will successfully innovate is given by $\eta(L_B)$, where $\eta(L_B)$ fulfills $\eta(0) \geq 0$, $\eta'(\,\cdot\,) > 0$, $\eta''(\,\cdot\,) < 0$ and $\eta(\bar{L}) \leq 1$.[16] Depending on whether $\eta(0) = 0$ or $\eta(0) > 0$, basic research is a necessary condition for innovation or not.

Accordingly, if a measure L_E of the population decided to become entrepreneurs and the probability of success for each of them was $\eta(L_B)$, the share of intermediate-good industries with successful innovation would be equal to $\eta(L_B)L_E$.[17] We note that property $L_E \leq 1$ enables entrepreneurs to perform research on a variety of the intermediate good different from others.[18]

3.3.4. Financing scheme

Public expenditures on basic research are financed by taxes. There are two sources of income on which the government can levy taxes: labor income or profits (in intermediate- and final-good production). We consider two scenarios involving lump-sum taxation. In our base case, we assume that the government can levy lump-sum taxes or make lump-sum transfers.[19] Later, we examine the case where this is not possible. A tax scheme

2008; Benz, 2009; Fuchs-Schündeln, 2009). Most studies find that entrepreneurship involves positive non-monetary benefits. Fuchs-Schündeln (2009) shows that there is heterogeneity across the population in such immaterial utilities and that they may be negative for some households.

[15] This does preclude conditioning taxation on λ_k. We note that if λ_k is common knowledge but tax policies do not condition thereon our results will remain unaffected.

[16] $\eta'(\,\cdot\,)$ and $\eta''(\,\cdot\,)$ denote the first and second derivative, respectively, of $\eta(\,\cdot\,)$ with respect to L_B.

[17] We use a suitable version of the law of large numbers for a continuum of random variables.

[18] Strictly speaking, we assume that there is no duplication of research efforts. It is straightforward to incorporate formulations in which several researchers compete for innovation on one variety. This would decrease the benefits from basic research for entrepreneurs and for the society.

[19] Our model allows for unsuccessful entrepreneurs earning zero profits. Consequently, if their share of the profits of the final-good firm are not too high, they may not be able to pay the lump-sum tax. For a broad range of parameter values, lump-sum taxes are negative in optimum, implying that this is not an issue. If not, we assume that all individuals have a certain endowment that could be drawn upon by the government in this case. Moreover, we will be examining the case where lump-sum taxation is not

is a vector (t_L, t_P, t_H) where t_L and t_P are the tax rates on labor income and on profits, respectively, and t_H denotes the lump-sum tax or transfer. We assume that there are upper bounds (and potentially lower bounds) for labor income and profit taxes. Upper bounds on taxation may either be specified explicitly in the constitution or they may arise implicitly from fiscal capacities in the spirit of Besley and Persson (2009), for example.[20] We denote the upper and lower bounds by $\bar{t}_j$ and $\underline{t}_j$, $j \in \{L, P\}$, respectively.[21] For our theoretical analysis we assume that the upper bounds are strictly smaller than 1, i.e. $\bar{t}_j \leq 1 - \varepsilon$ for some arbitrarily small $\varepsilon > 0$.[22]

Throughout this part of the thesis, we assume that the government needs to run a balanced budget, i.e. the government budget constraint is given by:

$$wL_B = t_L(\bar{L} - L_E)w + t_P\left(\pi_y + \eta(L_B)L_E\pi_{xm}\right) + t_H\bar{L}\ , \tag{3.4}$$

where $t_H = 0$ in the scenario without lump-sum taxes.

3.3.5. Sequence of events

We summarize the sequence of events as follows:

(1) The government hires a number L_B of researchers to provide public basic research and chooses a financing scheme.

(2) A share L_E of the population decide to become entrepreneurs. With probability $\eta(L_B)$ they will successfully innovate, which enables them to capture monopoly rents. A share $(1 - \eta(L_B))L_E$ will not be successful and will earn zero profits.

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feasible.

[20] Alternatively, upper bounds on tax rates may implicitly arise from harmful supply-side effects of taxation: supply effects of profit taxes are at the very heart of the analysis pursued here. Yet in an open economy, the government may also be confronted with additional harmful supply effects associated with high profit taxes that are not considered here and that may give rise to effective upper bounds on profit taxes. Similarly, supply effects of labor income taxes are only considered to the extent to which they affect the occupational choice by potential entrepreneurs. In addition, labor income taxes may affect the labor/leisure choice of workers and hence be effectively bound from above.

[21] Lower bounds on profit taxes, in particular, may be demanded by the international community. The European Council of Economics and Finance Ministers, for example, has agreed upon a code of conduct for business taxation that is intended to tackle harmful competition in the field of business taxation (European Union, 1998). Although this code of conduct does not explicitly define lower bounds on taxation and is not legally binding, it still represents a considerable political commitment not to have extremely low tax rates on profits.

[22] We choose $\varepsilon > 0$, as tax rates of 100 % are economically implausible and to avoid dealing with $\tau := \frac{1-t_P}{1-t_L} = \infty$, which will feature prominently in our subsequent analyses. Note, however, that our formal results do not depend on ε being positive.

(3) Each intermediate-good firm i hires a number $L_x(i)$ of workers to produce the intermediate good $x(i)$.

(4) The representative final-good firm buys the intermediate goods $x(i)$ at a price $p(i)$ and produces the homogeneous final good y.

3.4. Equilibrium for given policies

In this section we derive the equilibrium for a given amount of basic research and a given financing scheme.

3.4.1. Occupational choice by potential entrepreneurs

We first address the choice of occupation. Potential entrepreneurs, i.e. agents in the interval $[0, 1]$, can choose between (a) employment as workers and (b) the attempt to develop an innovation to be used in the production of intermediate goods. We are left with two cases: all agents choose to be workers or both occupations are chosen in equilibrium. If both occupations are chosen in equilibrium, the marginal entrepreneur has to be indifferent between being employed as a worker and becoming an entrepreneur. The expected net profit of an entrepreneur is:

$$\pi^E = (1 - t_P)\eta(L_B)\pi_{xm} = (1 - t_P)w\eta(L_B)m(1 - \gamma) .$$

The last expression indicates that the expected profit of the entrepreneur consists of the expected amount of labor saved in intermediate-good production:

$$\chi(L_B) := \eta(L_B)m(1 - \gamma) , \tag{3.5}$$

scaled by the wage rate net of profit taxes. Hence the expected utility for an individual k with (dis-)utility factor $\lambda_k = (1 - k)b$ from being an entrepreneur is:[23]

$$EU^E(k) = (1 - t_P)w\chi(L_B)(1 - k)b .$$

[23] Note that we have chosen a multiplicative functional form. An alternative approach is to use an additive functional form by deducting the cost (see, for example, Boadway et al., 1991; Scheuer, 2013). The multiplicative approach is more convenient and analytically much easier. In addition, it implies that the net immaterial benefit is scaled by entrepreneurial profits. The multiplicative approach may therefore be more appropriate in reflecting effort costs and social status benefits, in particular, as these would typically be related to profits. For $\lambda_k < 1$ the effort costs dominate, while for $\lambda_k > 1$ the social status benefits dominate. Qualitatively, however, the additive and the multiplicative approach involve the same trade-offs and pecking-order considerations.

If $EU^E(k) = (1-t_L)w$, the individual is indifferent between being employed as a worker and becoming an entrepreneur. Solving for the indifferent entrepreneur's index k yields the equilibrium amount of entrepreneurs denoted by L_E^e as:[24]

$$L_E^e = \max\left\{0; 1 - \frac{1-t_L}{1-t_P}\frac{1}{\chi(L_B)b}\right\}. \tag{3.6}$$

We note that L_E^e is independent of the wage level. Higher wages are associated with higher profits from entrepreneurship and, of course, imply higher labor income. In the following we use:

$$\tau := \frac{1-t_P}{1-t_L} \tag{3.7}$$

as an abbreviation for $\frac{1-t_P}{1-t_L}$, with the upper and lower bounds of τ denoted by $\overline{\tau}$ and $\underline{\tau}$ being defined by the respective bounds of t_L and t_P. τ is a measure of tax incentives given to (potential) entrepreneurs.[25] Moreover, let $\overline{\tau} \geq 1 \geq \underline{\tau}$, implying that a neutral tax policy $t_L = t_P$ is always possible.

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[24] In our model potential entrepreneurs differ in their immaterial costs and benefits from being an entrepreneur. Agents whose expected utility from being an entrepreneur exceeds the utility from working in the labor market opt to become entrepreneurs, thus giving rise to continuous occupational choice effects. We note that a similar result for the occupational choice would arise if agents differed in their risk attitude rather than in an extra (dis-)utility term. Suppose, for example, that potential entrepreneurs differ only in their degree of constant relative risk-aversion with $u_k(c) = \frac{c^{(1-r_k)}}{1-r_k}$, where r_k is distributed according to some continuous and differentiable distribution function $F_{r_k}(r_k)$ on $[0,1]$ satisfying $\frac{dF_{r_k}(\cdot)}{dr_k} > 0$, $\forall\, r_k \in [0,1]$. Suppose further that insurance against entrepreneurial risks is not possible. Then individual k opts to become an entrepreneur if his certainty equivalent from being an entrepreneur is at least as large as his after-tax wage: $[\eta(L_B)]^{\frac{1}{1-r_k}}(1-t_P)m(1-\gamma)w \geq (1-t_L)w$ for the case of no other income. It follows that all potential entrepreneurs with $r_k \leq \bar{r} = \max\left\{0; 1 - \frac{\ln(\eta(L_B))}{\ln(1-t_L)-\ln((1-t_P)m(1-\gamma))}\right\}$ will become entrepreneurs. The equilibrium number of entrepreneurs is then given by $L_E = F_{r_k}(\bar{r})$. As for the case with heterogeneous immaterial costs and benefits from being an entrepreneur, entrepreneurship is increasing in m, t_L, and L_B, decreasing in t_P and γ, and independent of w. However, basic research has an additional effect here: as well as increasing the expected profit from being an entrepreneur, it affects associated entrepreneurial risks.

[25] Empirical evidence in the literature suggests that the tax structure does indeed influence the level of entrepreneurial activities in an economy. Using cross-sectional data from US personal income tax returns, Cullen and Gordon (2007) estimate the impact of various tax measures on entrepreneurial risk-taking as proxied by an indicator variable for whether or not an individual reports business losses greater than 10% of reported wage income. They find that a cut in personal income tax rates significantly reduces entrepreneurial risk-taking. The evidence for a cut in corporate tax rates is less clear. Depending on the model specification used, such a cut is predicted to either raise or not significantly affect entrepreneurial risk-taking. As the risk-sharing of non-diversifiable entrepreneurial risks with the government is positively related to the corporate income tax rate, Cullen and Gordon interpret their results as being in line with their theory. Djankov et al. (2010) analyze cross-country data for 85 countries. They find that higher effective tax rates paid by a hypothetical new company have a significantly adverse effect on aggregate investment and entrepreneurship. Da Rin et al. (2011) find that corporate income taxes significantly reduce firm entry in a panel of 17 European countries. Gentry and Hubbard (2000) analyze 1979 to 1992 data from the Panel Study on Income Dynamics and find that less progressive tax rates significantly increase entrepreneurship.

Knowing L_E^e from (3.6), we obtain the amount of labor employed in the production of intermediates as:

$$L_x^e = \int_0^1 L_x(i)di = m - \chi(L_B)L_E^e \,, \tag{3.8}$$

if $x(i) = 1 \; \forall \, i$. This corresponds to the amount of labor necessary to produce the intermediate goods with standard technology less the (expected) amount of labor saved by the new technologies invented by the entrepreneurs.

3.4.2. Equilibrium for given basic research and financing scheme

We will now derive the equilibrium for given basic research and the given tax policy. Due to the indivisibility of the different varieties of the intermediate goods, we have to consider the case where despite diminishing returns to intermediate goods in final-good production, the final-good firm will not use all the different varieties or may even go out of business and not produce at all. We start by considering the equilibrium in the market for intermediate goods for the case of positive production in the final-good sector:

Lemma 3.1

(i) In any equilibrium with positive production in the final-good sector, intermediate-good producers supplying their product will charge $p(i) = mw$.[26]

(ii) In any equilibrium with positive production in the final-good sector, the final-good producer will use all varieties of intermediate goods.

The proof of Lemma 3.1 can be found in appendix A.3.1. As a consequence of point (ii) in Lemma 3.1, we can use the equilibrium number of entrepreneurs (3.6) and labor in intermediate-good production (3.8) together with the market clearing condition in the labor market:

$$\bar{L} = L_E^e + L_B + L_y^e + L_x^e \tag{3.9}$$

to derive the number of workers employed in the final-good sector in an equilibrium with positive final-good production:

$$L_y^e = \bar{L} - L_B - L_E^e - L_x^e \,. \tag{3.10}$$

[26] To avoid needing to discretize the strategy space in order to obtain the existence of equilibria in the price-setting game in the intermediate-good industry i, we assume as a tie-breaking rule that the final-good producer demands the product from the innovating entrepreneur if he offers the same price as non-innovating competitors.

Equation (3.3) yields the corresponding equilibrium wage rate as:

$$w^e = (1-\alpha)(\bar{L} - L_B - L_E^e - L_x^e)^{-\alpha} \, . \tag{3.11}$$

Finally, we determine when an equilibrium with positive production will occur, that is, under what condition(s) the final-good firm will make positive profits. Using the profit function (3.2) and Lemma 3.1, we obtain equilibrium profits in the final-good sector:

$$\pi_y^e = (L_y^e)^{1-\alpha} - w^e L_y^e - w^e m \, .$$

Inserting the equilibrium wage rate (3.11) yields:

$$\pi_y^e = \alpha (L_y^e)^{1-\alpha} - (1-\alpha) m (L_y^e)^{-\alpha}. \tag{3.12}$$

We observe that the final-good firm's profit strictly increases in the amount of labor it employs in equilibrium. This is very intuitive, as higher employment in final-good production yields higher output and this is associated with lower wages in equilibrium, implying that the prices of both the inputs labor and intermediate goods are lower. Consequently, according to (3.12), the final-good firm's profits will be positive if the amount of labor employed in final-good production exceeds the critical level, $L_y^c := m\frac{1-\alpha}{\alpha}$. By (3.6), (3.8), and (3.10), this will always be the case in equilibrium, if governmental policy (τ, L_B) satisfies the following Positive Profit Condition (PPC):

$$\frac{m}{\alpha} \leq \begin{cases} \bar{L} - L_B & \text{if } \frac{1}{\tau \chi(L_B) b} \geq 1 \\ \bar{L} - L_B + \left[1 - \frac{1}{\tau \chi(L_B) b}\right] [\chi(L_B) - 1] & \text{if } \frac{1}{\tau \chi(L_B) b} < 1 \end{cases} . \tag{PPC}$$

Otherwise the wage rate is too high so that the indivisible intermediate goods are too expensive to realize positive profits.[27] We observe that (PPC) depends only on parameters of the model and on government policy.

We are now in a position to characterize the allocation and prices in the equilibrium of the economy for given basic research investments L_B and a given financing scheme τ.

Proposition 3.1

(i) If L_B and τ satisfy condition (PPC)*, there is a unique equilibrium with $x^e(i) = 1 \; \forall \, i$ and:*

(1) $L_E^e = \max\left\{0; 1 - \frac{1}{\tau \chi(L_B) b}\right\}$

[27] Lemma 3.1 implies that the cost of intermediates are essentially a fixed cost, which is increasing in w^e. If wages are too high (L_y^e is too low), then the variable profits from operations are not large enough to compensate for these fixed costs.

(2) $L_x^e = m - \chi(L_B)L_E^e$

(3) $L_y^e = \bar{L} - L_B - m + L_E^e\left[\chi(L_B) - 1\right]$

(4) $w^e = (1-\alpha)\left(L_y^e\right)^{-\alpha}$

(5) $p^e(i) = m(1-\alpha)\left(L_y^e\right)^{-\alpha}\ \forall\, i$

(6) $y^e = \left(L_y^e\right)^{1-\alpha}$

(7) $\pi_y^e = \left(L_y^e\right)^{-\alpha}\left(\alpha L_y^e - m(1-\alpha)\right)$

(8) $\pi_{xm}^e = (1-\gamma)m(1-\alpha)(L_y^e)^{-\alpha}$

(ii) If L_B *and* τ *do not satisfy condition* (PPC)*, there is a unique equilibrium with* $x^e(i) = 0\ \forall\, i$*,* $L_E^e = L_x^e = L_y^e = 0$*, zero output, and zero profits.*

The proof of Proposition 3.1 can be found in appendix A.3.2. In the sequel we focus on case (i) of Proposition 3.1, in which the economic activities are viable.

3.5. Optimal policies

The government can affect the previously established equilibrium outcomes by investing in basic research and via the tax scheme. The government's objective is to maximize welfare in the economy, which comprises a material component – consumption – and an immaterial component, the entrepreneurs' (dis-)utility from being an entrepreneur. The utility from being an entrepreneur cannot be observed directly by the government. In our simple model framework, the government could determine the immaterial welfare component from the revealed occupational choices of the individuals together with the precise distribution of (dis-)utilities from being entrepreneur. As this distribution may be impossible to observe in reality, we first consider a government that concentrates on the material welfare component, that is, on aggregate consumption. We will show in appendix A.1.2 that our main insight regarding the taxation pecking order prevails and may be reinforced with a broader welfare measure that additionally accounts for the utility costs and benefits from becoming an entrepreneur. In order to simplify the notation, we assume in the remainder of this chapter that the equilibrium of Proposition 3.1 is realized, and we dispose of superscript e in all expressions.

We now begin our discussion of optimal policies with some preliminary considerations before turning to the solution of the government's maximization problem.

3.5.1. Preliminary considerations

Government policies and entrepreneurship

Note that before taxes, the expected profit of an entrepreneur is higher than the wage rate in goods production if $\chi(L_B) \geq 1$. That is, by entrepreneurial activity, the individual saves in expectation more labor in intermediate-good production than the unit of labor he could provide the labor market with himself. However, even if entrepreneurship had a negative impact on labor supply in final-good production and hence on output (i.e. if $\chi(L_B) < 1$), individuals may find it worthwhile to become entrepreneurs due to immaterial benefits and tax policy τ. To allow for both corner and interior solutions for entrepreneurship and output-increasing and output-decreasing entrepreneurship, we make the following assumption:

Assumption 3.1
(i) $\chi(0) < 1$ *(ii)* $1/\overline{\tau} < b \leq 1/\chi(0)$

Assumption 3.1(i) states that, in expectation, entrepreneurship will reduce the labor supply for final-good production and thus final output when no basic research is provided. The second inequality in (ii) enables the government to preclude output-reducing entrepreneurship by implementing a neutral tax policy and not investing in basic research. By contrast, the first inequality in (ii) ensures that in the situation with output-increasing entrepreneurship, the government will be able to induce a positive measure of individuals to become entrepreneurs via its tax policy.

Positive production in final-good sector

When setting its policy (t_L, t_P, t_H, L_B), the government has to consider the positive profit condition in the final-good sector (PPC), which determines the resulting equilibrium type. The following assumption ensures that any aggregate-consumption-optimal policy will yield an equilibrium with positive final-good production and that we can neglect (PPC) in the government's optimization problem.

Assumption 3.2
$\bar{L} \geq \frac{m}{\alpha}$

As we show at the beginning of the next section, the aim of the government's basic research and tax policies boils down to maximizing the amount of labor available for final-good production. As a consequence, if some feasible policy choice satisfies condition

(PPC), then so does the optimal policy choice.[28] By Assumption 3.1(ii), the government can fully suppress entrepreneurship by choosing $L_B = 0$ and $\tau = 1$. Assumption 3.2 ensures that final-good producers' profits are non-negative under this policy regime, so they will also be non-negative under the aggregate-consumption-optimal policy regime.

We now derive optimal policies when lump-sum taxes or lump-sum transfers are available to the government. As the number of entrepreneurs only depends on the relation between profit and labor income taxes as captured by τ, the assumption of lump-sum transfers enables us to separate the choice of L_B from the choice of the government's tax incentives to (potential) entrepreneurs.[29] If no lump-sum taxes and transfers are available, the choices of τ and L_B cannot be separated in all cases. We discuss these issues in appendix A.1.1 and leave out of account such problems in the next section.

3.5.2. Optimal policy

The government's problem – maximizing material welfare – boils down to maximizing aggregate consumption, C, by choosing the amount of basic research, L_B, and the optimal ratio between profit and labor taxes, τ, while either levying an additional lump-sum tax if labor and profit taxes satisfying optimal τ do not suffice to finance the desired amount of L_B or making a lump-sum transfer in the case of the revenue generated by τ being larger than required for basic research expenditures:

$$\begin{aligned}\max_{\{t_L,t_P,t_H,L_B\}} \quad C =& \pi_y + \eta(L_B)L_E\pi_{xm} + wL_y + wL_x + wL_B - (\bar{L} - L_E)wt_L \\ & - t_P\left[\pi_y + \eta(L_B)L_E\pi_{xm}\right] - t_H\bar{L} \\ \text{s.t.} \quad wL_B =& (\bar{L} - L_E)wt_L + t_P\left[\pi_y + \eta(L_B)L_E\pi_{xm}\right] + t_H\bar{L}\ .\end{aligned}$$

[28] The condition (PPC) can also be interpreted as an upper bound on the wage rate. If the wage rate is too high, the inputs in final-good production become too expensive to break even with a positive amount of output.

[29] Given that basic research investments account for a share of government expenditures only, the scenario with lump-sum taxes may also be interpreted as one where any excess funds are used to finance other government expenditures that benefit all members of the population equally. For a broad range of parameter values, lump-sum taxes are negative in optimum, i.e. we have lump-sum transfers. Then our analysis is equivalent to an analysis with no lump-sum taxes but investments in an additional public good g that can be produced by a one-to-one transformation of the consumption good and enters households' utilities as follows: $u(c, g) = c + \frac{g}{L}$. Cf. section 4.5 for a discussion.

Inserting the constraint into the objective function and using the aggregate income identity $y = \pi_y + \eta(L_B)L_E\pi_{xm} + wL_y + wL_x$ reduces the problem to:

$$\max_{\{\tau,L_B\}} \quad C(\tau, L_B) = y(\tau, L_B) = (L_y(\tau, L_B))^{1-\alpha}$$
$$= \left[\bar{L} - L_E(\tau, L_B) - L_B - L_x(\tau, L_B)\right]^{1-\alpha} \ .$$

Hence the objective of the government is to maximize the amount of productive labor in final-good production. By inserting L_x, the objective function can be written as:

$$y(\tau, L_B) = \left[\bar{L} - L_B - m + L_E[\chi(L_B) - 1]\right]^{1-\alpha} \ . \tag{3.13}$$

Maximizing (3.13) is equivalent to maximizing $\bar{L} - L_B - m + L_E[\chi(L_B) - 1]$, which we will use in the following.

It will be useful and informative to solve the government's problem in two steps. First, we determine the optimal tax policy to finance a given amount of basic research. In the second step, we use the optimal tax policy to derive optimal basic research investments. In the first step of optimization, the Kuhn-Tucker conditions with respect to the optimal tax policy are:

$$\frac{\partial L_E}{\partial \tau}[\chi(L_B) - 1] \gtreqless 0 \ , \tag{3.14a}$$
$$\frac{\partial L_y}{\partial \tau}(\tau - \underline{\tau})(\tau - \overline{\tau}) = 0 \ . \tag{3.14b}$$

The term in brackets on the left-hand side of (3.14a) expresses how much labor in intermediate-good production will be saved in expectation by an additional entrepreneur. We also observe in (3.14a) that the expected benefit of another entrepreneur depends on the level of basic research expenditures. For example, if $\eta(0) \approx 0$ implying $\chi(0) \approx 0$, an entrepreneur is not as productive in innovating as when working in final-good production. From the definition of $\chi(L_B)$ (see equation (3.5)), we observe that only if the amount of basic research is larger than $L_{B,min} := \max\{0, \eta^{-1}(1/[m(1-\gamma)])\}$, where $\eta^{-1}(\cdot)$ denotes the inverse of $\eta(\cdot)$, will an increase in entrepreneurship be favorable for aggregate consumption.[30] Note that from (3.6) $\frac{\partial L_E}{\partial \tau}$ is non-negative and with $L_B \geq L_{B,min}$ strictly

[30] Note that $L_{B,min}$ is positive by Assumption 3.1(i), stating that without basic research the entrepreneurs are not as productive in producing labor-saving innovations as in working in final-good production. This assumption is not necessary for our results in section 3.5. With $\chi(0) \geq 1$, the government would always choose a tax policy $\tau = \overline{\tau}$ and basic research investments, if positive, will strictly increase the number of entrepreneurs further. This is due to the fact that by our specification of the immaterial utility component of entrepreneurship, the corner solution $L_E = 1$ is precluded.

positive for τ in the neighborhood of $\overline{\tau}$ according to Assumption 3.1. Consequently, if $L_B > L_{B,min}$, the government benefits from increasing τ to its maximum to make entrepreneurship as attractive as possible. The opposite is the case if $L_B < L_{B,min}$. Then the government will aim at reducing the number of entrepreneurs to a minimum by setting τ at its lowest level.[31] The government's tax policy is indeterminate when $L_B = L_{B,min}$, and we assume that in this case it will set $\tau = \overline{\tau}$. Taken together, a strong version of a *taxation pecking order* is optimal where tax rates are located at opposing bounds of their respective feasible sets.

We summarize our findings in the next proposition.

Proposition 3.2 (Taxation Pecking Order)
For a given amount of basic research, L_B, the government levies taxes according to:

$$\tau = \begin{cases} \overline{\tau} & \text{if } L_B \geq L_{B,min} \\ \underline{\tau} & \text{if } L_B < L_{B,min} \end{cases} . \tag{3.15}$$

We now determine the optimal basic research investments in the second step of the government's optimization problem. Given Proposition 3.2, we can split the maximization problem at the second step into one where L_B is constrained on $L_B \geq L_{B,min}$ and another for $L_B < L_{B,min}$. The first problem is:

$$\max_{\{L_B \geq L_{B,min}\}} \quad C(\tau, L_B) = y(\tau, L_B)$$

$$\text{s.t.} \quad \tau = \overline{\tau} \ ,$$

which yields the necessary conditions for a maximum:

$$\frac{\partial L_E(L_B, \overline{\tau})}{\partial L_B}[\chi(L_B) - 1] + L_E(L_B, \overline{\tau})\chi'(L_B) - 1 \leq 0 \ , \tag{3.16a}$$

$$\frac{\partial L_y(L_B, \overline{\tau})}{\partial L_B}(L_B - L_{B,min}) = 0 \ . \tag{3.16b}$$

Marginally increasing basic research investments has three different effects on final-good production. First, it improves the innovation prospects of the pool of entrepreneurs as reflected by the second term in equation (3.16a). Second, the increase in innovation

[31] Note that for $L_B < L_{B,min}$, there are typically multiple tax policies that entirely discourage entrepreneurship. For instance, by Assumption 3.1(ii), for $L_B = 0$ the government is indifferent between any tax policies (t_L, t_P) satisfying $\tau \in [\underline{\tau}, 1]$. For simplicity we assume that in such cases the government will implement $\underline{\tau}$, i.e. $t_L = \underline{t}_L$, $t_P = \overline{t}_P$.

prospects attracts additional entrepreneurs as reflected in the first term of equation (3.16a). Note that since $L_B \geq L_{B,min}$ (and hence $\chi(L_B) \geq 1$), this rise in entrepreneurship increases final-good production. The optimal choice of L_B trades off these gains from investments in basic research against the loss of the marginal unit of labor used in basic research rather than in final-good production, which is the third effect. This marginal labor cost of basic research is reflected by the last term -1 in equation (3.16a). We use $\tilde{L}_B(\overline{\tau})$ to denote the solution of this constrained maximization problem. Note that if $\tilde{L}_B(\overline{\tau}) > L_{B,min}$, it will satisfy (3.16a) with equality.

With respect to the maximization problem constrained by $L_B < L_{B,min}$ with associated tax policy $\tau = \underline{\tau}$, we can directly infer that the solution will be $\tilde{L}_B(\underline{\tau}) = 0$. The reason is that basic research affects consumption only by improving the success probabilities of entrepreneurs. However, for all $L_B < L_{B,min}$, entrepreneurship will negatively affect final output and by Assumption 3.1 the government will be able to deter such inefficient entrepreneurship by not providing basic research.

Overall, the government decides between implementing the policies $(\tilde{L}_B(\overline{\tau}), \overline{\tau})$ or $(0, \underline{\tau})$. In the first situation, with positive basic research and entrepreneurship, we speak of an *entrepreneurial economy*. The second situation without basic research investments and entrepreneurship is called a *stagnant economy*. The government will implement the policy with positive basic research investments and a tax policy favoring entrepreneurship if and only if this will lead to higher labor supply in final-good production and hence higher consumption vis-à-vis the stagnant economy. In the stagnant economy, labor supply for final-good production is given by $L_y = \bar{L} - m$. Hence we observe from Proposition 3.1 (equations (1) and (3)) that the government will opt for the entrepreneurial economy if and only if it satisfies the following Positive Labor Savings (PLS) condition:

$$-\tilde{L}_B(\overline{\tau}) + \left[1 - \frac{1}{\overline{\tau} b \chi\left(\tilde{L}_B(\overline{\tau})\right)}\right]\left[\chi\left(\tilde{L}_B(\overline{\tau})\right) - 1\right] \geq 0\,. \qquad \text{(PLS)}$$

We summarize the optimal policy schemes as follows:

Proposition 3.3
Suppose the government maximizes aggregate consumption using (t_L, t_P, t_H, L_B) as policy instruments. Then:

(i) If and only if condition (PLS) *is satisfied, there will be an entrepreneurial economy with $\tau^* = \overline{\tau}$, $L_B^* = \tilde{L}_B(\overline{\tau})$ and $L_E = 1 - \frac{1}{\overline{\tau} b \chi(\tilde{L}_B(\overline{\tau}))}$.*

(ii) Otherwise, there will be a stagnant economy with $\tau^* = \underline{\tau}$, $L_B^* = 0$ and $L_E = 0$.

We next analyze condition (PLS) more closely in order to deduce when an entrepreneurial economy is likely to be optimal.

Corollary 3.1
Suppose the government maximizes aggregate consumption using (t_L, t_P, t_H, L_B) *as policy instruments. Then the higher* m*,* b*, and* $\overline{\tau}$*, and the lower* γ*, the more likely it is that an entrepreneurial economy will be optimal.*

The proof of Corollary 3.1 is given in appendix A.3.3. Corollary 3.1 implies that the more valuable innovations are, i.e. the higher m is and the lower γ is, the more likely it is that we will observe an entrepreneurial economy. Further, an entrepreneurial economy is more likely, the higher the maximum admissible level of τ, $\overline{\tau}$, is and the higher the utility benefits (the lower the utility costs) derived from becoming an entrepreneur will be, i.e. the higher b is. Intuitively, the higher $\overline{\tau}$ and b are, the higher the number of entrepreneurs will be who are willing to take up knowledge from basic research investments in the entrepreneurial economy and hence the more attractive entrepreneurial policies will be.

Note that with lump-sum taxes, separating the choice of L_B from that of the ratio between labor and profit taxes as captured in τ was feasible. In appendix A.1.1 we show that the pecking order result also holds when lump-sum taxes or transfers are not available.

3.6. The political economy of financing basic research

So far we have adopted the viewpoint of a government that seeks to maximize aggregate consumption and does not care about distributional effects. Our analyses of the previous sections suggest that innovation-stimulating investments in basic research should be complemented by a taxation pecking order. However, such innovation policies may have substantial distributional effects, in particular when there is inequality in the shareholdings of the final-good producer. Then, as we will see below, a share of individuals is worse off under an entrepreneurial policy vis-à-vis a stagnant economy. It is therefore by no means obvious that a change to an entrepreneurial policy will be supported politically. In this section we explore these distributional effects and indicate when policies fostering entrepreneurship are politically viable.

In our framework the government has two main policy areas at its discretion to foster entrepreneurship and innovation in the economy: basic research and tax policy. These policies have direct distributional effects. First, labor income and profit taxes allow for a redistribution of wealth between workers on the one hand and entrepreneurs and shareholders of the final-good producer on the other. Second, basic research investments have a direct effect on entrepreneurs by improving their chances of success. However, these direct effects are accompanied by substantial general equilibrium feedback effects. In particular, basic research investments support labor-saving technological progress in the intermediate-good sector. As a consequence of innovations, labor is set free in the intermediate-good sector and additionally supplied to final-good production. This increases output and the profits of the representative final-good producer, but it also lowers wages.[32,33] Hence, while ownership in the final-good firm is irrelevant for consumption-maximizing policies, it is crucial for the distributional effects of such policies.

In our political economy analysis, we focus on a politically decisive individual whom we refer to as the median voter and ask whether the median voter's preferred policy will be an entrepreneurial policy or a stagnant policy. We assume that the median voter is an employee (i.e. a worker in final or intermediate-good production or a basic researcher) with a fraction $s \geq 0$ of the per-capita shares in the final-good producer's profits.[34] Con-

[32] These implications are consistent with the common trend across industrialized economies that labor income – in particular labor income of low-skilled workers – as a share of total value added is decreasing over time. Timmer et al. (2010), for example, show that in the European Union the workers' share in total value added decreased from 72.1% in 1980 to 66.2% in 2005. In the US this share decreased from 66.8% to 63.2%. At the same time, the share of high-skilled workers' income in total value added increases rapidly over time. In the EU, this share increased from 8.3% in 1980 to 16.0% in 2005, while in the US it increased from 18.5% to 30.4%.

[33] With divisible intermediate goods, labor-saving technological progress in the intermediate-good sector would not result in a decrease in wages. Still, there would be a conflict between efficiency and equality in our economy as discussed here, at least if innovations are non-drastic as in Acemoglu et al. (2006): with divisible intermediates, an innovating entrepreneur would preferably charge a price $p(i) = \frac{mw\gamma}{\alpha}$. For $\gamma > \alpha$ this is not feasible due to competition from standard technology, and the innovative entrepreneur sets price $p(i) = mw$ instead. In that sense innovations are *non-drastic*. $p(i) = mw \; \forall\, i$, implies that $w = [1-\alpha]^{(1-\alpha)} \left[\frac{\alpha}{m}\right]^{\alpha}$ and hence the wage rate is independent of innovation step γ in the economy. Intuitively, wages depend on the marginal product of labor in final-good production and hence on the ratio of labor to intermediates used in production. With constant intermediate-good prices, this is the same irrespective of the production technology in the intermediate-good sector. The monopoly distortion in the intermediate-good sector prevents the introduction of more intermediate-good-intense production processes in final-good production and hence a higher marginal product of labor. Note that with constant gross wages, a conflict between efficiency and equality follows from tax policies. In the entrepreneurial economy, workers contribute to the provision of basic research and hence end up with lower net wages than in the stagnant economy, where government spendings are zero. Obviously, with constant returns to scale and divisible intermediates, the final-good producer will earn zero profits, and benefits from innovation accrue to the successful entrepreneurs. So, in such circumstances, shareholdings in the final-good firms do not matter for the distribution of gains from innovation.

[34] Of course, this includes the special case where the median voter is a worker without any shares. This occurs when a fraction $\frac{1}{2} < \mu < 1$ of the population are workers who do not own shares in the final-good producer. The situation where a majority of the population are workers who are not engaged in the stock market is in line with empirical evidence on stock market participation rates. Guiso et al. (2008), for example, establish for a selection of 12 OECD member states percentages of households that are engaged in the stock market. Even if indirect shareholdings are taken into consideration, Sweden is the only country where a majority of households is engaged in the stock market. In most countries, fewer

sequently, her after tax income is:

$$I = (1 - t_L)w + (1 - t_P)s\frac{\pi_y}{\bar{L}} - t_H \ .$$

An entrepreneurial policy is politically viable if it is supported by the median voter. The most common interpretation is as follows: We order voters according to their shares in final-good production and interpret the decisive individual as the voter with the median amount of shares whose preferred policy will be adopted as the platform of two parties in a Downsian framework of party competition. In appendix A.2.1 we rationalize this interpretation within our model set-up. Due to constitutional provisions or lobbying, etc., the decisive individual may differ from the individual with the median amount of shares. Our political economy analysis is flexible enough to accommodate such settings by adjusting the shareholdings of the decisive individual, s, accordingly.[35]

We will now characterize the preferred policy of the median voter. In doing so, we restrict our analysis in two ways: first, we restrict attention to *growth-oriented* entrepreneurial policies, where here and below we say that an entrepreneurial policy (and the associated entrepreneurial economy) is growth-oriented if it yields an increase in final-good production vis-à-vis the stagnant economy. Second, we focus on lump-sum redistribution and leave to future research considerations regarding targeted transfers to a fraction of workers only.[36] To simplify the exposition we further assume common tax bounds for labor income and for profit taxes, that is, we assume $\bar{t}_P = \bar{t}_L = \bar{t} \in [0, 1-\varepsilon]$ and $\underline{t}_P = \underline{t}_L = \underline{t} \in [0, 1-\varepsilon]$ for some arbitrarily small $\varepsilon > 0$ and $\bar{t} \geq \underline{t}$. Consequently, $\tau \in [\underline{\tau}, \overline{\tau}] := \left[\frac{1-\bar{t}}{1-\underline{t}}, \frac{1-\underline{t}}{1-\bar{t}}\right]$ and $\overline{\tau} < \infty$.

Of course, since relative to a stagnant economy a growth-oriented entrepreneurial policy means falling wages and increasing final-good profits, the median voter will support an entrepreneurial economy if she possesses a sufficient amount of shares in the final-good firms.[37] The more realistic and interesting case is when income is skewed in such a way that the median voter possesses less than the per-capita claims on final-good profits. In

than one-third of households hold shares.

[35] In section 4.3 we will consider the case where policies are determined by a small elite group of workers who own all shares in the final-good producer.

[36] Analytically, we remain within the framework introduced in section 3.5.2. Note that without lump-sum taxes, redistribution via tax policies is no longer feasible and it turns out that a growth-oriented entrepreneurial economy is no longer supported by the median voter if shareholdings are sufficiently skewed. In particular, the median voter will always prefer the stagnant economy over the entrepreneurial economy if she owns less than a fraction $\frac{\bar{L}}{\bar{L}+(1-\gamma)m}$ of the per-capita shares in the final-good producer. The reason is that in such case the gross income of the median voter is decreasing in aggregate output, as shown in the proof of Proposition 3.5. Hence she can be no better off in the growth-oriented entrepreneurial economy than in the stagnant economy with $t_L = t_P = 0$. Note that the condition discussed here is sufficient but not necessary for our result.

[37] Cf. also the discussion in section 4.3.

particular, we assume that $s \in \left[0, \frac{\bar{L}}{\bar{L}+(1-\gamma)m}\right)$, which implies that the median voter's gross income, $w + s\frac{\pi_y}{\bar{L}}$, decreases in aggregate output.[38] The resulting trade-off follows immediately. On the one hand wages are higher in the stagnant economy, and the median voter can maximally redistribute profits using the highest possible tax rate without considering incentives for occupational choice by potential entrepreneurs. On the other hand, the tax base is higher in a growth-oriented entrepreneurial economy, potentially allowing for higher redistributional transfers even if profit tax rates are lower. For this reason, an entrepreneurial economy may be preferred to a stagnant economy with maximal profit tax.

The trade-off faced by the median voter as described above can be captured in a convenient way by separating the two parts of the median voter's income, gross earnings and net transfers:

$$I = (1 - t_L)w + (1 - t_P)s\frac{\pi_y}{\bar{L}} - t_H = w + s\frac{\pi_y}{\bar{L}} + NT \ , \tag{3.17}$$

where $w + s\frac{\pi_y}{\bar{L}}$ reflects the median voter's gross income and $NT = -t_H - t_L w - t_P s\frac{\pi_y}{\bar{L}}$ denotes net transfers to her. We obtain lump-sum tax, t_H, from the government's budget constraint as:

$$t_H = \frac{1}{\bar{L}}\left[-t_L w\left(\bar{L} - L_E\right) - t_P\left(\pi_y + \eta(L_B)L_E\pi_{xm}\right) + wL_B\right] \ . \tag{3.18}$$

One important observation is that for given basic research investments, the level of entrepreneurship and production is determined only by the ratio of tax rates, $\tau = \frac{1-t_P}{1-t_L}$, but not by the absolute values of tax rates. Hence the median voter's gross income is uniquely determined by the choices of τ and L_B. The levels of the labor- and profit-tax rates only matter for the degree of redistribution, as becomes apparent when we insert the lump-sum transfers (3.18) into the formula for the net transfers NT.[39] As a consequence, we can determine the median voter's most preferred policy by the following procedure: first, we derive the optimal amount of redistribution by choosing the levels of t_L and t_P for given τ and L_B. This will allow us to write the median voter's objective as a function of τ and L_B and consequently to determine the median voter's most preferred levels of τ and basic

[38] Note that when the population is ordered according to shareholdings in the final-good sector, we must have $s \in [0, 2)$.

[39] Substituting the profits by their equilibrium values as provided in Proposition 3.1, we obtain for the net transfers to the median voter:

$$NT = \frac{w}{\bar{L}}\left[t_P\left[\left(\frac{\alpha}{1-\alpha}L_y - m\right)(1-s) + \chi(L_B)L_E\right] - t_L L_E - L_B\right] \ . \tag{3.19}$$

research investments L_B.

We discuss the median voter's maximization problem in detail in appendix A.2.2. In the first step in the optimization problem (for given τ and L_B), the median voter aims at setting t_L and t_P to maximize net transfers NT. In particular, we observe in the typical case that the median voter will either push t_L or t_P to its boundary $\bar{t}$. As a consequence, for any policy (τ, L_B), the level of redistribution that can be realized is constrained by the economy's upper bound on tax rates, which, as discussed in the introduction, may be constitutional in nature or reflect the state's capacity to collect taxes. Now any growth-oriented entrepreneurial economy involves a loss in gross income for the median voter that needs to be compensated for by transfers if it is to be politically viable. Whether the transfers are sufficiently large depends crucially on the upper bounds of taxation. As stated in the following proposition, any growth-oriented entrepreneurial policy can be supported by sufficient redistribution when $\bar{t}$ is close enough to one:

Proposition 3.4
If there exists an entrepreneurial economy $(\hat{\tau}, \hat{L}_B)$ with higher aggregate output than a stagnant economy, then there also exists a constitutional upper limit of tax rates $\bar{t}$ such that $\hat{\tau} \in [\underline{\tau}, \overline{\tau}]$ and the median voter will prefer the entrepreneurial economy over a stagnant economy.

The proof is given in appendix A.3.4. The intuition is straightforward: with $\bar{t}$ sufficiently close to 1, it is feasible to implement any τ with t_P close to 1. Hence, all profits can effectively be redistributed in the entrepreneurial economy via the lump-sum transfer, allowing all workers to benefit from the increase in aggregate output.

The main insight of Proposition 3.4 is that incentives for entrepreneurship by a high value of τ as well as redistribution of profits by a sufficiently high value of t_P can be reconciled if the upper boundary on tax rates is very close to 1. However, if the upper and lower bounds on taxation are too low, it will not be possible to provide both incentives for economic feasibility and redistribution for the political viability of an entrepreneurial economy.

Proposition 3.5
Let $\underline{t} = 0$. If $\bar{t}$ is sufficiently low, the median voter will support a stagnant economy.

The proof of Proposition 3.5 is given in appendix A.3.5. Intuitively, for sufficiently restrictive tax bounds, redistribution of profits via the lump-sum taxes can no longer compensate for the decrease in labor income associated with the entrepreneurial economy, so the median voter will prefer the stagnant economy.

Using the results in Propositions 3.4 and 3.5, we argue in the next proposition that for every growth-oriented entrepreneurial policy there exists a unique level of $\bar{t}_c$ making the policy politically viable in an economy with $\bar{t} \geq \bar{t}_c$ but not if $\bar{t} < \bar{t}_c$.[40]

Proposition 3.6

Let $\underline{t} = 0$. For any growth-oriented entrepreneurial policy $(\hat{\tau}, \hat{L}_B)$, there exists a critical value $0 < \bar{t}_c < 1$ such that $\hat{\tau} \in [\underline{\tau}, \overline{\tau}]$, and the median voter will prefer the entrepreneurial policy over the stagnant economy if and only if $\bar{t} \geq \bar{t}_c$.

The proof of Proposition 3.6 is given in appendix A.3.6. The key observation is now that each growth-oriented entrepreneurial policy is associated with a unique $\bar{t}_c$. Hence, considering the entire set of growth-oriented entrepreneurial policies, we can determine the infimum $\bar{t}_{inf} = \inf\{\bar{t}_c\}$. This infimum of critical upper tax bounds is particularly interesting as it tells us that an economy will only be able to escape a stagnant policy regime if its constitutional upper bound on taxes or its fiscal capacity is sufficiently large to satisfy $\bar{t} \geq \bar{t}_{inf}$. We summarize this insight in the next corollary, which follows immediately from Proposition 3.6:[41]

Corollary 3.2

The median voter will opt for a growth-oriented entrepreneurial policy if and only if $\bar{t} \geq \bar{t}_{inf}$. Otherwise, the median voter will support the stagnant economy.

Note that $\bar{t}_{inf} > 0$ follows directly from Proposition 3.5. Corollary 3.2 implies that entrepreneurial policies are precluded if upper tax bounds are too low and the society is 'trapped' in a stagnant economy. Upper bounds on taxation specified in the constitution are frequently intended to protect against expropriation, in particular to protect the wealthy members of society. Our analysis suggests that such policy instruments need not always be efficient. While for a given policy τ, L_B, workers with large shareholdings (i.e. $\tilde{s} > 1 + \frac{L_E\left[\chi(L_B) - \frac{1}{\tau}\right]}{\frac{\alpha}{1-\alpha}L_y - m}$) will prefer to have a low upper tax bound,[42] this is not necessarily

[40] More formally, let $\underline{t} = 0$ and fix any entrepreneurial policy $(\hat{\tau}, \hat{L}_B)$ with $\hat{L}_y \geq L_y^S$. Proposition 3.4 implies that this entrepreneurial economy will be preferred to the stagnant economy by the median voter if $\bar{t}$ is sufficiently high. Proposition 3.5 implies that this is no longer the case if $\bar{t}$ is sufficiently low. In principle, there are two possibilities why this might happen: first, $\bar{t}$ might prevent sufficiently large transfers to the median voter; second, for $\bar{t}$ too low, $\hat{\tau}$ might no longer be available, i.e. we might have $\hat{\tau} \notin [\underline{\tau}, \overline{\tau}]$. Let us say that the entrepreneurial economy $(\hat{\tau}, \hat{L}_B)$ is *feasible* in the median voter framework if $\hat{\tau} \in [\underline{\tau}, \overline{\tau}]$ and if it is preferred to the stagnant economy by the median voter. Then, for every such entrepreneurial economy there must exist a threshold value $\bar{t}_c^l$ such that the entrepreneurial economy is no longer feasible if $\bar{t} < \bar{t}_c^l$ and a threshold value $\bar{t}_c^u$ such that the entrepreneurial economy is feasible if $\bar{t} \geq \bar{t}_c^u$. We summarize these insights in Proposition 3.6 and show in appendix A.3.6 that these two threshold values coincide.

[41] Recall that we are disregarding policies with output-decreasing entrepreneurship and/or basic research.

[42] The result follows from the fact that for τ and L_B given, their net transfers decrease in t_P by equation (A.10).

the case if the policy τ, L_B is determined in the political process. In such cases, wealthy households with at least as many shares as the median voter may prefer to have a higher $\bar{t}$. The following corollary is a manifestation of this logic:

Corollary 3.3

Consider two upper tax bounds $\bar{t}_h$ and $\bar{t}_l$ satisfying $\bar{t}_h > \bar{t}_{inf} > \bar{t}_l$. Then we can always find parameter values such that the wealthy households with shareholdings $\tilde{s} > s$ will prefer living in an economy with $\bar{t}_h$ to living in an economy with $\bar{t}_l$.

Corollary 3.3 follows immediately from consideration of the limiting case of $\bar{L} = \frac{m}{\alpha}$. Here the final-good producer has zero profits in the stagnant economy and shareholdings are worthless, irrespective of tax policies. Corollary 3.2 implies that the median voter with s shares will prefer any $\bar{t} \geq \bar{t}_{inf}$ to any alternative $\bar{t} < \bar{t}_{inf}$. As all individuals with shareholdings larger than s will benefit even more from the profits accruing in a growth-oriented entrepreneurial economy, they will also prefer $\bar{t}_h > \bar{t}_{inf}$ to $\bar{t}_l < \bar{t}_{inf}$.[43]

Such unintended harmful effects are not limited to constitutional tax bounds but may also apply to alternative means of protecting against excessive taxes. In particular, supermajority rules might have similar effects in our model.[44] Some entrepreneurial economies supported by the median voter may not be supported by voters with fewer shares and hence may not pass supermajority requirements.[45] It follows that for $\bar{t}$ given, a society with supermajority requirements may be 'trapped' in a stagnant economy, whereas an entrepreneurial economy would be politically feasible in the median voter framework.

3.6.1. Numerical example

We now provide a numerical example to illustrate the arguments behind the political feasibility of entrepreneurial policies. We specify the parameters in the model such that an entrepreneurial economy matches OECD data on basic research expenditures and en-

[43] A formal argument why all individuals with larger shareholdings than the median voter will prefer an entrepreneurial economy if the median voter does so is provided in appendix A.2.1.

[44] Several US states have supermajority rules for tax increases (cf. National Conference of State Legislatures (2010); Gradstein (1999) provides a historical overview). In the past, similar clauses have also been proposed at the federal level, but they have not been accepted (cf. Knight, 2000). These supermajority rules have also been addressed in the literature. Gradstein (1999) rationalizes them as a precommitment device for a benevolent government in a model with time-leading private productive investments. In his model, there is a time-inconsistency in the government's preferences, as the government would like to levy high taxes once private investments have been made. Supermajority rules can help resolve this time-inconsistency. Knight (2000) presents US-based evidence suggesting that supermajority requirements do indeed have a dampening effect on taxes.

[45] Formally, in appendix A.2.1, we show that in our model the single-crossing condition holds for workers' preferences over policies. In particular, in Lemma A.2 we show that if a worker with shares $\hat{s}$ prefers a growth-oriented entrepreneurial policy to the stagnant economy, then so do all workers with shares $s \geq \hat{s}$.

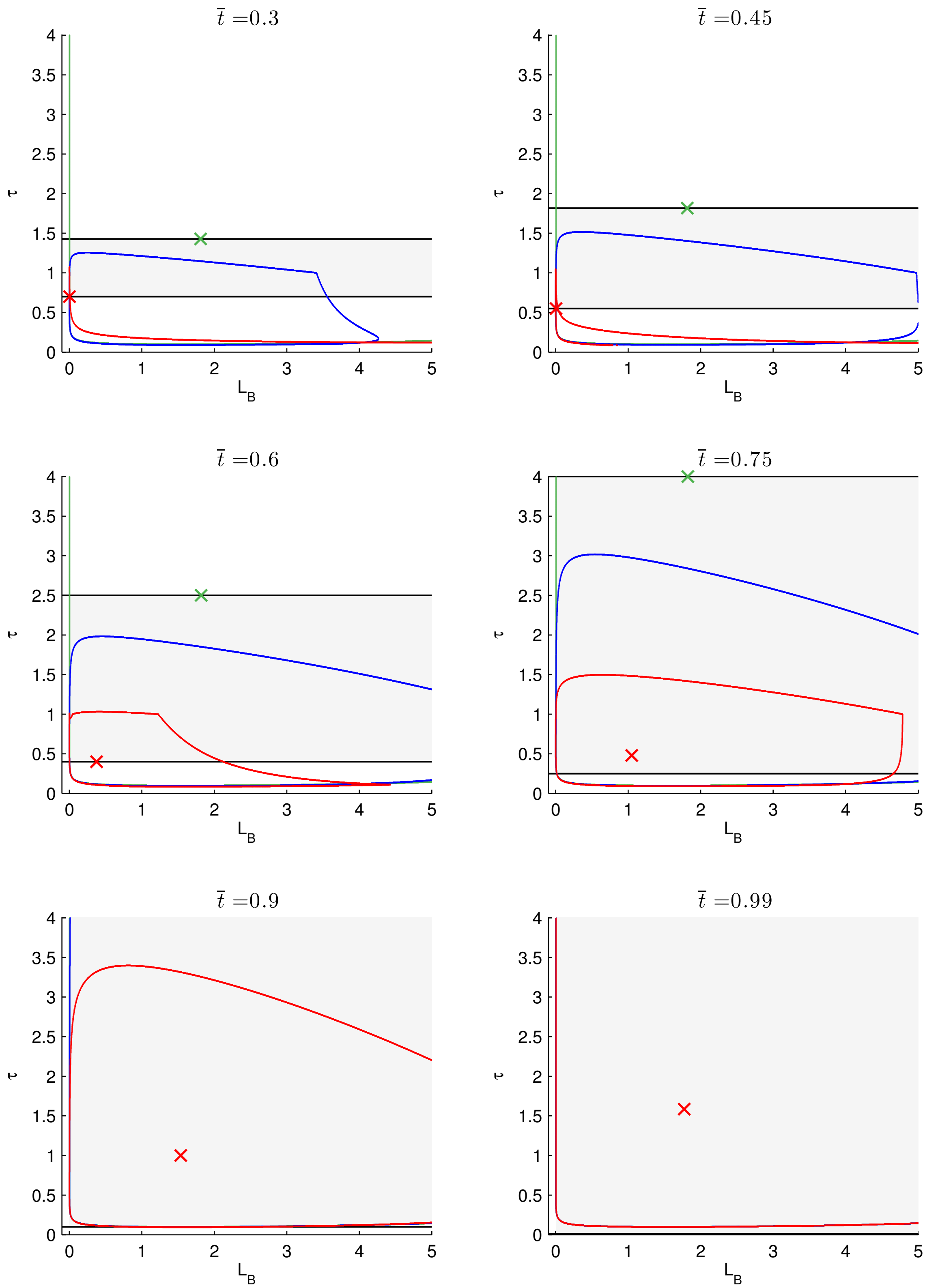
trepreneurship and assume that output is 5.7% higher in the entrepreneurial than in a baseline stagnant economy. This corresponds to the average rate of total factor productivity growth in OECD countries between 1996 and 2006. The details of our parameter value choices are provided in appendix A.2.3.

We use the calibration of our model to illustrate the effects of a change in the upper bound on taxation. For that purpose, we consider a median voter with $s = 0.5$ shares.[46] Moving from the top-left panel to the bottom-right panel in Figure 3.2, the upper bound on tax rates, $\bar{t}$, increases from 0.3 to 0.99. In each of the panels in Figure 3.2, the black lines represent the smallest and largest level of τ that is feasible with the respective upper tax bound. Only policies inside the area enclosed by these two lines – shaded in gray in Figure 3.2 – are feasible in the sense that $\tau \in [\underline{\tau}, \overline{\tau}]$. The green line in the policy space (τ, L_B) indicates policy choices for which the condition (PLS) is equal to zero, thereby separating the growth-oriented entrepreneurial policies to the upper right of the line from the output-decreasing entrepreneurial policies on the lower left. A growth-oriented entrepreneurial policy in our context means that output is higher and the wage rates lower than in a stagnant economy. Accordingly, the median voter with a sufficiently small amount of shares in final-good production will not support a growth-oriented entrepreneurial policy without compensation from net transfers.

For each policy (τ, L_B), we can derive the median voter's optimal amount of net transfers given the upper bounds on tax rates, $\bar{t}$. We can then compare these net transfers to the net transfers in the stagnant economy. The blue lines in Figure 3.2 indicate entrepreneurial policies for which the net transfers are just as large as in the stagnant economy. Only in the area enclosed by these blue lines is the net transfer higher in the entrepreneurial economy, and we can thus hope for political support for a growth-oriented entrepreneurial policy. Adding up the differences in gross income and in net transfers between the entrepreneurial economy and the stagnant economy yields the difference in net income. All entrepreneurial policies for which this difference is positive are preferred by the median voter to the stagnant economy. In Figure 3.2, this is the case for all policies inside the areas enclosed by the red lines. All policies in the intersection of these areas with the areas shaded in gray are feasible in the sense that the median voter will prefer them to the stagnant economy and that $\tau \in [\underline{\tau}, \overline{\tau}]$. We note that the set of growth-oriented entrepreneurial policies supported by the median voter is a subset of the growth-oriented entrepreneurial policies where the net transfer difference is positive. This is because in the move from the stagnant policy to a growth-oriented entrepreneurial policy the median voter's gross income will decline.

[46] In appendix A.2.4 we show results for $s = 0$ and for $s = 1$, respectively.

Figure 3.2.: Illustration of politically feasible entrepreneurial policies: $s = 0.5$



Moving from the top-left panel to the bottom-right panel, the upper tax bound becomes larger, thereby increasing possibilities for redistribution. As our theory predicts, this increases the set of entrepreneurial policies with higher net transfers than in the stagnant economy, that is, it increases the area enclosed by the blue lines in the different panels. Of course, the higher redistributive possibilities imply that the balance between efficiency and redistribution can be achieved for a greater set of entrepreneurial policies. Consequently, the area enclosed by the red lines increases as well. In accordance with Proposition 3.4, we observe in the bottom-right panel that when $\bar{t}$ approaches 1, the entire area comprising growth-oriented entrepreneurial policies will be politically viable. In the top-left panel we observe the opposite case, where the tax bound is too restrictive and the median voter will prefer the stagnant economy, as indicated by the red cross, which marks her most preferred policy. As $\bar{t}$ increases, this most preferred policy becomes more growth-oriented, i.e. the median voter will prefer a higher τ and a higher L_B. Yet this policy is clearly inefficient vis-à-vis the output-maximizing policy, as indicated by the green cross.

3.6.2. Discussion

In this section we have analyzed the political economy of financing basic research investments. The political process implies that tax policies can be inefficient – in the sense that aggregate output is not maximal – if the income distribution (in our case the distribution of shareholdings) is skewed to the right as in the classical findings by Romer (1975), Roberts (1977), and Meltzer and Richard (1981). We take the insights from this literature further as in our model such inefficiencies can arise both at the extensive and at the intensive margin. If bounds on taxation are too restrictive, then the median voter will prefer a stagnant economy to any growth-oriented entrepreneurial policy and her policy choice is inefficient at the extensive margin. If her preferred policy choice is an entrepreneurial policy, then inefficiency will arise vis-à-vis the optimal policies at the intensive margin. This inefficiency follows directly from the fact that $t_P = 0$ maximizes aggregate consumption in an entrepreneurial economy and this can never be optimal from the point of view of the median voter. Both inefficiencies are the more severe, the fewer shares the median voter possesses, i.e. the more skewed the income distribution is. However, if $\bar{t} = 1 - \varepsilon$ and $\varepsilon \to 0$, then the inefficiencies generally become arbitrarily small, irrespective of the median voter's shareholdings.[47]

The inefficiency also concerns basic research investments. Consider any choice of labor

[47] This is not necessarily the case if the median voter can earn more than the per-capita income in the output-maximizing entrepreneurial economy. Cf. footnote 22 in appendix A.2.5.

income and profit taxes, $\hat{t}_L, \hat{t}_P$ with $\hat{L}_B = \tilde{L}_B(\hat{\tau}) > 0$, i.e. given this tax policy it is socially desirable to invest in basic research.[48] Then $\frac{\partial L_y}{\partial L_B}\Big|_{\hat{t}_L,\hat{t}_P,\hat{L}_B} = 0$ but $\frac{\partial I}{\partial L_B}\Big|_{\hat{t}_L,\hat{t}_P,\hat{L}_B} \neq 0$ in general. In fact, the median voter will typically invest too little in basic research vis-à-vis the social optimum. Intuitively, via a reduction in the lump-sum transfer, the median voter pays the per-capita share of any increase in basic research investments. However, she benefits less than average from the associated increase in aggregate output due to the decrease in gross income.[49] Interestingly, with the median voter investing less than the social optimum in basic research, the political equilibrium can help explain the surprisingly high rates of return to public (basic) research typically found in empirical studies.[50]

With bounds on taxation at center stage in our model, these results also have important implications for the design of tax rules in the constitution. Typically, decisions on tax bounds in the constitution are thought to be taken behind a veil of ignorance. We perform the simplest exercise in this framework. Suppose that the only uncertainty individuals face behind the veil of ignorance is the amount of shares they will possess. Knowing that after the resolution of the uncertainty the median voter will exhaust her possibilities for maximizing her income, a tax bound close to one will be implemented in the constitution. This will resolve the conflict between efficiency and equality that is present for lower constitutional tax bounds and will thus induce the median voter to opt for a more growth-oriented policy. In turn, this will increase the expected income of an individual before lifting the veil of ignorance.[51]

An alternative view on the upper bounds on taxation is to interpret them as a reduced form for fiscal capacity, as in Besley and Persson (2009) and Acemoglu (2005). Then our model provides a new and intuitive political economy rationale for why weak fiscal capacity may have a detrimental effect on economic growth. In the absence of strong fiscal capacities and with imperfect trickle-down effects of growth-oriented supply-side policies, it may not be viable to sufficiently redistribute the gains from innovation for a majority of the population to support such policy changes.[52]

[48] Recall that we limit our attention to growth-oriented entrepreneurial economies. For $\hat{t}_L, \hat{t}_P$ with $\hat{L}_B = \tilde{L}_B(\hat{\tau}) = 0$ no such economy exists.

[49] For $\hat{\tau} \geq 1$, this can be shown analytically. In particular, suppose by contradiction that the median voter invests $L'_B > \tilde{L}_B(\hat{\tau})$ in basic research. Note that for $L_B = 0$ we have $L_y(0, \hat{\tau}) \leq L_y^S$ and that by assumption we have $L_y(L'_B, \hat{\tau}) \geq L_y^S$. Then, by continuity of y in L_B and by the optimality of $\tilde{L}_B(\hat{\tau})$, there exists $\mathring{L}_B < L'_B$ such that $L_y(\mathring{L}_B, \hat{\tau}) = L_y(L'_B, \hat{\tau})$. Now the median voter's gross income is the same for both choices of L_B. However, $\chi(L'_B) > 1$ and $\hat{\tau} \geq 1$ imply that net transfers are larger for $\mathring{L}_B$ than for L'_B, a contradiction to L'_B being optimal for the median voter.

[50] Cf. Salter and Martin (2001) and Toole (2012), for example.

[51] The detailed argument can be found in appendix A.2.5.

[52] Within our model, if distributional reasons prevent the existence of an entrepreneurial economy, it may be optimal to tax profits in the final-good sector differently from those in the innovative intermediate-good

3.7. Conclusions

We have outlined a rationale for a taxation pecking order to finance basic research investments, thus presenting a new perspective on the theory of optimal income taxation. We have subsequently assumed a political economy perspective and characterized the conditions under which the optimal policy scheme is politically viable. In particular, our political economy analysis suggests that entrepreneurial policies may harm workers with little in the way of shareholdings. We have shown that upper bounds on taxation – explicitly specified in the constitution or implicitly arising from fiscal capacity – can undermine the political support for growth-stimulating policies. Hence our analysis provides a political economy rationale for why weak fiscal capacities are associated with low future income levels, the point being that the political process tends to result in inefficient policies vis-à-vis the social optimum. This inefficiency encompasses the amount of basic research investments, which tend to be too low. Our work may therefore also explain the surprisingly high rates of return to public investments in (basic) research frequently found in empirical studies.

The above findings have further implications for the design of tax constitutions. While upper bounds on taxation in constitutions are sometimes proposed as a means for protecting investors from excessive indirect expropriation, the mechanisms considered here suggest that such measures may only be efficient if growth policies are *given*. If, by contrast, growth policies are subject to the political process, they may actually harm the firm-owners they are meant to protect.

Future work may set out to integrate our analysis of the optimal financing of basic research investments into the theory on optimal taxation in the tradition of Mirrlees (1971). With concave utilities and the traditional supply-side effects of labor income taxation, optimal policies would account for losses in aggregate utility from income inequality and for potentially adverse effects on labor supply. These additional efficiency-equality trade-offs might push optimal tax policies towards a more egalitarian economy. Finally, in the presence of incomplete markets, concave utilities might also allow additional beneficial effects of basic research on entrepreneurship and thus innovation in the economy, as basic research can reduce idiosyncratic risks. While some of these extensions may mitigate the effects considered here, we believe that the underlying mechanisms are still at play and

sector. This would allow redistribution of profits from final-good firms without affecting occupational choices. Typically, such tax discrimination is either not possible or is limited in its scope. For instance, intermediate-good firms and final-good firms would find it profitable to integrate and to shift profits through transfer pricing to intermediate-good production. Moreover, asymmetric information regarding innovation capabilities makes it impossible for the government to distinguish between firms with promising innovation prospects and those with no such prospects.

that they need to be taken into consideration when analyzing growth policies, both from a normative and from a positive perspective.

4. Extensions

4.1. Introduction

Overview

In the previous chapter we analyzed the optimal financing of basic research. Basic research is a public good that has a large variety of effects. The financing of basic research has important implications for its productive use, as it affects the occupational choice of potential entrepreneurs. Given the highly interdependent multiple effects at play, it is a priori not clear how to jointly optimize the public provision of basic research and the financing thereof. A key insight we gain from our previous analysis is that in order to incentivise optimal use of publicly provided basic research, it should be complemented by tax policies, thus motivating a *taxation pecking order*. In particular, investments in basic research large enough to render entrepreneurship socially desirable should be complemented by high labor income and low profit taxes. If the distribution of shareholdings is skewed to the right – as is the case for most industrialized economies – such an *entrepreneurial economy* may not, however, be politically viable. In such circumstances stagnation may prevail. Moreover, even if growth-oriented entrepreneurial policies are politically viable, they are inefficient vis-à-vis the output-maximizing policy.

In this chapter we present some corroborative analyses to both challenge and further support these results. In most of it we limit our attention to counterparts of the base-case scenario presented in the previous chapter, i.e. we assume that the government seeks to maximize material welfare from consumption and that lump-sum taxes are available.

Organization of this chapter

We first present two additional perspectives on exactly the same model as the one analyzed in chapter 3. In section 4.2 we show that if one tax measure is increased while the other tax measure and investments in basic research are held constant, tax revenues in working-hour equivalents may follow Laffer Curves. In our model we only consider supply-side effects to the extent to which they concern the occupational choice of potential entrepreneurs. Hence the existence of Laffer Curves is in itself an interesting result. It is of additional importance here, as the Laffer Curves have an impact on the optimal policies in the scenario with no lump-sum taxes, as discussed in appendix A.1.1.

Section 4.3 presents an alternative perspective on the political economy of financing basic research. In particular, we assume that policies are determined by a small elite group of workers who own shares in the final-good firm. We consider the scenario with lump-sum taxes and show that if shareholdings are sufficiently concentrated, these shareholder-workers will opt for a policy in the neighborhood of the output-maximizing entrepreneurial economy.

In sections 4.4 and 4.5 we discuss variants of the core model presented in the previous chapter. In section 4.4 we ignore immaterial costs and benefits associated with being an entrepreneur. Instead, we assume that potential entrepreneurs differ in their entrepreneurial skills. These entrepreneurial skills are reflected in the respective probability of successful innovation. We show that, with linear utility and this alternative assumption about entrepreneurial skills, optimal tax policy is always neutral in the sense that it does not distort the occupational choice by potential entrepreneurs. The intuition is that the trade-off faced by the policy-maker when deciding on whether or not to further stimulate entrepreneurship is just the trade-off faced by the marginal entrepreneur when making his occupational choice with neutral tax policy.

In section 4.5 we present a primer on general government financing. There, we assume that next to investing in basic research, the government can use public funds to provide another public good that directly impacts on household utilities. We show that under certain simplifying assumptions this set-up with no lump-sum taxes is analytically equivalent to our base-case scenario with lump-sum taxes, as in section 3.5.2.

The analyses presented in this chapter refer to, or are based on, the core model presented in chapter 3. For ease of presentation we start our discussion with a brief summary of this model. Where applicable, changes in the assumptions are discussed at the onset of the respective section.

Summary of the core model

The economy is populated by a continuum of measure $\bar{L} > 1$ of households deriving utility $u(c) = c$ from a final consumption good. The output of the final consumption good, denoted by y, is produced by a representative final-good firm whose production technology is given by:

$$y = L_y^{1-\alpha} \int_0^1 x(i)^\alpha \, di \ ,$$

where L_y denotes labor and $x(i)$ the amount of the indivisible intermediate good i employed in final-good production. In equilibrium, we either have $x(i) = 1$ or $x(i) = 0 \; \forall \, i$, implying that positive output levels of the final good depend only on L_y^e, the equilibrium amount of labor used in final-good production.

Intermediate goods can be produced using $m > 0$ units of labor. In equilibrium, all intermediates are offered at a price $p(i) = mw$, where w is the wage rate. Innovation reduces the labor input needed to γm, $\gamma < 1$, enabling successful entrepreneurs to earn a monopoly profit of $(1-\gamma)mw$. The government can foster innovation by providing basic research, L_B. Specifically, the probability of successful innovation for each entrepreneur is given by $\eta(L_B)$. Basic research is financed by a combination of labor income, profit, and lump-sum taxes, (t_L, t_P, t_H). There are upper and, potentially, lower bounds on labor income and profits taxes, denoted by $\bar{t}_j$ and $\underline{t}_j$, $j \in \{L, P\}$, respectively, and where $\bar{t}_j \leq 1 - \varepsilon$ for some arbitrarily small $\varepsilon > 0$.

There is a measure 1 of individuals $[0,1] \subset [0, \bar{L}]$ who are potential entrepreneurs. These agents are ordered in $[0,1]$ according to the immaterial utilities they receive from being an entrepreneur. In particular, individual k faces a utility factor $\lambda_k = (1-k)b$ ($k \in [0,1]$, b being a positive parameter). This factor rescales the profits earned in order to take into account immaterial costs (such as cost from exerting effort as an entrepreneur or utility cost from entrepreneurial risk-taking that are not reflected in the utility from consumption) and immaterial benefits (such as excitement, initiative, or social status) associated with entrepreneurial activity.[1] In equilibrium, the marginal entrepreneur is just indifferent between becoming an entrepreneur and being employed on the labor market, implying that $L_E^e = \max\left\{0; 1 - \frac{1}{\tau\chi(L_B)b}\right\}$, where again $\tau := \frac{1-t_P}{1-t_L}$ is a measure of tax incentives for entrepreneurs and $\chi(L_B) := m(1-\gamma)\eta(L_B)$ is the expected amount of labor saved in intermediate-good production by each entrepreneur. Labor input available for final-good production, L_y^e, is given by the residual of total labor supply and labor used on basic research, L_B, entrepreneurial activities, L_E^e, and intermediate-good production, $L_x^e = m - \chi(L_B)L_E^e$:

$$L_y^e = \bar{L} - L_B - m + L_E^e \left[\chi(L_B) - 1\right] \ .$$

As in chapter 3, we will henceforth simplify notation and leave out the superscript ^{e}

[1] Cf. footnote 14 in chapter 3 for empirical evidence on immaterial utilities associated with being an entrepreneur.

denoting equilibrium values.

4.2. Analysis of Laffer Curves

In appendix A.1.1 of chapter 3 we analyze aggregate consumption maximizing policies for a scenario with no lump-sum taxes. We show that in this case a taxation pecking order is optimal where either labor income taxes or profit taxes are used first, depending on whether or not entrepreneurship has a positive effect on final-good production at the desired level of basic research. In the discussion of these results, potential Laffer Curves of taxation play an important role. The intuition is as follows: Suppose the government seeks to finance a level $\hat{L}_B$ of basic research such that $\chi(\hat{L}_B) > 1$, i.e. such that entrepreneurship has a positive effect on final-good production. Then it is optimal to finance this level of basic research in an τ-maximizing way, i.e. to predominantly use labor income taxes and profit taxes only if the former cannot be used further to finance basic research. This would make it possible to complement investments in basic research by tax policies stimulating the take-up of these investments by innovating entrepreneurs. Now the preferred tax measure can only be used as long as it reaches neither its upper bound nor the peak of the associated Laffer Curve, if such a Laffer Curve exists.

The existence of Laffer Curves is not obvious in our model as we do not introduce any supply-side effects of taxation apart from those exerted on the occupational choice by potential entrepreneurs. Proposition 4.1 accordingly analyzes the Laffer Curves associated with t_L and t_P in our model. It considers tax revenues in working-hour equivalents, TR, which – given that tax revenues are used to employ labor in basic research – is the measure of interest. From equation (A.2) we know that in the absence of lump-sum taxes TR is given by:

$$TR = t_L \left[\bar{L} - L_E\right] + t_P \left[\frac{\alpha}{1-\alpha} L_y - m + L_E \chi(L_B)\right] .$$

Proposition 4.1 shows that Laffer Curves in TR may indeed exist for both tax measures, t_L and t_P.

Proposition 4.1
Let L_B be feasible in the sense that it satisfies the positive profit condition of the final-good producer, condition (PPC).

(i) Suppose the government increases t_P while holding t_L and L_B constant, and define

$$t_{P,max} := 1 - \left[\frac{\frac{1-t_L}{\chi(L_B)b}\left(\frac{\chi(L_B)-\alpha}{1-\alpha} - t_L\right)}{\frac{\alpha}{1-\alpha}\left(\bar{L} - L_B - \frac{m}{\alpha}\right) + \frac{\chi(L_B)-\alpha}{1-\alpha}}\right]^{\frac{1}{2}}.$$

(a) If $t_L \geq \frac{\chi(L_B)-\alpha}{1-\alpha}$, then TR is monotonically increasing in t_P.

(b) If $t_L < \frac{\chi(L_B)-\alpha}{1-\alpha}$ and $t_{P,max} \geq \min\left\{\bar{t}_P, 1 - \frac{1-t_L}{\chi(L_B)b}\right\}$, then TR is monotonically increasing in t_P.

(c) If $t_L < \frac{\chi(L_B)-\alpha}{1-\alpha}$ and $t_{P,max} < \min\left\{\bar{t}_P, 1 - \frac{1-t_L}{\chi(L_B)b}\right\}$, then TR initially follows a Laffer Curve that peaks at $t_{P,max}$. For $t_P \geq 1 - \frac{1-t_L}{\chi(L_B)b}$, TR is again monotonically increasing in t_P.

(ii) Suppose the government increases t_L while holding t_P and L_B constant, and define $t_{L,max} := \frac{1}{2}\left[(\bar{L}-1)(1-t_P)\chi(L_B)b + 1 + t_P\frac{\chi(L_B)-\alpha}{1-\alpha}\right]$. Then TR follows a Laffer Curve that peaks at $\min\left\{\max\left\{t_{L,max}, 1-(1-t_P)\chi(L_B)b, 0\right\}, \bar{t}_L\right\}$.

A proof of Proposition 4.1 is given in appendix B.1.1.

4.3. An alternative view on the political economy of financing basic research

In section 3.6 we analyzed the political economy of financing basic research. In particular, we assumed the perspective of a politically decisive individual with a fraction s of the per-capita shares in the final-good firm. Our main focus was on a median voter with less than the per-capita shares. We showed that in our model there is a trade-off between equality and efficiency. This trade-off can be mitigated if upper bounds on tax rates are sufficiently flexible. If not, the median voter may reject any growth-stimulating entrepreneurial policies and the society may be 'trapped' in a stagnant economy. We also showed that even if the median voter supports some growth-stimulating entrepreneurial policy, her preferred policy choice is inefficient vis-à-vis the social optimum.

As already indicated in section 3.6, our political economy analysis can readily accommodate alternative settings for the political process, simply by adjusting the shareholdings of the decisive individual accordingly. In this section, we present one such alternative. More specifically, we analyze a scenario where a small elite group of workers owning shares in the final-good producer can determine policies. We subsequently refer to these workers as *shareholder-workers*.

We assume that a share $\tilde{\mu} < 1$ of the population are shareholder-workers. These workers own equal shares of the final-good producer. There are no other shareholders of the final-good producer in the economy. We consider the counterpart of our analyses in chapter 3, i.e. a scenario with lump-sum taxes. Lump-sum taxes enable us to separate the choice of optimal investments in basic research from the optimal tax policies. We show that if shareholdings are sufficiently concentrated, shareholder-workers will opt for an economy in the neighborhood of an aggregate-consumption-optimal entrepreneurial economy.

Combining equations (3.17) and (3.18) and taking into account that the shareholder-worker owns a fraction $s_{sw} = \frac{1}{\tilde{\mu}}$ of the per-capita shares, we obtain for his income, I_{sw}:

$$I_{sw} = (1 - t_L)w + (1 - t_P)\frac{1}{\tilde{\mu}\bar{L}}\pi_y + t_L w\frac{\bar{L} - L_E}{\bar{L}} + t_P\frac{\pi_y + \eta(L_B)L_E\pi_{xm}}{\bar{L}} - w\frac{L_B}{\bar{L}} \ ,$$

which we can rewrite as:

$$I_{sw} = \frac{y}{\bar{L}} + (1 - t_P)\frac{\pi_y}{\bar{L}}\left[\frac{1}{\tilde{\mu}} - 1\right] + (1 - t_L)w\frac{L_E}{\bar{L}} - (1 - t_P)\chi(L_B)w\frac{L_E}{\bar{L}} \ .$$

Intuitively, shareholder-workers receive final-good production per capita plus any extra after-tax dividend earnings resulting from $\tilde{\mu} < 1$ minus the extra after-tax income earned by entrepreneurs compared to workers.

Now suppose that the entrepreneurial economy with $\tau = \overline{\tau}$ and $L_B = \tilde{L}_B(\overline{\tau})$ is uniquely output-maximizing. Then $(1-t_P)\frac{\pi_y}{\bar{L}}\left[\frac{1}{\tilde{\mu}} - 1\right]$ is uniquely maximized in the entrepreneurial economy. As Proposition 4.2 shows, this implies that if shareholdings are sufficiently concentrated, i.e. if $\tilde{\mu}$ is sufficiently small, shareholder-workers will opt for an economy in the neighborhood of the output-maximizing entrepreneurial economy. Intuitively, the income of the decisive agent in this case is dominated by the after-tax dividend payments he receives.

Proposition 4.2

Suppose that an entrepreneurial economy with $t_L = \overline{t}_L$, $t_P = \underline{t}_P$, $L_B = \tilde{L}_B(\overline{\tau})$ is uniquely output-maximizing. Furthermore, use $(t_{L,sw}, t_{P,sw}, L_{B,sw})$ to denote the I_{sw}-optimal policy choice. Then for every $\epsilon > 0$, there exists a $\bar{\mu} > 0$ such that $(t_{L,sw}, t_{P,sw}, L_{B,sw}) \in B_\epsilon(\overline{t}_L, \underline{t}_P, \tilde{L}_B(\overline{\tau}))$ for every $\tilde{\mu} < \bar{\mu}$ and where $B_\epsilon(\tilde{x})$ denotes an open ball around $\tilde{x} \in X$ defined as: $B_\epsilon(\tilde{x}) := \{x \in X : \|x - \tilde{x}\| < \epsilon\}$ for some set X.

A proof of Proposition 4.2 is given in appendix B.1.2.

4.4. A pure ability variant for entrepreneurial skills

We consider growth through innovative entrepreneurship. The government can stimulate growth via basic research and tax policies. Basic research provides the knowledge base that entrepreneurs can draw upon and hence improves their innovation prospects. The government can complement these investments with tax policies that induce a larger share of the population to become entrepreneurs.

Hence the occupational choice of potential entrepreneurs is at the heart of our model. We assume that these potential entrepreneurs differ in their immaterial costs and benefits from being an entrepreneur. In particular, individual k is assumed to face a utility factor $\lambda_k = (1-k)b$ ($k \in [0,1]$, b being a positive parameter). This factor rescales the profits earned in order to take into account immaterial costs (such as cost from exerting effort as an entrepreneur or utility cost from entrepreneurial risk-taking that are not reflected in the utility from consumption) and immaterial benefits (such as excitement, initiative, or social status) associated with entrepreneurial activity. It gives rise to continuous occupational choice effects in our model.

In footnote 24 of chapter 3, we show that differences in risk-aversion across potential entrepreneurs would give rise to similar occupational choice effects. In this section, we consider yet another source of continuous occupational choice: entrepreneurial skills. In particular, we consider a special case where entrepreneurial skills are solely reflected in the entrepreneur's probability of successful innovation. Entrepreneurs do not receive any skill- or preference-dependent extra (dis-)utility from being an entrepreneur. We show that with linear utility and this alternative assumption about entrepreneurial skills, optimal tax policy is always neutral in the sense that it does not distort the occupational choice by potential entrepreneurs. The intuition is that the marginal entrepreneur faces a trade-off between becoming an entrepreneur and being employed in the labor market, and that this trade-off is exactly the trade-off faced by the policy-maker.

4.4.1. Change in assumptions

As in chapter 3, we assume that there is a measure 1 of individuals $[0,1] \subset [0,\bar{L}]$ who are potential entrepreneurs. These agents are ordered in $[0,1]$ according to their entrepreneurial skills $\lambda_k = 1-k$, where k is distributed according to some continuous and differentiable distribution function $F_k(k)$ on $[0,1]$ satisfying $\frac{dF_k(\cdot)}{dk} > 0, \forall\, k \in [0,1]$. The lower k is, the more talented individuals are.

We no longer assume that these potential entrepreneurs have an immaterial utility factor that rescales profits earned from entrepreneurial activities. Instead entrepreneurial skills are assumed to influence the probability of successful innovation. Specifically, the probability of successful innovation by an entrepreneur k is assumed to be composed of two factors: the skill-dependent factor λ_k and a factor common to all potential entrepreneurs which can be fostered by basic research. This common factor is the same as in chapter 3, i.e. it is given by $\eta(L_B)$, where $\eta(L_B)$ fulfills $\eta(0) \geq 0$, $\eta'(\cdot) > 0$, $\eta''(\cdot) < 0$ and $\eta(\bar{L}) \leq 1$, and where L_B $(0 \leq L_B \leq \bar{L})$ denotes public investment in basic research. However, we assume here that this common probability component is multiplied by the skill-dependent factor λ_k.

Taken together, the probability of successful innovation by an entrepreneur k is $\rho_k = \eta(L_B)\lambda_k$. In equilibrium, all potential entrepreneurs with $k \leq \tilde{k}$, $\tilde{k} \in [0, 1]$, will opt to become entrepreneurs. All other potential entrepreneurs will opt to become workers. As before, property $L_E \leq 1$ enables entrepreneurs to perform research on a variety different from others. Accordingly, the share of intermediate-good industries with successful innovation is equal to $\eta(L_B) \int_0^{\tilde{k}} \lambda_k \, dF_k(k)$.[2]

The remainder of the model is the same as the one presented in chapter 3 and briefly summarized in section 4.1.

4.4.2. Equilibrium

Equilibrium in the economy considered here is analogous to the equilibrium presented in the previous chapter. We therefore characterize it briefly, merely highlighting the differences from the equilibrium in chapter 3.

As before, the occupational choice of potential entrepreneurs is a key determinant of equilibrium outcomes. If both occupations are chosen in equilibrium, then risk neutrality implies that the net wage $w(1 - t_L)$ has to be equal to the expected net profit for the marginal entrepreneur. The expected pre-tax profit from being an entrepreneur of an individual k is:

$$\pi^E(k) = \lambda_k \eta(L_B)\pi_{xm} = (1 - k)\eta(L_B)mw(1 - \gamma).$$

If $(1 - t_P)\pi^E(k) = (1 - t_L)w$, potential entrepreneur k is indifferent between being employed as a worker and becoming an entrepreneur. Solving for the index k of the

[2] We use a suitable version of the law of large numbers for a continuum of random variables.

marginal entrepreneur, $\tilde{k}$, yields:

$$\tilde{k} = \max\left\{0, 1 - \frac{1}{\tau\chi(L_B)}\right\}. \tag{4.1}$$

This corresponds to an equilibrium number of entrepreneurs equivalent to $L_E = F_k(\tilde{k})$. Knowing $\tilde{k}$, we obtain the amount of labor employed in the production of intermediates as:

$$L_x = \int_0^1 L_x(i)\, di = m - \chi(L_B) \int_0^{\tilde{k}} \lambda_k \, dF_k(k)\,, \tag{4.2}$$

if $x(i) = 1 \; \forall\, i$.

As in chapter 3, equilibrium outcomes depend on whether or not the final-good producer can earn non-negative profits. In the variant of the model considered here, the final-good producer will earn non-negative profits if and only if the following Positive Profit Condition is satisfied:

$$\frac{m}{\alpha} \leq \begin{cases} \bar{L} - L_B & \text{if } \frac{1}{\tau\chi(L_B)} \geq 1 \\ \bar{L} - L_B - F_k(\tilde{k}) + \chi(L_B) \int_0^{\tilde{k}} \lambda_k \, dF_k(k) & \text{if } \frac{1}{\tau\chi(L_B)} < 1 \end{cases}. \tag{PPC2}$$

As in the previous chapter, for $L_E = 0$, which corresponds to $\tilde{k} = 0$ here, condition (PPC2) reduces to $\bar{L} - L_B \geq \frac{m}{\alpha}$.

Using condition (PPC2) enables us to characterize the equilibrium allocations and prices for given basic research, L_B, and a given financing scheme, τ:

Proposition 4.3

(i) If L_B and τ satisfy condition (PPC2)*, there is a unique equilibrium with $x(i) = 1 \; \forall\, i$ and:*

(1) $\tilde{k} = \max\left\{0, 1 - \frac{1}{\tau\chi(L_B)}\right\}$

(2) $L_E = F_k(\tilde{k})$

(3) $L_x = m - \chi(L_B) \int_0^{\tilde{k}} (1-k)\, dF_k(k)$

(4) $L_y = \bar{L} - L_B - F_k(\tilde{k}) - m + \chi(L_B) \int_0^{\tilde{k}} (1-k)\, dF_k(k)$

(5) $w = (1-\alpha)\,(L_y)^{-\alpha}$

(6) $p(i) = m(1-\alpha)\,(L_y)^{-\alpha} \;\; \forall\, i$

(7) $y = (L_y)^{1-\alpha}$

(8) $\pi_y = (L_y)^{-\alpha}\,(\alpha L_y - m(1-\alpha))$

(9) $\pi_{xm} = (1-\gamma)m(1-\alpha)(L_y)^{-\alpha}$

(ii) If L_B and τ do not satisfy condition (PPC2)*, there is a unique equilibrium with $x(i) = 0 \,\forall\, i$, $L_E = L_x = L_y = 0$, zero output, and zero profits.*

The proof of Proposition 4.3 would be analogous to the proof of Proposition 3.1 and has therefore been omitted.

4.4.3. Optimal policies

We next analyze optimal policies, limiting our attention to the case with lump-sum taxes, as this yields the most insights. In fact, as we show below, optimal policies with lump-sum taxes require $\tau = 1$. It follows that lump-sum taxes are not needed to implement optimal policies unless bounds on taxation prevent the government from financing the desired amount of basic research without lump-sum taxes, a special case that is not very interesting economically.

In the model considered here, aggregate welfare is equal to aggregate consumption, irrespective of the distribution of consumption across the population. To see this, observe that all agents obtain utility from consumption given by $u(c) = c$. Hence the government maximizes aggregate consumption, which in the case of $x_i = 1 \,\forall\, i$ is given by:

$$y = [\bar{L} - L_E - L_B - L_x]^{1-\alpha}. \tag{4.3}$$

As in section 3.5.2, the government's decision problem boils down to maximizing the amount of labor available for final-good production, L_y.

We again make Assumption 3.2, which guarantees that the final-good producer's profits are non-negative in the equilibrium with maximal output. Hence we can ignore condition (PPC2) when analyzing optimal policies. Inserting the equilibrium values for L_E and L_x in (4.3), the objective function can be written as:

$$\bar{L} - L_B - F_k(\tilde{k}) - m + \chi(L_B) \int_0^{\tilde{k}} (1-k)\, dF_k(k) \,,$$

and the Kuhn-Tucker conditions with respect to the optimal tax policy are:

$$-\frac{\partial \tilde{k}}{\partial \tau} f_k(\tilde{k}) + \chi(L_B)(1-\tilde{k}) f_k(\tilde{k}) \frac{\partial \tilde{k}}{\partial \tau} \gtreqless 0 \,, \tag{4.4a}$$

$$\frac{\partial L_y}{\partial \tau}(\tau - \underline{\tau})(\tau - \overline{\tau}) = 0 \,. \tag{4.4b}$$

where $f_k(\cdot) := \frac{dF_k(\cdot)}{dk}$.

Let τ^* denote the optimal tax policy. By assumption, $f_k(k) > 0 \,\forall\, k \in [0,1]$. Hence (4.4a) implies that $\tau^* = 1 \,\forall\, \tilde{k} > 0$.[3] $\tau \neq 1$ is only optimal if $\frac{1}{\chi(L_B)} > 1$, implying that $\tilde{k}\Big|_{\tau=1} = 0$ and $\frac{\partial \tilde{k}}{\partial \tau}\Big|_{\tau=1} = 0$. Trivially, in this case any choice τ satisfying $\frac{1}{\tau\chi(L_B)} > 1$ yields zero entrepreneurship in the economy. We conclude that the government should not use tax policies to distort the occupational choice by potential entrepreneurs and summarize these insights in the following proposition:

Proposition 4.4

Let entrepreneurial skills be solely reflected in the success probability of potential entrepreneurs and no immaterial cost or benefits arise from entrepreneurial activities. Then the government should not distort the occupational choice by potential entrepreneurs via tax policies.

Intuitively, in the absence of distortionary taxes, the net effect of the marginal entrepreneur on aggregate welfare is equal to the net effect on his private welfare. When working as an employee, he earns the wage rate, which is equal to the marginal product of his labor in final-good production. By contrast, when becoming an entrepreneur his expected profit is equal to the expected labor cost savings in intermediate-good production. These savings are equal to the labor input saved multiplied by the wage rate, i.e. the marginal product of their labor in final-good production. It follows that he will effectively value the loss of not working in the labor market against the expected gain from labor savings in intermediate-good production. This is exactly the trade-off faced by the government in its decision on whether or not to marginally increase entrepreneurship via tax policies. Hence, in the absence of distortionary taxes, the occupational choice by potential entrepreneurs is socially efficient. It follows that in the variant of the model considered here, the government's decision problem effectively reduces to choosing the optimal amount of basic research.

Two remarks are in order. First, we learn from our analysis of chapter 3 that as soon as we introduce a skill- or preference-dependent extra (dis-)utility term of the kind considered there, this result would no longer be valid. The existence of such immaterial utilities from being an entrepreneur has been validated in various empirical studies.[4]

Second, even in a setting without such an extra (dis-)utility term, the strong result of tax neutrality optimality would not survive in its generality if utility functions were concave rather than linear. With decreasing marginal utility from consumption, the government

[3] To see this result, substitute $\tilde{k}$ by its equilibrium value given in Proposition 4.3 and observe that for $\tau = 1$ the two summands on the left-hand side of equation (4.4a) just cancel.

[4] Cf. footnote 14 in chapter 3.

might face a trade-off between efficiency and equality similar to the ones analyzed in the literature since Mirrlees (1971).[5] In particular, from Proposition 4.3 we observe that an increase in aggregate output reduces both pre-tax wages earned by workers and pre-tax profits earned by successful entrepreneurs and increases pre-tax profits of the final-good producers. This gives rise to more inequality, in particular if shareholdings in the final-good producer are distributed unequally. Depending on the concavity of the utility function, the government might then find it optimal to compromise on some efficiency for a more egalitarian distribution of incomes. These implications are similar to the ones we scrutinized in section 3.6, where we analyzed preferred policies of a median voter with less than the per-capita shares. They also depend critically on the upper tax bounds $\bar{t}_j$, $j \in \{L, P\}$. Intuitively, if these are sufficiently flexible, then the government can make use of lump-sum transfers to establish equality in the economy without having to compromise on efficiency.

4.5. A primer on general government financing

In the main part of chapter 3 and in appendix A.1.2, we assume that lump-sum taxes are available. Lump-sum taxes make it possible to separate the choice of optimal investments in basic research from the optimal tax policy. Depending on whether or not tax revenues from optimal labor income and profit taxes exceed the cost of investing in basic research, an additional lump-sum tax is levied or a lump-sum transfer is granted.

In our model public funds are exclusively used for investments in basic research. Of course, investments in basic research account only for a minor share of total government expenditure.[6] Hence, if optimal policies are associated with a lump-sum transfer, we might think of this lump-sum transfer as reflecting other government spending.

To cement this conjecture, we now consider an economy where the government uses public funds to invest in basic research and to provide an additional public good that directly impacts on household utilities. We show that under certain conditions this set-up is equivalent to allowing for lump-sum taxes. In this sense, we might interpret our set-up with lump-sum taxes as a reduced-form analysis for general government financing.

[5] Cf. the literature overview in section 3.2 for a brief discussion of this strand.

[6] OECD countries spend approximately 0.5% of their GDP on basic research, the main part of which is publicly funded. Cf. the discussions in sections 1.3.1 and 3.2.

4.5.1. Change in assumptions

We introduce an additional public good, $g \geq 0$, which can be produced by a one-to-one transformation of the final consumption good. g directly enters household utility as follows:

$$u(c, g) = c + v(g) .$$

We analyze the special case of $v(g) = \theta g$ in detail. We show that as long as lump-sum taxes are negative in optimum, i.e. as long as we have lump-sum transfers, $\theta = \frac{1}{\bar{L}}$ is equivalent to the set-up with lump-sum taxes considered in chapter 3. We then briefly discuss the general case of $v(g)$ with $v'(\,\cdot\,) > 0$ and $v''(\,\cdot\,) < 0$.

With public spending on g and no lump-sum tax, the government budget constraint is given by:

$$wL_B + g = t_L \left(\bar{L} - L_E\right) w + t_P \left[\pi_y + \eta(L_B) L_E \pi_{xm}\right] . \tag{4.5}$$

The remainder of the model is the same as the one presented in chapter 3 and briefly summarized in section 4.1.

4.5.2. Optimal policies

We start by deriving the modified government decision problem. As in section 3.5.2, we consider the case of a government maximizing material welfare, i.e. we assume that it does not take into account immaterial costs and benefits associated with being an entrepreneur. In appendix A.1.2 we show that these immaterial utilities are additively separable in the aggregate welfare function. Hence these utilities would not affect our main insights here, which concern the relationship between a lump-sum tax or transfer and the public good g, which both affect material welfare.

With public good g, material welfare is given by:

$$C + \bar{L}v(g) = \left[\pi_y + \eta(L_B) L_E \pi_{xm}\right](1 - t_P) + \left(\bar{L} - L_E\right) w(1 - t_L) + \bar{L}v(g) .$$

Using the government budget constraint, equation (4.5), to substitute for g, we obtain the following government decision problem:

$$\begin{aligned}\max_{\{t_L,t_P,L_B,g\}} \quad C+\bar{L}v(g) = & \left[\pi_y+\eta(L_B)L_E\pi_{xm}\right](1-t_P)+\left(\bar{L}-L_E\right)w(1-t_L) \\ & +\bar{L}v\left(\left[\pi_y+\eta(L_B)L_E\pi_{xm}\right]t_P+\left(\bar{L}-L_E\right)wt_L-wL_B\right) \\ \text{s.t.} \quad & \left[\pi_y+\eta(L_B)L_E\pi_{xm}\right]t_P+\left(\bar{L}-L_E\right)wt_L-wL_B\geq 0 \\ & \pi_y\geq 0\ ,\end{aligned} \tag{4.6}$$

where $\left[\pi_y+\eta(L_B)L_E\pi_{xm}\right]t_P+\left(\bar{L}-L_E\right)wt_L-wL_B\geq 0$ is the non-negativity constraint for public good provision, $\pi_y\geq 0$ is the non-negativity constraint for profits of the final-good producer, and L_E, L_x, L_y, w, π_y, and π_{xm}, respectively, assume the equilibrium values outlined in Proposition 3.1(i). Obviously, the non-negativity constraint for g is equivalent to the requirement that investment in basic research should not exceed tax returns.

4.5.2.1. A special case with $v(g)=\frac{1}{L}g$

Suppose now that $v(g)=\theta g$ with $\theta=\frac{1}{L}$. Then $C+\bar{L}v(g)$ simplifies to:

$$C+\bar{L}v(g)=\pi_y+\eta(L_B)L_E\pi_{xm}+\left(\bar{L}-L_E-L_B\right)w\ .$$

Using the aggregate income identity, we can rewrite the government decision problem (4.6) as follows:

$$\begin{aligned}\max_{\{t_L,t_P,L_B,g\}} \quad C+g = & \left[\bar{L}-L_E-L_B-L_x\right]^{1-\alpha} \\ \text{s.t.} \quad & \left[\pi_y+\eta(L_B)L_E\pi_{xm}\right]t_P+\left(\bar{L}-L_E\right)wt_L-wL_B\geq 0 \\ & \pi_y\geq 0\ .\end{aligned} \tag{4.7}$$

Comparing this decision problem to the one analyzed in section 3.5.2, it becomes apparent that these are equivalent up to the non-negativity constraint for investment in public good g. We subsequently refer to the decision problem discussed in section 3.5.2 as the *unconstrained decision problem* and the corresponding optimal solution as the *unconstrained optimum*. As long as the unconstrained optimum satisfies the non-negativity constraint for g, i.e. as long as $t_H\leq 0$, decision problem (4.7) is equivalent to its respective unconstrained counterpart. The intuition is straightforward: with $v(g)=\frac{g}{L}$, the social return on investment in public good g is just the same as the social return on investment in private consumption. Hence a lump-sum transfer can be replaced by investments in the public good g without affecting material welfare. We summarize these insights in the following proposition:

Proposition 4.5
Let $u(c, g) = c + \frac{g}{L}$ *and let* $(t_L^*, t_P^*, t_H^*, L_B^*)$ *denote the optimal policy choice according to the unconstrained decision problem analyzed in section 3.5.2. Then, if* $t_H^* \leq 0$*, decision problem* (4.7) *is equivalent to its unconstrained counterpart.*

In the following, we make Assumptions 3.1 and 3.2, implying that the optimal solution with lump-sum taxes but no investment in g – the *unconstrained optimum* – is as characterized in Proposition 3.3.

The equivalence stated in Proposition 4.5 holds only if the unconstrained optimum according to Proposition 3.3 satisfies the non-negativity constraint for investment in public good g. If an economy according to Proposition 3.3(ii) is optimal, i.e. an economy with $\tau = \underline{\tau}$ and $L_B = 0$, this is trivially the case. If, by contrast, an entrepreneurial economy according to Proposition 3.3(i) is optimal, then whether or not this unconstrained optimum satisfies the non-negativity constraint for investment in g depends on parameter values and functional forms. In particular, it depends on upper and lower bounds on taxation. As an illustration, consider the polar case of $\bar{t}_L$ and $\underline{t}_P$ both very close to 0 and where optimal investment in basic research is large. Then these optimal investments would need to be financed via lump-sum taxes, so this optimum is obviously not feasible in the variant of the model considered here.

However, for a broad range of parameter values, the non-negativity constraint for g is non-binding. A sufficient condition is given in Corollary 4.1:

Corollary 4.1
Let Assumptions 3.1 and 3.2 be satisfied and suppose that $\bar{t}_L \geq \frac{m(1-\gamma)-1}{\bar{L}-1}$*. Then the decision problem* (4.7) *is equivalent to the decision problem with lump-sum taxes analyzed in section 3.5.2.*

A proof of Corollary 4.1 is given in appendix B.1.3. We note that the condition given in Corollary 4.1 is sufficient, irrespective of other parameter values. We note further that it is never necessary. Yet this condition on $\bar{t}_L$ is satisfied for a broad range of parameter values. For example, it is satisfied if $\bar{t}_L \geq \alpha(1-\gamma)$.[7]

[7] This follows from the observation that $\frac{m(1-\gamma)-1}{\bar{L}-1} \leq \frac{m(1-\gamma)-1}{\frac{m}{\alpha}-1} < \frac{m(1-\gamma)}{\frac{m}{\alpha}} = (1-\gamma)\alpha$.

4.5.2.2. A general case with $v'(\cdot) > 0$ and $v''(\cdot) < 0$

With $v(\cdot)$ strictly concave, the government faces some additional trade-offs. Suppose that an entrepreneurial economy according to Proposition 3.3(i), i.e. an economy with $\overline{\tau}, \tilde{L}_B(\overline{\tau})$, maximizes material welfare in our baseline model as considered in chapter 3. Let x^{uo} denote the value of variable x in this optimum. Furthermore, define:

$$g^{uo} := t_L^{uo}\left(\bar{L} - L_E^{uo}\right)w^{uo} + t_P^{uo}\left[\pi_y^{uo} + \eta(L_B^{uo})L_E^{uo}\pi_{xm}^{uo}\right] - w^{uo}L_B^{uo} \ ,$$

as the total investment in public good g if the optimal policy according to Proposition 3.3(i) were implemented in the variant of the model considered here. For simplicity, we limit our attention to the case where $g^{uo} > 0$.

Now, if $v'(g^{uo}) = \frac{1}{L}$, then the solution according to Proposition 3.3(i) would also be optimal in the variant of the model considered here. Intuitively, in such a case final-good production is maximized and efficiently allocated between final-good consumption and investment in g.

If, by contrast, $v'(g^{uo})$ is greater or smaller than $\frac{1}{L}$, the allocation of funds between final-good consumption and investment in g is inefficient. Then the government will trade off some final-good production for a more efficient allocation thereof. It follows that the optimal policy always deviates from the output-maximizing policy.[8]

[8] This can easily be seen for L_B: $\left.\frac{\partial L_y^{uo}}{\partial L_B}\right|_{L_B=L_B^{uo}} = 0$, i.e. a marginal change in L_B would not change final-good production. By contrast, $\left.\frac{\partial g^{uo}}{\partial L_B}\right|_{L_B=L_B^{uo}} < 0$. To see this, observe that with $\frac{\partial L_y}{\partial L_B} = 0$ and hence $\frac{\partial w}{\partial L_B} = 0$, $\frac{\partial g}{\partial L_B}$ simplifies to:

$$\frac{\partial g}{\partial L_B} = -w - t_L\frac{\partial L_E}{\partial L_B}w + t_P\left[\eta'(L_B)m(1-\gamma)L_E w + \chi(L_B)\frac{\partial L_E}{\partial L_B}w\right] \ . \tag{4.8}$$

Furthermore, $\frac{\partial L_y}{\partial L_B} = 0$ implies that:

$$t_P w\left[\eta'(L_B)m(1-\gamma)L_E + \chi(L_B)\frac{\partial L_E}{\partial L_B}\right] = t_P w + t_P w\frac{\partial L_E}{\partial L_B} \ . \tag{4.9}$$

Plugging equation (4.9) into equation (4.8) and simplifying terms yields:

$$\frac{\partial g}{\partial L_B} = w\left[-(1-t_P) + (t_P - t_L)\frac{\partial L_E}{\partial L_B}\right] \ ,$$

and hence $\left.\frac{\partial g}{\partial L_B}\right|_{\substack{t_L=t_L^{uo}\\ t_P=t_P^{uo}\\ L_B=L_B^{uo}}} < 0$.

Part III.

Comparative Advantages with Quality Differentiation

5. Foundations and Key Results

5.1. Introduction

Countries compete over a heterogeneous set of products. While this heterogeneity is multidimensional, it is certainly true that products differ largely in their complexity – ranging, at the hs4 classification level, from cocoa beans and cotton shirts, through hydraulic turbines and inorganic acids, to nuclear reactors and various kinds of high-tech machines. A standard Ricardian argument suggests that countries should specialize according to their comparative advantages, i.e. we would expect that industrialized countries specialize in complex products, whereas developing countries specialize in simple products.[1] Yet often both rich and poor countries successfully export the same products, and the share of products for which this is the case tends to increase over time.[2]

Why do we not observe a stronger specialization of countries in products? Empirical evidence suggests that this might happen because countries specialize within products in quality.[3] There is undoubtedly ample room for industrialized countries to compete by producing high quality.[4] As an example, while you can buy an analog watch for less than

[1] More generally, comparative advantages, whether they are arising from production technologies or factor endowments, should presumably give rise to a (block-) diagonal pattern of specialization in international trade. Costinot (2009a) shows that in a Ricardian model specialization occurs if countries can be ranked according to some characteristic (e.g. institutions), if products can be ranked according to some other characteristic (e.g. complexity), and if factor productivity is log-supermodular in both characteristics. Intuitively, in such a case, good institutions are more valuable in the production of complex products, inducing countries with good institutions to specialize in complex products. A similar result holds true for comparative advantages arising from factor endowments, if in addition, factors can be ranked according to some characteristic (e.g. human capital), if factor productivity is log-supermodular in factor and product characteristics, and if factor endowments are log-supermodular in country and factor characteristics. Intuitively, if countries with good institutions have large endowments with labor of high human capital, and human capital has higher value in production of more complex products, then countries with good institutions again specialize in complex products. However, Costinot (2009a) shows that such strong specialization does not occur in general if comparative advantages are allowed to arise from both technological differences and factor endowments.

[2] Cf. Schott (2004) and Pham (2008), for example. China is an important driver of this development (Pham, 2008).

[3] Cf. Schott (2004), Hummels and Klenow (2005), Pham (2008), Khandelwal (2010), and Hallak and Schott (2011), for example.

[4] For the purpose of our discussion here and below, a product's quality summarizes all product attributes

a Euro on the Internet, many Swiss watches are sold at a price of several thousand Euros and Vacheron Constantin even sells its 'Tour de l'Ile' at the price of more than one million Euros.[5] Yet it is not clear what such specialization within products implies for comparative advantages across products, and the underlying mechanisms have not been studied in the literature so far. We will analyze the interplay between product-intrinsic complexity and endogenously chosen quality in a general equilibrium model of international trade. Our work reveals a novel mechanism that can explain a rich set of empirical observations, in particular:

- how specialization within products in quality can equalize comparative advantages across products;
- why, nonetheless, poor countries cannot successfully compete for a broad range of products;
- why the share of products for which this is the case tends to diminish over time.

We further show that this mechanism motivates the use of a censored regression model to estimate the link between a country's GDP per capita and the quality of its exports.

We start from the simple Ricardian rationale outlined above. In our model countries differ in the skill level of their labor, while products differ in complexity. High-skill countries are better at producing all products. Yet they have a comparative disadvantage for simple products, because the skill intensity increases with the complexity of a product. This changes, however, if we introduce an endogenous choice of product quality into our model. Then high-skill countries can successfully compete for simple products by producing high quality, and across-product specialization is replaced by within-product specialization as suggested above.

Does this rationale imply that there are no comparative advantages across products? Our answer is no. The reason for this is the existence of minimum-quality requirements. These minimum-quality requirements arise from different sources. In many cases, they are product-intrinsic. Referring to the watch example, even the cheapest version of a watch requires a balance wheel (pendulum), a spring, and a suspension of reasonable quality, and these parts need to be assembled in a reasonably accurate manner for the watch to serve its intended purpose. Similarly, banknotes and computer software certainly have to meet minimum requirements in terms of safety, air beds and glass in terms of resistance, photo lenses and clinical diagnostics in terms of precision, and autopilots and refrigerated trucks in terms of reliability. Yet (stricter) minimum-quality requirements are

that increase a consumer's willingness to pay for that product.

[5] http://www.manager-magazin.de/magazin/artikel/a-357485.html, retrieved on 25 October 2013.

also often introduced by law. Many products sold within the European Economic Area, for example, have to bear the *CE* mark indicating that they conform to European product requirements.[6,7]

The crucial observation is that these minimum-quality requirements are product specific, and in particular, that satisfying them is more demanding for complex products than for simple ones. Producing a functional air bed is certainly less of a challenge than producing an autopilot that can safely navigate you through Moscow's traffic snarl.[8] Minimum-quality requirements thus impose critical restrictions on the specialization of countries on quality. They prevent low-skill countries from successfully competing for complex products. Products like nuclear reactors and high-tech machines are just too difficult to produce, even in a minimum-quality version.

Hence the interplay between product-intrinsic complexity and endogenously chosen quality gives rise to an upper-triangular structure of comparative advantages. While high-skill countries can always compete for simple products by producing high quality, low-skill countries cannot always compete by producing low quality, due to the minimum-quality requirements.

These implications are in line with what we observe in the data. Industrialized countries are successfully exporting the complex products, but also most of the simpler products.[9] At the other extreme, countries like Algeria, Somalia, and Turkmenistan, for example, are successfully exporting only a few – presumably simple – products.[10] More to the point, an upper-triangular structure of international specialization is observed by Hausmann and Hidalgo (2011) and Tacchella et al. (2012).[11]

[6] Such legal product requirements are a significant barrier to trade and, among others, feature prominently in the negotiations on a free trade agreement between the EU and the US (cf. e.g. http://online.wsj.com/news/articles/SB10001424127887324162304578301662368145012, retrieved on 27 January 2014).

[7] Minimum-quality requirements may also implicitly arise from the competitive fringe. As an example, firms in the semiconductor equipment industry compete to provide high-tech machines enabling the production of ever smaller and more powerful computer chips. The market is strongly concentrated in the hands of the technology leader: Currently, ASLM dominates this market, with a market share of around two thirds, whereas the market was dominated by Canon and Nikon in 1990 (cf. http://corporate.zeiss.com/content/dam/Corporate/pressandmedia/downloads/innovation_ger_20.pdf, retrieved on 27 January 2014).

[8] Moscow is the city with the worst traffic congestions worldwide according to the TomTom traffic index (cf. http://www.tomtom.com/news/category.php?ID=4&NID=1487&Year=2013&Language=3 &TT=16a0bfb2-baba37bd-00000000-00000000-0000001b-4j1f8h7dvltbtibhj84n7mccg0, retrieved on 28 January 2014).

[9] In 2010, Germany, the USA, Belgium, and the Netherlands, for example, had a *revealed comparative advantage* of at least 0.05 for around 95% of the products at the hs4 classification level, with revealed comparative advantage referring to the measure originally proposed by Balassa (1965).

[10] In 2010, these countries had revealed comparative advantage of at least 0.05 for less than 10% of the products at the hs4 classification level.

[11] We briefly discuss and summarize this evidence in appendix C.1.

Moreover, the proposed rationale provides an intuitive explanation why the share of products that are co-exported by poor and rich countries tends to increase over time, as observed by Schott (2004). If comparative advantages stem from minimum-quality requirements, they naturally subside as countries develop.[12]

Our work reflects the empirical observation that richer countries export higher quality. Yet our work also has important implications for this strand in the literature. If low-skill countries cannot successfully compete for complex products because they are bounded by a minimum-quality constraint, then this information could – and should – be exploited in an empirical analysis of the link between a country's GDP per capita and the quality of its exports. We show that our theoretical set-up rationalizes the use of a censored regression model. Taking this model to the data, we observe a much stronger link between a country's GDP per capita and the quality of its exports than when using OLS, as to be expected according to our theory.

Relation to the literature

Our work complements a growing literature that studies various aspects related to quality upgrading in international trade. Flam and Helpman (1987), Stokey (1991), Murphy and Shleifer (1997), and Matsuyama (2000), for example, consider non-homothetic preferences for quality in models of north-south trade to study product cycles and the welfare effects from trade, among others. More recently, Baldwin and Harrigan (2011), Kugler and Verhoogen (2012), Johnson (2012), Hallak and Sivadasan (2013), and Benedetti Fasil and Borota (2013), for example, integrate quality into trade models with firm-level heterogeneity to derive richer predictions on the exporting behavior of firms and countries. Yet none of these strands in the literature addresses the implications of quality differentiation for the comparative advantages of countries over a heterogeneous set of products, which is the main focus here.

A key element of our model is the existence of a two-dimensional commodity space. In particular, we consider horizontally differentiated *products* that differ vertically in *quality*.[13] Only a few models consider a horizontally and vertically differentiated commodity space in international trade. To the best of our knowledge, Jaimovich and Merella (2014)

[12] Note that when making this observation, Schott (2004) classifies countries as rich and poor based on a comparison with the cross-section of countries.

[13] Another strand in the literature considers horizontally differentiated varieties within products (or industries). Helpman and Krugman (1985), Bernard et al. (2007), Okubo (2009), and Fan et al. (2011), for example, consider multi-sector versions of the Krugman (1979, 1980) and the Melitz (2003) model, respectively. Chor (2010) and Costinot et al. (2012), for example, present multi-sector versions of the Ricardian trade model developed by Eaton and Kortum (2002).

and Alcalá (2012) are the only papers analyzing the interplay between horizontal specialization across products and vertical specialization within products.

In both these models, comparative advantages are driven by country-product specific efficiency parameters.[14] Moreover, these models assume '*quality-biased efficiency*' (Alcalá, 2012), i.e. productivity differences increase in quality. Countries specialize within products on quality. However, across-product specialization is nonetheless pinned-down by the exogenous efficiency parameters. Jaimovich and Merella (2014) analyze quality upgrading in a model with non-homothetic preferences. In their model, all countries always produce all products.[15] However, they export more of the products for which they have comparative advantage according to their efficiency parameter. In fact, as the world becomes richer and consumers increase their demand for quality, the specialization of countries across products intensifies, reflecting the quality-biased efficiency.[16]

Alcalá (2012) presents a rich model with firm level heterogeneity to study specialization within and across a heterogeneous set of products. In his model, firm efficiency has higher value in production of some products than in production of other products if quality is fixed. This is no longer the case if firms can endogenously choose quality. Then a firm's productivity depends only on the exogenous efficiency parameter, but no longer on product characteristics. Hence, if firms could choose the products they produce, then quality differentiation would imply that they specialize within products on quality rather than across products. We study these implications at the country level. By contrast, in the model presented by Alcalá (2012), there is no such efficiency-dependent choice of products. The comparative advantages of countries across products are driven by the exogenous efficiency draws of their firms and the quality-bias of efficiency gives rise to a positive relationship between a country's comparative advantage for a product and its export quality.

To study the implications of within-product specialization on quality for comparative ad-

[14] To be precise, in Alcalá (2012), there is firm-level heterogeneity within countries and products, implying that comparative advantages are driven by the distribution of firm-level efficiencies.

[15] In their model, commodities are also differentiated by origin, i.e. a French and an Italian wine of the same quality are different commodities, and households always consume some French wine and some Italian wine.

[16] Fajgelbaum et al. (2011) and Jaimovich and Merella (2012) also study horizontal and vertical product differentiation in models with non-homothetic preferences. Fajgelbaum et al. (2011) prescind from technological differences and study trade driven by home-market effects. Their model provides a demand-sided rationale explaining why richer countries export higher-quality goods. Jaimovich and Merella (2012) show how differences in the scope for quality upgrading of products can lead to income divergence when aggregate productivity increases in a model of north-south trade. Intuitively, countries with comparative advantage in products with large scope for quality upgrading, i.e. products for which it is easy to upgrade quality, benefit as aggregate productivity rises and consumers shift demand towards higher quality. In their model, however, these comparative advantages are exogenous and do not depend on quality.

vantages of countries across products, we consider a stylized economy. In our model countries differ in one reduced-form parameter only, which captures their economic strength. To be precise, we will assume that countries differ in the skill level of their labor, but the origins of this economic strength are not essential for any of our results. Following Kremer (1993), we assume that production is based on an O-ring process that uses labor as the only input. Production requires successful accomplishment of all tasks. The skill level of labor determines the probability of successful accomplishment of any given task. Products differ in the number of simultaneous tasks – their *complexity*.[17] At constant quality, high-skill countries then have comparative advantage for complex products, as originally shown by Kremer (1993).[18]

We combine this production technology with a new way of modeling the endogenous choice of quality in an O-ring process. In particular, we suggest that producing higher output quality requires higher quality of every individual task involved in production, which, in turn, renders the successful accomplishment of every task more demanding.[19] This modeling choice generalizes Kremer's rationale in a natural way. It nicely reflects his guiding example of the failure of the space shuttle *Challenger*, as well as the concept of *Total Quality Management*, which is well established in management science.[20] Moreover, it provides a simple rationale for quality-biased efficiency and cross-product differences in the scope for quality differentiation, two assumptions that are common in the literature and that are supported by the data. Skills are more valuable in the production of high quality for the very same reason that they are more valuable in the production of complex products.[21] And quality upgrading is more difficult for complex products

[17] Costinot (2009b) considers the same source of product heterogeneity in a model of international trade. However, as opposed to our model, workers have to spend a fixed amount of their endowment with efficient labor on learning each task they are working on. Moreover, a worker fails if and only if he shirks, implying that the probability of a worker failing is independent of the number of tasks he is working on. Firms then face a simple trade-off: Increasing the division of labor reduces learning costs but increases the probability of at least one worker shirking and hence failure of production. This trade-off implies that countries with higher human capital and better institutions have a comparative advantage for the more complex products.

[18] Formally, the productivity of labor is log-supermodular in product complexity and the skill level of labor.

[19] Antràs and Chor (2013) also consider quality upgrading in a production process with a continuum of tasks. In their model, these tasks are sequential and they study vertical integration of firms. As in our model, all tasks are essential. However, in the model presented by Antràs and Chor (2013), higher quality in one task can partly compensate lower quality in other tasks.

[20] The idea can also be illustrated by the prototype of the *Devel Sixteen* presented at the *Dubai International Motorshow 2013*. According to *Defining Extreme Vehicles Car Industry L.L.C.*, the firm presenting the prototype, this prototype is equipped with an engine of 5000hp. At present, however, it is not possible to drive the *Devel Sixteen* because there are neither tires, nor gear drives, nor clutches available on the market that could cope with such a powerful engine (cf. http://www.spiegel.de/auto/aktuell/devel-sixteen-premiere-eines-brachial-autos-aus-dubai-mit-5000-ps-a-932513.html, retrieved on 12 November 2013).

[21] Quality-biased efficiency is assumed by Alcalá (2012) and Jaimovich and Merella (2014), for example, as discussed above. It is also in line with reduced-form specifications that directly link the quality of

because it requires higher quality of every task involved in production.[22]

In the context of our model, this extension of Kremer's O-ring theory implies that high-skill countries specialize on producing high quality, in line with what we observe from the data. This within-product specialization replaces across-product specialization. The basic intuition is that comparative advantages refer to the difficulty of production. With an endogenous choice of quality, this difficulty is no longer exogenously determined by the product complexity, but it becomes endogenous as well.

As argued previously, we further suggest that specialization within products is subject to product-specific minimum-quality requirements. This precludes low-skill countries from being competitive for complex products and gives rise to an upper-triangular structure of specialization of countries on products, in line with what we observe from the data.

Our insights also have important implications for two related strands in the literature. First, Hidalgo and Hausmann (2009) and Tacchella et al. (2012) propose new measures for the economic strength of countries and the complexity of products, based on a binary country-product matrix that indicates for every country the products for which it has a revealed comparative advantage. Broadly speaking, these measures classify a country as strong if it has revealed comparative advantage for many, complex products – a product being considered complex if few, strong countries have a revealed comparative advantage for it. Empirical evidence suggests that these measures can uncover important information on the economic strength of countries. Hidalgo and Hausmann (2009) and Hausmann and Hidalgo (2011) provide a rationale why this might be the case. They suggest that there exists a large set of non-tradeable capabilities and that products differ in their capability requirements. Then the products a country makes are naturally informative about the capabilities available, and hence the country's economic strength. We provide an alternative rationale for the proposed algorithms. We show that the interplay between product complexity and product quality introduces a systematic link between the economic strength of a country – as captured by a single reduced-form parameter – and the range of products it can successfully compete for on the world market. This link can be exploited by the proposed algorithms.

Second, as already indicated, our work motivates the use of a censored regression model to estimate the link between a country's GDP per capita and the quality of its exports.

inputs to the quality of outputs, as in Verhoogen (2008), for example.

[22] Khandelwal (2010), Jaimovich and Merella (2012), and Kugler and Verhoogen (2012), for example, assume product-specific scope for quality upgrading. They model this scope by introducing parameters either in the production function (Jaimovich and Merella, 2012, and Kugler and Verhoogen, 2012) or in the consumers' indirect utility function (Khandelwal, 2010). Khandelwal (2010) presents empirical evidence in support of such cross-product differences in the scope for quality differentiation.

The use of a censored regression model is new to this strand in the empirical literature, and it has important implications on the results, indicating a much stronger link than the one observed when using OLS. We briefly discuss the related literature at the onset of our empirical section below.

Organisation of this chapter

The remainder of this chapter is organized as follows. Section 5.2 presents our model. In section 5.3 we derive the equilibrium in our economy. We discuss the equilibrium pattern of comparative advantages and specialization in international trade in section 5.4. In section 5.5 we derive the censored regression model to estimate the link between a country's GDP per capita and the quality of its exports, and take this model to the data. Section 5.6 concludes.

5.2. Model

The world is composed of N_c countries. We consider the case of a footloose economy, where firms are free to locate production in whichever countries they deem best and to supply the world market from there. There are no tariffs, transportation costs, or other barriers to trade. Hence, in our economy, there is a single world market and a single price for every good.

5.2.1. Households

The world is populated by a continuum of households $h \in [0, 1]$ who derive utility from consumption of a continuum of products $i \in [0, N]$. Consumption of each product i is split across a continuum of varieties that differ in their quality $q \in [1, \bar{q}_i]$. Utility depends on the quantity and the quality consumed, where quality can be interpreted as a reduced form capturing any product attributes valued by the household:[23]

$$U^h \left(\left\{ c_{i,q}^h \right\}_{(i,q)\in[0,N]\times[1,\bar{q}_i]} \right) = C^h \tag{5.1}$$

$$C^h := \left(\int_0^N \left(\int_1^{\bar{q}_i} q c_{i,q}^h \, dq \right)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} , \tag{5.2}$$

[23] Baldwin and Harrigan (2011) vividly describe these preferences as *box-size-quality* preferences: Consumers are indifferent between a box of size 1 with quality 2 and a box of size 2 with quality 1.

where $c^h_{i,q}$ denotes the amount of the variety with quality q of product i consumed by household h.[24] There is a one-to-one mapping from qualities to varieties, and we therefore subsequently refer to qualities directly, unless this might cause confusion.

Qualities of the same product are perfect substitutes. The elasticity of substitution between products is given by σ. $\bar{q}_i$ denotes the maximum quality of product i available, where $\bar{q}_i \geq 1\ \forall\, i$ and $\lim_{i \to 0} \bar{q}_i = \infty$.[25,26] We assume $1 < \sigma < 1 + \lambda$, which guarantees that all products will be consumed in equilibrium.[27]

Households live in one of N_c countries. They differ in the efficiency of their labor, r. Across the world, these efficiencies are distributed according to $F_r(r)$ on the interval $[\underline{r}, \overline{r}]$, with $0 < \underline{r} \leq \overline{r} < 1$, i.e. $F_r(r)$ is the total mass of households with efficiency less than or equal to r. We use $\mathcal{R}$ to denote the support of the associated probability distribution function, i.e. $\mathcal{R}$ is the set of efficiency levels of labor available. We are most interested in analyzing how countries with different levels of economic strength compete over a heterogeneous set of products. For the main part, we will therefore assume that all households living in country k have the same efficiency level r^k and that $r^k \neq r^l,\ \forall\, k, l \in \{1, 2, ..., N_c\}$ with $k \neq l$. In principle, however, households can also be heterogeneous within countries, the efficiency levels of households can overlap across countries, and the distribution of efficiencies can be continuous or discrete.[28] To simplify notation, we will henceforth identify countries by the efficiency of their labor, r, and drop the country index.[29] To be concrete, we will speak of r as the *skill level* of a country (of its labor), but the origins of the country-specific efficiency r do not matter, and it may reflect institutions, production technologies, and human capital, for example. Labor is perfectly mobile across products, but immobile across countries.

Each household inelastically supplies L units of labor and maximizes utility subject to its

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[24] In the equilibrium, only a discrete subset of these varieties may be available. To simplify the exposition, we abuse notation and use the integral sign to denote a finite sum in such case. We follow this convention throughout this part of the thesis.

[25] In principle, every product i can be produced with any quality $q \geq 1$. However, as long as $i > 0$, there exists an upper threshold for quality, $\bar{q}_i$, beyond which firms will not find it profitable to increase quality further.

[26] Some expressions throughout this part of the thesis are not well defined if $i = 0$. In such case, we assume that the expression is obtained by taking its limit when $i \to 0$.

[27] $\sigma > 1$ implies that households love variety. $\sigma < 1 + \lambda$ ensures that this love for variety is sufficiently large. In the words of Bernard et al. (2003, p. 1276), it ensures that: *'goods are sufficiently heterogeneous in consumption relative to their heterogeneity in production so that buyers do not concentrate their purchases on a few low-price goods.'* This assumption is not needed in a variant of our model where all products involve the same number of tasks but differ in their minimum-quality requirements (cf. appendix C.7).

[28] In our model the allocation of efficiency levels of labor to countries does not matter for aggregate outcomes. Cf. appendix C.2 for a brief discussion.

[29] Analogously, we will use the set of efficiency levels of labor available, $\mathcal{R}$, to represent the set of countries.

budget constraint:

$$\int_0^N \int_1^{\bar{q}_i} p_{i,q} c_{i,q}^h \, dq \, di \leq L w^h + I^h \ , \tag{5.3}$$

where $p_{i,q}$ is the price of quality q of product i, w^h is the wage rate earned by household h, and I^h denotes other income, stemming from shareholdings in our model.[30] In equilibrium, labor with skill level r will earn the same wage rate, w_r, irrespective of its country of residence, and hence a household's labor income will depend only on the skill level of its labor.[31]

With CES utilities, we can work with a representative household whose budget constraint is given by:

$$\int_0^N \int_1^{\bar{q}_i} p_{i,q} c_{i,q} \, dq \, di \leq L \int_{\underline{r}}^{\overline{r}} w_r \, dF_r(r) + \overline{I} \ ,$$

where $L \int_{\underline{r}}^{\overline{r}} w_r \, dF_r(r)$ is the average labor income and $\overline{I}$ denotes average other income. To solve the representative household's decision problem, we note that perfect substitutability between different qualities of the same product implies that all qualities of product i will be sold at the same quality-adjusted price $\rho_i := \frac{p_{i,q}}{q}$ in equilibrium. This, in turn, implies that the representative household is indifferent between consuming any combination of these qualities and, hence, its demand is defined at the product level only. Let $\tilde{c}_i := \int_1^{\bar{q}_i} q c_{i,q} \, dq$ denote total quality-adjusted consumption of product i by the representative household. Following standard steps, we then get:

$$\tilde{c}_i = C P^\sigma \left[\rho_i\right]^{-\sigma} \tag{5.4}$$

$$PC = L \int_{\underline{r}}^{\overline{r}} w_r \, dF_r(r) + \overline{I} \tag{5.5}$$

$$\text{with} \quad P := \left(\int_0^N \left[\rho_i\right]^{1-\sigma} di \right)^{\frac{1}{1-\sigma}} \ . \tag{5.6}$$

The specification of the utility function in equations (5.1) and (5.2) above implies that households care about quality-adjusted consumption of product i, $\tilde{c}_i$. Accordingly, equation (5.4) expresses quality-adjusted demand for product i as a function of the quality-adjusted price of product i, ρ_i, the quality-adjusted consumption index, C, and the quality-adjusted price index, P.

[30] With homothetic preferences, the distribution of firm ownerships does not matter for aggregate outcomes and we thus ignore them throughout this part of the thesis. This implies that in our model trade balances are not equal to 0 in general, while current accounts balance due to compensating net factor incomes from abroad.

[31] This is trivially the case if we assume that the skill levels of labor do not overlap across countries. Note, however, that this is the case more generally. Cf. appendix C.2 for a brief discussion.

5.2.2. Firms

There is a continuum of monopolistically competitive firms. Firm $i \in [0, N]$ has a global patent for all qualities of product i. Total demand for product i is given by equation (5.4). Production is organized in production sites. Each production site can produce any amount of one specific quality of product i. We have a footloose economy, i.e. the firm is free to open up production sites at no costs anywhere in the world and to supply the world market from there. There are no transportation costs, tariffs, or other barriers to trade.[32]

5.2.2.1. Production technology

Production is based on an O-ring technology in the spirit of Kremer (1993), but with an endogenous choice of output quality. In particular, if firm $i \in [0, N]$ opens up a production site in country $r \in \mathcal{R}$ and hires a mass $L_i(r)$ of labor to produce quality q of its product, then expected output, $E[x_{i,q}]$, is given by:

$$E[x_{i,q}] = [r]^{iq^\lambda} L_i(r), \quad q \geq 1 . \tag{5.7}$$

This technology has the following interpretation: Producing product i requires successful accomplishment of a continuum of measure i of simultaneous tasks. If the firm hires a worker with skill level r to work on a set of tasks with measure Δ, then the worker will successfully accomplish these tasks with probability $[r]^{\Delta q^\lambda}$.[33] This probability is the same, irrespective of the tasks the worker is working on, i.e. there are no gains from specialization of labor on a specific set of tasks. Each product has a standard version with quality $q = 1$. It can be refined by producing higher quality, but the inverse is not true: The product has to be at least of standard quality.[34] Higher quality, i.e. $q > 1$, renders the successful accomplishment of each individual task more demanding and, hence, lowers the probability of success.[35] $\lambda > 0$ is a parameter determining how difficult it is to raise quality. The production technology implies that more *complex* products, i.e. products with a higher index i, are more difficult to produce, and that quality improvements are more demanding for these products. It also implies that skills are *complexity-biased* and *quality-biased* in the sense that they are of higher value in production of more complex and/or higher-quality products.

[32] As alternatives, we could assume perfect competition or Bertrand competition for each product. The results would essentially be the same.
[33] Note that, by assumption of $0 < \underline{r} \leq \overline{r} < 1$, we have $r \in (0, 1)$.
[34] Cf. the discussion in section 5.1 for a motivation.
[35] Our guiding rationale is that higher output quality requires higher quality of every single task involved in production. Cf. section 5.1 for a discussion.

Labor is organized in a continuum of teams. The probability of successful operation of each team is $[r]^{iq^{\lambda}}$. Its expected output is given by this probability, times the mass of labor employed in the team. With a continuum of teams, we can apply the law of large numbers and ignore the expectation operator in the production function henceforth. The production technology exhibits constant returns to scale with respect to $L_i(r)$. We note that the complexity of the product increases the difficulty of the production process and thus lowers the probability of successful operation of any given team, but not more labor is needed to accomplish the increased number of tasks: Given the same success probability, $[r]^{iq^{\lambda}}$, the same mass of labor employed in production, $L_i(r)$, yields the same output, irrespective of the complexity of the product, and hence the number of tasks involved in the production process.[36]

We further illustrate the production technology by means of the following simple example.[37]

Example 5.1
Paula wants to run a Swiss-watch business. Each watch is composed of three main parts: (1) A balance wheel (pendulum), (2) a spring, and (3) a suspension. A watch only works properly if all three components are well-functioning, which can only be observed upon assembly of the watch. Otherwise, the watch is worthless. Let $\lambda = 1$*, for simplicity, and let* q_w *denote the quality of the watch produced. Then a worker with skill level r working on component* $j \in \{1, 2, 3\}$ *successfully produces this component with probability* $(r)^{q_w}$*. Suppose one workday is needed for every attempt to produce a watch. Then the production function for watches is given by:*

$$E\left[x_{w,q_w}\right] = \left[(r)^3\right]^{q_w} L_w(r) ,$$

where x_{w,q_w} *is the number of watches with quality* q_w *produced, and* r *and* $L_w(r)$ *are the skill level and the mass in workdays of labor employed, respectively.*

Paula can produce two types of watches: A standard watch with $q_w = 1$ *and a high precision watch with* $q_w = 2$*. There are three types of workers: John with skill level* $r^J = \exp\left(-\frac{1}{2}\right) \approx 0.61$*, Thomas with* $r^T = \exp\left(-\frac{1}{3}\right) \approx 0.72$*, and Amy with* $r^A = \exp\left(-\frac{1}{6}\right) \approx 0.85$*. Now suppose that Paula hires John for two days to produce standard watches. Then her (expected) output is*

[36] The specification of the production technology in equation (5.7) implies that all workers working in a team have the same skill level of labor, i.e. we rule out the possibility that the firm hires different skill levels of labor to work on different tasks involved in production. With the assumptions made on the cross-country distribution of skills, this is trivially not possible. Note, however, that a standard result following Kremer (1993) implies that it is never optimal for a firm to form heterogeneous teams, i.e. ruling out this possibility does not impair the applicability of our subsequent analyses to alternative cross-country distributions of skills. We briefly discuss the more general set-up in appendix C.2.

[37] Throughout the remainder of this and in the following section, we will repeatedly refer back to this example to illustrate our results. The example may be skipped, if desired.

given by: $\left[(r^J)^3\right]^1 * 2 \approx 0.45$. *Suppose, by contrast, she hires Amy for three days to produce high-precision watches. Then her (expected) output is given by:* $\left[(r^A)^3\right]^2 * 3 \approx 1.1$.

5.2.2.2. Firm's decision problem

Firm $i \in [0, N]$ chooses a set of countries where to open up production sites, $\mathcal{R}_i \subseteq \mathcal{R}$. This choice is driven by the skill level of labor living in a country. For each $r \in \mathcal{R}_i$, the firm chooses a quality of product i to produce, $q_i(r)$, its price level, $p_{i,q_i(r)}$, total output, $x_{i,q_i(r)}$, and the mass of labor employed, $L_i(r)$.[38] It maximizes its profits, taking as given the production technology, (5.7), the input prices, i.e. the wage rate in each country, $\{w_r\}_{r\in\mathcal{R}}$, and the demand for product i, (5.4). This demand is specified in total quality-adjusted consumption of all qualities with the lowest quality-adjusted price, ρ_i. Hence firm i's choice of output prices reduces to the choice of ρ_i, and it can freely allocate its quality-adjusted output to qualities.

In summary, we get the following profit maximization problem of firm i:

$$\max_{\substack{\mathcal{R}_i,\rho_i,\{q_i(r)\}_{r\in\mathcal{R}_i} \\ \left\{x_{i,q_i(r)}\right\}_{r\in\mathcal{R}_i},\{L_i(r)\}_{r\in\mathcal{R}_i}}} \int_{r\in\mathcal{R}_i} \left[\rho_i q_i(r) x_{i,q_i(r)} - L_i(r) w_r\right] dr \tag{5.8}$$

$$\begin{aligned} \text{s.t. } & x_{i,q_i(r)} = [r]^{iq_i(r)^\lambda} L_i(r), \quad \forall\, r \in \mathcal{R}_i \\ & \int_{r\in\mathcal{R}_i} q_i(r) x_{i,q_i(r)}\, dr = CP^\sigma [\rho_i]^{-\sigma} \\ & q_i(r) \geq 1 \quad \forall\, r \in \mathcal{R}_i \\ & \mathcal{R}_i \subseteq \mathcal{R}\,. \end{aligned}$$

We now analyze firm i's decision problem in detail. Let us refer to quality-adjusted output as *effective output* and let $\chi_i := \int_{r\in\mathcal{R}_i} q_i(r) x_{i,q_i(r)}\, dr$ denote the total effective output of product i. Then, in essence, firm i's decision problem boils down to the following two basic decisions:

(i) Choose locations for production sites and the qualities they produce to minimize the costs per unit of effective output;

(ii) Given these costs per unit of effective output, choose a (quality-adjusted) price to maximize profits.

If several production sites share the minimal costs per unit of effective output, then the

[38] In principle, the firm could produce several qualities in country $r \in \mathcal{R}_i$. However, as we show in Lemma 5.1, this will never be the case in equilibrium. To simplify notation, we thus ignore this possibility here.

allocation of total effective output, χ_i, to these production sites is a matter of indifference. We proceed by considering the firm's cost minimization problem first.

(i) Cost minimization problem

When opening up a production site, firm $i \in [0, N]$ chooses a location, r, and an output quality, q, for product i to solve the following cost minimization problem:

$$\begin{aligned} \min_{q,r} \quad & \frac{w_r}{q\,[r]^{iq^\lambda}} \\ \text{s.t.} \quad & q \geq 1 \\ & r \in \mathcal{R}\,, \end{aligned}$$

where $\frac{w_r}{q[r]^{iq^\lambda}}$ are the costs per unit of effective output. It will be instructive to solve this problem in two steps. First, we take the location of a production site, i.e. the skill level of labor employed, as given and derive the optimal choice of quality. Then we discuss the choice of skill levels.

Suppose firm i operates a production site in a country with skill level $r \in \mathcal{R}$. With r – and hence the wage rate – fixed, minimizing the costs per unit of effective output is equivalent to maximizing the effective output per worker, which is given by $q\,[r]^{iq^\lambda}$. Then the choice of q involves a simple trade-off: When raising q, the firm weighs the gain from a more valuable product against the loss of a lower output due to the increased difficulty of production. Formally, the choice of q solves the following first order condition:

$$[r]^{iq^\lambda} = -\lambda q^\lambda i \log(r)\,[r]^{iq^\lambda} \quad , \tag{5.9}$$

and it turns out that there is a unique cost-minimizing choice of quality, $q_i(r)$:

Lemma 5.1

$\forall (i, r) \in [0, N] \times \mathcal{R}$, *let firm* i *run a production site in country* r. *Then it produces quality:*

$$q_i(r) = \max\left\{1, \left[-\frac{1}{\lambda i \log(r)}\right]^{\frac{1}{\lambda}}\right\} .$$

A proof of Lemma 5.1 is given in appendix C.3.1. For $-\frac{1}{\lambda i \log(r)} > 1$, quality increases with the skill level of labor used in production, r, reflecting a quality-bias of skills.[39]

[39] Formally, the productivity of labor in terms of effective output is log-supermodular in the skill level of labor and output quality.

Furthermore, optimal product quality decreases with the complexity of the product, i, and λ, the factor characterizing how difficult it is to increase quality. When operating in a low-skill country, the firm would ideally simplify production by producing a variety with a quality that is lower than the minimum quality. As this is not feasible, it can do no better than producing the minimum quality instead.

Example 5.1 (continued)

Amy optimally produces high precision watches: $-\frac{1}{3\log(r^A)} = 2$. *Thomas optimally produces standard watches:* $-\frac{1}{3\log(r^T)} = 1$. *John, however, is bounded by the minimum-quality constraint. For him, producing standard watches is very demanding and he would preferably produce quality* $-\frac{1}{3\log(r^J)} = \frac{2}{3}$. *As this is not feasible, however, his best alternative is to also produce standard watches instead.*

The optimal choice of product quality pins down the costs per unit of effective output up to the choice of the location of the production site, i.e. the skill level of labor employed. Depending on this choice of r, the firm can produce *preferred quality* or not, with preferred quality given by $\left[-\frac{1}{\lambda i \log(r)}\right]^{\frac{1}{\lambda}}$. Let us introduce the following notation for threshold complexity levels as a function of skills, $\tilde{i}(r)$, and threshold skill levels as a function of complexity, $\tilde{r}(i)$:

$$\tilde{i}(r) := -\frac{1}{\lambda \log(r)}$$
$$\tilde{r}(i) := e^{-\frac{1}{\lambda i}} .$$

$\tilde{i}(r)$ denotes the maximal complexity of the products that can be produced at preferred quality in country r, i.e. the complexity level for which the minimum-quality constraint is just binding when labor with skill level r is used in production. Conversely, $\tilde{r}(i)$, which is the inverse of $\tilde{i}(r)$, denotes the minimal skill level needed in production of product i to produce at preferred quality, i.e. the skill level for which the minimum-quality constraint is just binding when producing product i.

Example 5.1 (continued)

The threshold complexity levels for Amy, Thomas, and John, are $-\frac{1}{\log(r^A)} = 6$, $-\frac{1}{\log(r^T)} = 3$, *and* $-\frac{1}{\log(r^J)} = 2$, *respectively. The threshold skill level for watches is* $\exp\left(-\frac{1}{3}\right) \approx 0.72$, *Thomas' skill level.*

Let $\left.\frac{L_i(r)w_r}{\chi_i}\right|_q$ denote firm i's costs per unit of effective output if it produces quality q in country r. Then, with the optimal choice of quality, $q_i(r)$, we have:

$$\left.\frac{L_i(r)w_r}{\chi_i}\right|_{q_i(r)} := \frac{w_r}{q_i(r)\,[r]^{iq_i(r)^\lambda}} = \begin{cases} w_r\,[-e\lambda i\log(r)]^{\frac{1}{\lambda}} & \text{if } r \geq \tilde{r}(i) \\ w_r\,[r]^{-i} & \text{otherwise} \end{cases} . \tag{5.10}$$

Firm i opens up production sites in an arbitrary combination of the countries where its costs per unit of effective output, (5.10), are minimal. This choice depends on the shape of the wage scheme, $\{w_r\}_{r\in\mathcal{R}}$, and we thus analyze it in connection with our discussion of the equilibrium wage scheme in section 5.3.1 below. For now, we take the choice of countries $\mathcal{R}_i \subseteq \mathcal{R}$ as given and briefly discuss firm i's profit maximization problem first.

(ii) Profit maximization problem for $\mathcal{R}_i$ given

All qualities of product i are sold at the same quality-adjusted price. Hence total revenue of firm i is simply given by $\rho_i\chi_i$. Moreover, as the costs per unit of effective output are the same for all the firm's production sites, let us assume that all production occurs in country $r \in \mathcal{R}_i$, without loss of generality. Then, for firm i's profit maximization problem, we obtain:

$$\begin{aligned} \max_{\rho_i,\chi_i} \quad & \rho_i\chi_i - \chi_i\frac{w_r}{q_i(r)\,[r]^{iq_i(r)^\lambda}} \\ \text{s.t.} \quad & \chi_i = CP^\sigma\,[\rho_i]^{-\sigma} \\ & (5.10)\,. \end{aligned}$$

We can follow standard steps to get:

$$\rho_i = \begin{cases} \frac{\sigma}{\sigma-1}w_r\,[-e\lambda i\log(r)]^{\frac{1}{\lambda}} & \text{if } r \geq \tilde{r}(i) \\ \frac{\sigma}{\sigma-1}w_r r^{-i} & \text{otherwise} \end{cases} . \tag{5.11}$$

The quality-adjusted price is equal to the well-known constant mark-up over the marginal costs of producing effective output.

5.3. Equilibrium

In this section we analyze the equilibrium, starting with its definition.

Definition 5.1 (Equilibrium)
An equilibrium is:

(i) for each firm $i \in [0, N]$, a set of countries where the firm operates a production site, $\{\mathcal{R}_i\}_{i\in[0,N]}$

(ii) for each production site of each firm, a quality, $\{q_i(r)\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$, an output level, $\left\{x_{i,q_i(r)}\right\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$, and a mass of labor employed, $\{L_i(r)\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$

(iii) for each household $h \in [0, 1]$, a set of consumption levels for each quality of each product, $\left\{c^h_{i,q_i(r)}\right\}_{(i,r,h)\in[0,N]\times\mathcal{R}_i\times[0,1]}$

(iv) a set of good prices, $\left\{p_{i,q_i(r)}\right\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$

(v) a set of wage rates, $\{w_r\}_{r\in\mathcal{R}}$

such that:

(i) $\frac{p_{i,q_i(r)}}{q_i(r)} = \rho_i, \ \forall\,(i, r) \in [0, N] \times \mathcal{R}_i$ and some $\rho_i \geq 0$

(ii) $\mathcal{R}_i$, $\{q_i(r)\}_{r\in\mathcal{R}_i}$, $\left\{x_{i,q_i(r)}\right\}_{r\in\mathcal{R}_i}$, $\{L_i(r)\}_{r\in\mathcal{R}_i}$, and ρ_i solve firm i's profit maximization problem, (5.8)*, $\forall\, i \in [0, N]$*

(iii) $\left\{c^h_{i,q_i(r)}\right\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$ maximize household h's utility, (5.1)*, subject to its budget constraint,* (5.3)*, $\forall\, h \in [0, 1]$*

(iv) good markets clear for each quality of each product

(v) labor markets clear in all countries

From our discussion of the firm we know that equilibrium outcomes depend on whether or not firm i locates production in a country with skill level $r \geq \tilde{r}(i)$. We start by analyzing the labor market and identify a condition for *sufficient skills* in the economy which guarantees that $r \geq \tilde{r}(i), \ \forall\,(i, r) \in [0, N] \times \mathcal{R}_i$ in equilibrium. A sequence of preliminary results, along with this condition, eventually allow to characterize equilibrium wages as outlined in Proposition 5.1. We then derive the remaining equilibrium outcomes for the case of sufficient skills and summarize these findings in Proposition 5.2.

5.3.1. Equilibrium wage

In our economy there is a separate labor market in each country. Labor is immobile across countries, but firms are not. They can freely locate production wherever they deem best. We thus start our analysis of the labor market by reconsidering the optimal choice of a location for a production site by firm $i \in [0, N]$, i.e. its demand for skills. Firm i chooses $\mathcal{R}_i$ to minimize its costs of producing one unit of effective output as specified in equation (5.10). This optimal choice depends on the shape of the wage scheme $\{w_r\}_{r\in\mathcal{R}}$. It is instructive to consider the choice between two countries with skill levels $r^h, r^l \in \mathcal{R}$ first, where $r^h > r^l \geq \tilde{r}(i)$. Then, from equation (5.10), it follows that firm i would be indifferent between producing in either of the two countries if wages satisfied:

$$w_{r^h} = \left[\frac{\log(r^l)}{\log(r^h)}\right]^{\frac{1}{\lambda}} w_{r^l} \ .$$

This holds true $\forall\, r^l, r^h \in [\tilde{r}(i), \overline{r}]$. More generally, take $w_{\underline{r}} = 1$ to be the numéraire and let wages satisfy:

$$w_r = \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} \ \forall\, r \in \mathcal{R} \ . \tag{5.12}$$

Then firm i is indifferent between producing in any country with a skill level at least as high as its threshold level $\tilde{r}(i)$. The wage premium earned by workers in the high-skill country when compared to workers in the low-skill country just compensates for their higher productivity, provided that the firm is not bounded by the minimum-quality constraint $q \geq 1$ in both countries.

Next, consider the trade-off between two countries $r^h \geq \tilde{r}(i)$ and $r^l < \tilde{r}(i)$ for the case of wages given by equation (5.12) above. Then we have:

$$\begin{aligned} \left.\frac{L_i(r^l)w_{r^l}}{\chi_i}\right|_{q_i(r^l)} &= w_{r^l}\left[r^l\right]^{-i} \\ &> w_{r^l}\left[-e\lambda i \log(r^l)\right]^{\frac{1}{\lambda}} = w_{r^h}\left[-e\lambda i \log(r^h)\right]^{\frac{1}{\lambda}} = \left.\frac{L_i(r^h)w_{r^h}}{\chi_i}\right|_{q_i(r^h)} . \end{aligned}$$

The inequality follows from the fact that producing quality $q_i(r^l) = \left[-\frac{1}{\lambda i \log(r^l)}\right]^{\frac{1}{\lambda}} < 1$ would be uniquely cost minimizing in country r^l if it was feasible. Hence firm i strictly prefers producing in country r^h to producing in country r^l. Intuitively, in country r^l it cannot produce preferred quality, $\left[-\frac{1}{\lambda i \log(r^l)}\right]^{\frac{1}{\lambda}} < 1$, but produces quality $q = 1$ instead. This quality constraint implies an additional advantage of high-skill over low-skill countries which is not compensated for by their wage premium.

We summarize these insights on firm i's demand for skills in Lemma 5.2 below. In addition to what was discussed previously, this lemma states that firm i also prefers producing in country r^h to producing in country r^l for the case of $\tilde{r}(i) > r^h > r^l$. The intuition is that the minimum quality $q = 1$ is closer to the preferred quality in the high-skill country than to the preferred quality in the low-skill country. A proof of this statement is given in appendix C.3.2.

Lemma 5.2

Let wages be given by equation (5.12)*. Then:*

(i) $\forall \left(i, r^l, r^h\right) \in [0,N]\times\mathcal{R}\times\mathcal{R}$ *such that* $r^h > r^l \geq \tilde{r}(i)$*, firm* i *is indifferent between producing in country* r^l *and in country* r^h*;*

(ii) $\forall \left(i, r^l, r^h\right) \in [0,N]\times\mathcal{R}\times\mathcal{R}$ *such that* $r^h > r^l$ *and* $r^l < \tilde{r}(i)$*, firm* i *strictly prefers producing in country* r^h *to producing in country* r^l*.*

Example 5.1 (continued)

Let John's wage be the numéraire, i.e. we have $w^J = 1\$$*. Further, let wages for Thomas and Amy satisfy equation* (5.12) *above, i.e. we have* $w^T = \frac{\log(r^J)}{\log(r^T)} = 1.5\$$ *and* $w^A = \frac{\log(r^J)}{\log(r^A)} = 3\$$*. Now suppose Paula hires John. John needs* $\frac{2}{(r^J)^3} \approx 8.96$ *workdays on average to produce two watches of standard quality. This costs Paula* $\sim 8.96\$$*. Thomas, by contrast, needs* $\frac{2}{(r^T)^3} \approx 5.44$ *workdays on average to produce two watches of standard quality. This costs Paula* $\sim 8.15\$$*. Finally, Amy needs* $\frac{1}{[(r^A)^3]^2} \approx 2.72$ *workdays to produce one high-precision watch which is as good as two watches of standard quality. This costs Paula* $\sim 8.15\$$ *as well. Hence Paula is indeed indifferent between hiring Amy and Thomas, and strictly prefers hiring either one of them to hiring John.*

Lemma 5.2 immediately implies that equilibrium wages must satisfy the following condition:[40]

Corollary 5.1

In equilibrium we must have:

$$\frac{w_{r^h}}{w_{r^l}} \geq \left[\frac{\log(r^l)}{\log(r^h)}\right]^{\frac{1}{\lambda}} \;\forall\, r^l, r^h \in \mathcal{R} :\; r^h \geq r^l \;. \tag{5.13}$$

We now analyze under which conditions the equilibrium wages are characterized by equation (5.12). From Lemma 5.2 we know that such an equilibrium is associated with indeterminacy in terms of where firms locate their production sites. Every firm $i \in [0, N]$ is indifferent between producing in any country with skill level $r \geq \tilde{r}(i)$. It follows that the mass of labor employed by firm i is also undetermined. To analyze the equilibrium on the

[40] To show the result stated in Corollary 5.1, consider two countries with skill levels $r^l, r^h \in \mathcal{R}$ with $r^h > r^l$ and suppose, by contradiction, that their respective wages $(\hat{w}_{r^l}, \hat{w}_{r^h})$ satisfy $\frac{\hat{w}_{r^h}}{\hat{w}_{r^l}} < \left[\frac{\log(r^l)}{\log(r^h)}\right]^{\frac{1}{\lambda}}$. Then we can conclude from Lemma 5.2 that all firms would strictly prefer producing in country r^h to producing in country r^l. Hence there would be excess supply of labor in country r^l, a contradiction to $(\hat{w}_{r^l}, \hat{w}_{r^h})$ being the equilibrium wages in countries r^l and r^h, respectively.

labor market, we therefore introduce the following concept of *effective labor*, $\tilde{L}(r)$:

$$\tilde{L}(r) := L(r) \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} . \tag{5.14}$$

This concept of effective labor normalizes labor of skill level $r \in \mathcal{R}$ in terms of labor with the lowest skill level, $\underline{r}$, for the case of both skill levels being able to operate at preferred quality. It follows that firm i's demand for effective labor is uniquely determined, irrespective of the exact skill level $r \geq \tilde{r}(i)$ it uses in production.[41]

With this notation, we can identify conditions such that the wage scheme (5.12) is an equilibrium. In particular, because firm i is willing to produce in any country with skill level $r \geq \tilde{r}(i)$, the following two conditions are sufficient for labor market clearing in all countries $r \in \mathcal{R}$: First, every firm $i \in [0, N]$ must be able to satisfy its total demand for effective labor, $\tilde{L}_i$, in countries with skill level $r \geq \tilde{r}(i)$, i.e. there must be no excess demand for skills. Second, the overall labor market must clear, i.e. total supply of effective labor must equal total demand.

Let us turn to the former condition first. Consider some firm $\hat{\imath} \in [0, N]$. $\tilde{r}(i)$ is increasing in i. Hence a necessary condition for all firms $i \in \left[\hat{\imath}, N\right]$ being able to satisfy their demand for effective labor in a country with skill level $r \geq \tilde{r}(i)$ is that the total supply of effective labor in countries with skill level $r \geq \tilde{r}(\hat{\imath})$ is no less than total demand for effective labor by firms $i \in \left[\hat{\imath}, N\right]$. Now suppose that this condition is satisfied $\forall\, \hat{\imath} \in [0, N]$. Then firms can locate their production sites such that $r \geq \tilde{r}(i)\ \forall\, (i, r) \in [0, N] \times \mathcal{R}_i$, i.e. such that the minimum-quality constraint is never binding, and we say that we have *sufficient skills* in the economy.[42]

Definition 5.2 (Sufficient Skills)
We say that there are sufficient skills in the economy if the following condition is satisfied:

$$L \int_{e^{-\frac{1}{\hat{\imath}\lambda}}}^{\overline{r}} \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} dF_r(r) \geq \int_{\hat{\imath}}^{N} \tilde{L}_i \, di, \quad \forall\, \hat{\imath} \in [0, N] \, . \tag{SSC}$$

[41] Suppose firm $i \in [0, N]$ wants to produce χ_i units of effective output in country $r \geq \tilde{r}(i)$. Then it needs:

$$\begin{aligned}\tilde{L}_i(r) &= L_i(r) \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} \\ &= \left[-e\lambda i \log(\underline{r})\right]^{\frac{1}{\lambda}} \chi_i\end{aligned}$$

units of effective labor, which is indeed independent of the exact skill level $r \geq \tilde{r}(i)$.

[42] Note, however, that of course more skills would always be desirable, as high-skill workers are more productive.

Condition (SSC) rules out that there is excess demand for skills.[43] Hence, if, in addition, the overall market for effective labor clears, i.e. if condition (SSC) holds with equality for $\hat{i} = 0$, labor markets are in equilibrium.

We summarize our insights on equilibrium wages in the following proposition, in which we use $\tilde{L}_i\left(\{\hat{w}_r\}_{r\in\mathcal{R}}\right)$ to denote the effective labor input used by firm i when confronted with the wage scheme $\{\hat{w}_r\}_{r\in\mathcal{R}}$:

Proposition 5.1
Let $\{\hat{w}_r\}_{r\in\mathcal{R}}$ be a wage scheme satisfying $\hat{w}_r = \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}}\ \forall\, r \in \mathcal{R}$.

(i) $\{\hat{w}_r\}_{r\in\mathcal{R}}$ is the unique equilibrium wage scheme if and only if $\left\{\tilde{L}_i\left(\{\hat{w}_r\}_{r\in\mathcal{R}}\right)\right\}_{i\in[0,N]}$ satisfies condition (SSC).

(ii) Otherwise, the equilibrium wage scheme, $\{w^\star_r\}_{r\in\mathcal{R}}$ satisfies:

$$w^\star_r \begin{cases} = \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} & \text{if } r \le \hat{r} \\ > \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} & \text{otherwise} \end{cases},$$

for some $\hat{r} \in \mathcal{R}$ such that $\hat{r} < \max\{\mathcal{R}\}$, and where

$$\frac{w_{r^h}}{w_{r^l}} \ge \left[\frac{\log(r^l)}{\log(r^h)}\right]^{\frac{1}{\lambda}} \quad \forall\, r^l, r^h \in \mathcal{R} : \ r^h \ge r^l \, .$$

A proof of Proposition 5.1(i) is given in appendix C.3.3. Proposition 5.1(ii) follows immediately from Proposition 5.1(i) and Corollary 5.1. Intuitively, if condition (SSC) is not satisfied given $\{\hat{w}_r\}_{r\in\mathcal{R}}$, there are fewer skills available in the economy than demanded given a wage scheme $\{\hat{w}_r\}_{r\in\mathcal{R}}$. This excess demand for skills implies that workers in high-skill countries must earn an extra wage premium, leading to a wage scheme as characterized in Proposition 5.1(ii).

Without sufficient skills, we will always observe some block-diagonal pattern of special-

[43] In principle, labor in high-skill countries may be fully employed in production of products with low complexity, and thus not be available for use in production of the most complex products, even though we have sufficient skills in the economy. To avoid this caveat, we assume that in case of indifference, labor will always opt to work in production of the most complex product. We motivate this 'tie-breaking-rule' by the following thought experiment: Consider an economy with two firms i and j, $i > j$, and two countries r^l and r^h, $r^h > r^l$. Let $r^h \ge \tilde{r}(i) > \tilde{r}(j)$ and $\tilde{r}(i) > r^l \ge \tilde{r}(j)$ and suppose labor in country r^l is selling at wage 1. Then firm j's maximal willingness to pay for labor in country r^h is $w_{r^h} = \left[\frac{\log(r^l)}{\log(r^h)}\right]^{\frac{1}{\lambda}}$. By contrast, being able to produce in country r^h has some extra value for firm i, as it enables production with preferred quality, which is not the case for country r^l. Hence, if necessary, firm i will be willing to offer a marginally higher wage to labor in country r^h to break these workers' indifference between joining firm i and j.

ization of countries on products.[44] We are most interested in analyzing how countries specialize on quality for a heterogeneous set of products. Hence, in the remainder of this chapter, we will make the following assumption:

Assumption 5.1

$$\frac{\int_{e^{-\frac{1}{\lambda i}}}^{\overline{r}} [-\log(r)]^{-\frac{1}{\lambda}} \, dF_r(r)}{\int_{\underline{r}}^{\overline{r}} [-\log(r)]^{-\frac{1}{\lambda}} \, dF_r(r)} \geq 1 - \left(\frac{i}{N}\right)^{\frac{1+\lambda-\sigma}{\lambda}} , \quad \forall\, i \in [0, N]$$

Assumption 5.1 restricts the set of feasible distributions $F_r(r)$. As we will show, it guarantees that we have sufficient skills in the economy, i.e. that we have an equilibrium according to Proposition 5.1(i) above. While Assumption 5.1 may seem technical, it is important to bear in mind that, in economic terms, it simply states that there are enough high-skill countries such that these countries do not only produce complex products, but also some of the simple products. This is exactly what we observe from the data.

5.3.2. Other equilibrium values

From above we know that with sufficient skills, equilibrium wages are given by:

$$w_r^{\star} = \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} \ \forall\, r \in \mathcal{R} ,$$

where the superscript * denotes equilibrium values. The derivations of the other equilibrium values are straightforward and are thus relegated to appendix C.3.4. There, we also use $\tilde{L}_i^{\star}$ in condition SSC to show that indeed Assumption 5.1 implies sufficient skills.

We summarize our insights in the following proposition:

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[44] In an equilibrium according to Proposition 5.1(ii), all firms $i \in \left[0, \tilde{i}(\hat{r})\right]$ will only produce in countries with skill level $r \leq \hat{r}$. On the other hand, if some firm $\hat{i} > \tilde{i}(\hat{r})$ chooses to produce in some country $r^h > \hat{r}$, then all firms $i \in \left(\hat{i}, N\right]$ will only produce in countries with skill level $r > \hat{r}$. This follows from the fact that with an optimal choice of output quality we have:

$$\frac{\partial}{\partial i}\left[\frac{\left.\frac{\chi_i}{L_i(r)}\right|_{q_i(r^h)}}{\left.\frac{\chi_i}{L_i(\hat{r})}\right|_{q_i(\hat{r})}}\right] > 0, \quad \forall\, i > \tilde{i}(\hat{r}) ,$$

where $\left.\frac{\chi_i}{L_i(r)}\right|_q$ denotes firm i's effective output per unit of labor input if it produces quality q in country r.

Proposition 5.2

Let Assumption 5.1 be satisfied. Then in any equilibrium it holds that:

(i) $w_r^\star = \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} \;\forall\, r \in \mathcal{R}$

(ii) $\mathcal{R}_i^\star \subseteq \{r \in \mathcal{R} : \, r \geq \tilde{r}(i)\} \;\forall\, i \in [0, N]$

(iii) $q_i^\star(r) = \left[-\frac{1}{\lambda i \log(r)}\right]^{\frac{1}{\lambda}} \;\forall\, (i, r) \in [0, N] \times \mathcal{R}_i^\star$

(iv) $\rho_i^\star = \frac{\sigma}{\sigma - 1}\left[-e\lambda i \log(\underline{r})\right]^{\frac{1}{\lambda}} \;\forall\, i \in [0, N]$

(v) $\chi_i^\star = \tilde{L}\left[-e\lambda \log(\underline{r})\right]^{-\frac{1}{\lambda}} \frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} \left[i\right]^{-\frac{\sigma}{\lambda}} \;\forall\, i \in [0, N]$

(vi) $\tilde{L}_i^\star = \tilde{L}\frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} \left[i\right]^{\frac{1-\sigma}{\lambda}} \;\forall\, i \in [0, N]$

(vii) $P^\star = \frac{\sigma}{\sigma-1}\left[-e\lambda \log(\underline{r})\right]^{\frac{1}{\lambda}} \left[\frac{\lambda}{1-\sigma+\lambda}\right]^{\frac{1}{1-\sigma}} N^{\frac{1-\sigma+\lambda}{(1-\sigma)\lambda}}$

(viii) $C^\star = \tilde{L}\left[-e\lambda \log(\underline{r})\right]^{-\frac{1}{\lambda}} \left[\frac{\lambda}{1+\lambda-\sigma}\right]^{\frac{1}{\sigma-1}} N^{\frac{1+\lambda-\sigma}{(\sigma-1)\lambda}}$

The equilibrium is unique up to the allocation of total effective output of product i, $\chi_i^\star$, to production sites, $\mathcal{R}_i^\star$, and hence the choice of qualities and actual output, price, and labor input levels for these qualities.

5.4. Comparative advantages with sufficient skills

Our discussions so far have focused on the firm. Let us now change focus and consider the implications of sufficient skills for specialization in international trade. From above we know that, in an equilibrium with sufficient skills, the minimum-quality constraint is never binding. Hence the following corollary follows immediately from Lemma 5.1:

Corollary 5.2

With sufficient skills in the economy, (high-) low-skill countries specialize on producing (high) low quality.

This specialization of countries evens out comparative advantages across products that exist in the absence of a quality choice. Suppose, for example, that all products have minimum quality, $q_i = 1 \;\forall\, i \in [0, N]$. Let $\left.\frac{\chi_i}{L_i(r)}\right|_q$ denote firm i's effective output per unit of labor input if it produces quality q in country $r \in \mathcal{R}$. With $q = 1$, we have:

$$\left.\frac{\chi_i}{L_i(r)}\right|_1 = [r]^i \; . \tag{5.15}$$

Now consider two countries with skill levels $r^h, r^l \in \mathcal{R}$, where $r^h > r^l$. Equation (5.15) implies that the more complex the product, the more productive is the high-skill country relative to the low-skill country:

$$\frac{\left.\frac{\chi_i}{L_i(r^h)}\right|_1}{\left.\frac{\chi_i}{L_i(r^l)}\right|_1} = \left[\frac{r^h}{r^l}\right]^i ,$$

i.e. high-skill countries have a comparative advantage for complex products.[45] This is a standard result already shown by Kremer (1993). We introduce a second dimension of product differentiation: the endogenous choice of product quality. With an interior solution for product quality, we have:

$$\left.\frac{\chi_i}{L_i(r)}\right|_{q_i(r)} = \left[-\frac{1}{\lambda i \log(r)}\right]^{\frac{1}{\lambda}} [r]^{-\frac{1}{\lambda \log(r)}} = [-e\lambda i \log(r)]^{-\frac{1}{\lambda}} , \tag{5.16}$$

and for the ratio of productivities of the two countries r^h and r^l it follows:

$$\frac{\left.\frac{\chi_i}{L_i(r^h)}\right|_{q_i(r^h)}}{\left.\frac{\chi_i}{L_i(r^l)}\right|_{q_i(r^l)}} = \left[\frac{\log(r^l)}{\log(r^h)}\right]^{\frac{1}{\lambda}} . \tag{5.17}$$

Indeed, this ratio is independent of the complexity of the product, i.e. with an interior solution for quality, there are no comparative advantages of countries for products. Intuitively, comparative advantages are rooted in differences as to the difficulty of production. This difficulty depends on the quality-weighted number of tasks, iq^λ. The crucial observation is that with an endogenous choice of quality, this difficulty is no longer exogenously given by product complexity, but endogenously chosen by firms. When choosing quality, the firms weigh the gains from a more valuable product against the losses from a lower probability of success, and hence a lower output. In the optimum, all firms in country r choose the same difficulty of production, irrespective of the complexity of their product.[46] In fact, all firms choose the same probability of success, irrespective of the complexity of their product and the skill level of the country where they locate production.[47] Hence countries compete by differentiating in quality and not in output levels.[48]

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[45] Formally, labor productivity is log-supermodular in the skill level of labor and the complexity of the product.

[46] With an interior solution for quality we have: $i\,[q_i(r)]^\lambda = -\frac{1}{\lambda \log(r)}$.

[47] With an interior solution for quality we have: $r^{iq_i(r)^\lambda} = [e]^{-\frac{1}{\lambda}}$.

[48] The comparative advantages that exist when firms always produce minimum quality, $q_i = 1\ \forall i$, are equalized because the high-skill country gains in absolute advantage and this gain is the larger, the less complex the product, i.e. the larger the scope for quality differentiation. To see this, let us decompose

In essence, by introducing an endogenous choice of product quality, across-product specialization is replaced by within-product specialization in the spirit of Schott (2004). Within-product specialization is truncated by the minimum-quality constraint, $q \geq 1$. In equilibrium, this implies that high-skill countries can successfully compete for even the simplest products by specializing on high quality, but not vice versa. Low-skill countries cannot successfully compete for complex products because these products are just too difficult, even in their minimum-quality version. Formally, the following corollary follows immediately from Proposition 5.2:

Corollary 5.3

In an equilibrium with sufficient skills, each country $r \in \mathcal{R}$ is competitive for all products $i \in \left[0, \tilde{i}(r)\right]$.

Hence an equilibrium with sufficient skills is associated with an upper-triangular structure of competitiveness of countries for products. A country with skill level $r^h \in \mathcal{R}$ is competitive for all products a country with a lower skill level $r^l < r^h$ is competitive for, plus some additional – more complex – products. The exact mapping of products to countries is undetermined in equilibrium. We therefore consider a simple numerical example next, to illustrate how the described pattern of comparative advantages translates into an upper-triangular structure of specialization in international trade, in line with what we observe from the data.[49,50]

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the relative productivity as follows:

$$\frac{q_i(r^h)\left[r^h\right]^{iq_i(r^h)^\lambda}}{q_i(r^l)\left[r^l\right]^{iq_i(r^l)^\lambda}} = \frac{\left[r^h\right]^{iq_i(r^l)^\lambda}}{\left[r^l\right]^{iq_i(r^l)^\lambda}} \times \frac{q_i(r^h)\left[r^h\right]^{iq_i(r^h)^\lambda}}{q_i(r^l)\left[r^h\right]^{iq_i(r^l)^\lambda}} .$$

The first component is the relative productivity if firm $i \in [0, N]$ produces quality $q_i(r^l)$ in both countries. $q_i(r^l) = \left[-\frac{1}{\lambda i \log(r_i)}\right]^{\frac{1}{\lambda}} \geq 1$ implies $\frac{\left[r^h\right]^{iq_i(r^l)^\lambda}}{\left[r^l\right]^{iq_i(r^l)^\lambda}} \geq \frac{\left[r^h\right]^i}{\left[r^l\right]^i}$, i.e. the absolute advantage of the high-skill country increases as both produce higher quality. As $q_i(r^l)$ is inversely proportional to $i^{\frac{1}{\lambda}}$, the associated gain in absolute advantage of the high-skill country just offsets comparative advantages that exist when firms always produce minimum quality. The second component is the additional gain of the high-skill country due to the fact that it produces quality $q_i(r^h)$. This gain is the same, irrespective of the complexity of the product. Note that the optimality of $q_i(r^h)$ implies $\frac{q_i(r^h)\left[r^h\right]^{iq_i(r^h)^\lambda}}{q_i(r^l)\left[r^h\right]^{iq_i(r^l)^\lambda}} > 1$, and hence $\frac{q_i(r^h)\left[r^h\right]^{iq_i(r^h)^\lambda}}{q_i(r^l)\left[r^l\right]^{iq_i(r^l)^\lambda}} > \frac{\left[r^h\right]^i}{\left[r^l\right]^i}$.

49 Cf. appendix C.1.

50 To be precise, we need to slightly strengthen Assumption 5.1 for an upper-triangular structure of specialization to occur in equilibrium:

Assumption 5.1(a)

$$\frac{\int_{e^{-\frac{1}{\lambda i}}}^{\overline{r}} \left[-\log(r)\right]^{-\frac{1}{\lambda}} dF_r(r)}{\int_{\underline{r}}^{\overline{r}} \left[-\log(r)\right]^{-\frac{1}{\lambda}} dF_r(r)} \geq 1 - \left(\frac{i}{N}\right)^{\frac{1+\lambda-\sigma}{\lambda}} , \quad \forall\, i \in [0, N] ,$$

5.4.1. Numerical example

We consider the equilibrium in a world with N_c countries, N_p products, and sufficient skills. For simplicity, we assume that countries are equally sized, each having one unit of labor, i.e. we have $L = N_c$. We present a numerical example where we randomly allocate products to countries, subject to the constraint that all firms $i = 1, 2, ..., N_p$ produce only in countries that are competitive for their product.

To calibrate our model, we first set $N_c = 149$ and $N_p = 1239$ to match the number of countries and products, respectively, considered in Figures C.1 to C.3. We then require that the distribution of equilibrium wages, $w_r^\star$, matches the distribution of GDP per capita in purchasing power parities (PPP) in 2010 for the selection of countries considered in Figures C.1 to C.3, as observed from World Bank (2013).[51] Out of the selection of 149 countries included in Figure C.1, we observe data on GDP per capita in PPP for 140 countries only, i.e. this calibration step reduces N_c to 140. It determines the distribution of skill levels, $F_r(r)$, up to the choice of $\underline{r}$, which we set equal to $\underline{r} = 0.01$. We assume that the complexities of products are uniformly distributed on the set $\left\{\frac{N}{N_p}\left[i - \frac{1}{2}\right] : i = 1, 2, ..., N_p\right\}$, and choose $N = 4$. As to the remaining parameter values, we assume $\lambda = 1$ for simplicity, and $\sigma = 1.5$, the midpoint of its feasible range.

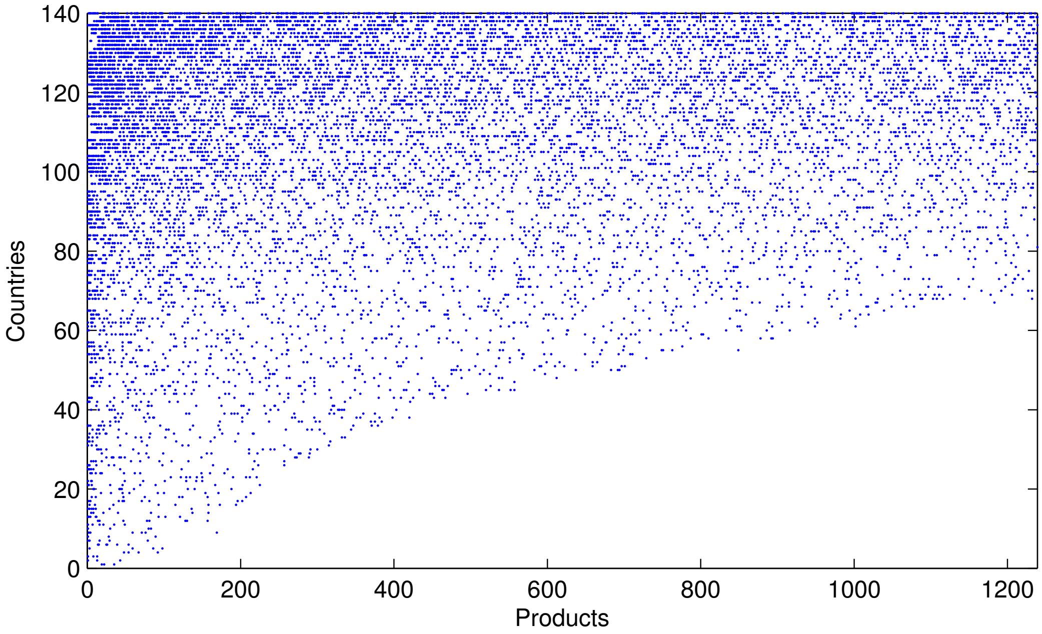
We divide production of product i in small production steps. Each such step consists of a fixed amount of effective labor and is randomly allocated to countries as outlined in appendix C.4. The simulation results in one specific realization of equilibrium outcomes. For this equilibrium, we can observe the effective output of product i produced in country r for every country-product pair $(r, i) \in \mathcal{R} \times \{1, 2, ..., N_p\}$. We follow Hausmann and Hidalgo (2011) and Tacchella et al. (2012) in visualizing the implied pattern of international specialization graphically. In particular, we use the equilibrium allocation of production to derive a binary matrix M that indicates for every country the products for which it has a revealed comparative advantage.[52] We then order countries from the lowest to the highest

with the inequality being strict $\forall\, i > 0$.
If the condition stated in Assumption 5.1 was to hold with equality for some $\hat{\imath} \in (0, N]$, then while countries with skill level $r \geq \tilde{r}(\hat{\imath})$ would still be competitive for products $i < \hat{\imath}$, their labor force would be fully employed in production of products $i \geq \hat{\imath}$. Hence high-skill countries would never produce products with low complexity in equilibrium.

[51] Note that, in our model, GDP per capita is equal to $\frac{\sigma}{\sigma-1} w_r$ and, hence, is proportional to equilibrium wages.

[52] This can be achieved by first multiplying the effective outputs with quality-adjusted prices to get equilibrium revenues. Second, by computing the revealed comparative advantages and connecting products to all countries exporting them with revealed comparative advantage of at least 1, as originally proposed by Hidalgo and Hausmann (2009). As opposed to the real-world application of Hidalgo and Hausmann (2009), we base our computations on total production and not on exports only. Using total production should give a more comprehensive picture of a country's productive capacities (cf. also Hausmann and Hidalgo, 2011).

Figure 5.1.: Revealed comparative advantages in an equilibrium with sufficient skills



Source: Own illustration, based on the numerical example as described in the main text and in appendix C.4. Countries and products are ranked according to the skill level of their workforce, r, and their complexity, i, respectively. For every country-product pair, a dot indicates that the country has *revealed comparative advantage* of at least 1 for that product.

skill level, and products from the simplest to the most complex. We plot the accordingly rearranged matrix M in Figure 5.1. Comparing Figure 5.1 to the real-world counterparts shown in appendix C.1 reveals that, indeed, our model gives rise to the same basic pattern of international specialization as the one we observe from the data.

5.4.2. Discussion

We present a parsimonious model to analyze the interplay between product complexity and product quality in international trade. In this model, there is one dimension of country heterogeneity – the skill level of a country's labor, r – and one dimension of product heterogeneity – a product's complexity, i. Countries specialize on quality. We show that this specialization eliminates comparative advantages across products. Our model thus introduces a new theoretical mechanism showing how countries successfully compete for a heterogeneous set of products. We further suggest that the specialization on quality is subject to product-specific minimum-quality requirements. These requirements impose no restrictions on high-skill countries, as these countries deliberately produce higher quality. Low-skill countries, however, are bounded by the minimum-quality requirements for complex products. For them, even the simplest versions of these products are very difficult to produce, and they cannot successfully compete for these products on the world market. Hence we introduce an alternative mechanism underlying comparative advantages, which is rooted in product complexity. In an equilibrium with sufficient skills, this mechanism gives rise to an upper-triangular structure of specialization in international trade, in line with what we observe from the data.

The basic mechanism we consider can also explain why the share of products that are co-exported by rich and poor countries tends to increase over time. If minimum-quality requirements are an important source of comparative advantages, then these comparative advantages naturally subside as the world economy develops. In fact, according to our model, comparative advantages subside as the low-skill countries develop, irrespective of the development of high-skill countries.

To simplify the exposition, we assumed that all workers living in country $k \in \{1, 2, ..., N_c\}$ have the same skill level r^k. However, allowing for heterogeneity of labor within countries would not affect our main insights as long as countries differ as to the highest skill level available. Also, for concreteness, we attributed the productivity of labor living in a country as captured in r^k to the skill level of this labor. Yet the origins of the differences in r^k do not matter for any of the implications of our model, and we can think of r^k as a reduced form for institutions, production technologies, and/or human capital, for example.

Our work has important implications for related fields of the literature. Hidalgo and Hausmann (2009) and Tacchella et al. (2012) propose new measures for the economic strength of countries and for the complexity of products, based on trade data. Precisely, these measures are based on a binary country-product matrix, indicating for each country the products it has a revealed comparative advantage for on the world market. Broadly speaking, they classify a country as strong if it has a revealed comparative advantage for many, complex products – a product being considered as complex if few, strong countries have a revealed comparative advantage for it. Our model can provide an economic rationale for the proposed algorithms. It introduces a systematic link between the economic strength of a country and the range of products it can successfully compete for on the world market. It follows that the binary country-product matrix indeed entails important information on the economic strength of countries and the complexity of products. As opposed to the rationale proposed by Hidalgo and Hausmann (2009) and formalized by Hausmann and Hidalgo (2011), our rationale is not based on a large set of non-tradeable capabilities and product-specific capability requirements, but on the interplay between product complexity and product quality. Country heterogeneity is summarized in a single reduced-form parameter, r, which – as mentioned above – can reflect various sources of economic strength discussed in the literature. Hence our model suggests that these new measures may well be informative on a more general scale about a country's economic strength, without relying on a heterogeneous set of capabilities. We substantiate this conjecture by means of a simple Monte Carlo experiment in appendix C.5, where we apply the proposed algorithms to binary country-product matrices that we derive from our numerical example of section 5.4.1. We then compare the rankings based on the proposed algorithms with the fundamental rankings of countries and products according to our model. This simple experiment suggests that the proposed algorithms can indeed well recover the fundamental rankings of countries and products, at least in a world as described by our model.

If low-skill countries cannot successfully compete for complex products because they are bounded by a minimum-quality constraint, this will also have important implications for empirical analyses to estimate the link between a country's skill level and the quality of its exports. We discuss these implications next.

5.5. Empirical analysis

The rationale developed in our theoretical model is centered on the observation that richer countries export higher quality. As already mentioned in the introduction, this observation is well established in the empirical literature. Schott (2004) estimates the elasticities of unit values of exports to the US with respect to the exporter's GDP per capita and its factor endowments. For a large and increasing share of product categories, this elasticity is positive.[53] Hummels and Klenow (2005) estimate the elasticities of the extensive and the intensive margin of a country's exports with respect to its GDP per worker and total employment. They observe that the extensive margin is more important for richer as opposed to larger economies, in line with the interpretation that a higher skill level allows a country to diversify into a broader set of products. They further decompose the intensive margin into a price and a quantity component, also concluding that richer countries tend to export higher quality goods. Khandelwal (2010) estimates product quality using information on a country's market share, controlling for its price level. Regressing this measure on log GDP per capita, he also finds a positive relationship.[54]

The studies by Schott (2004) and Khandelwal (2010) share in common that they estimate the link from a country's GDP per capita to its export quality from a regression using the

[53] Pham (2008) substantiates this result, considering imports to Brazil, India, and Japan.

[54] Similarly, Hallak and Schott (2011) use information on a country's trade balance, controlling for its export prices, to infer on the quality of its exports. They find that their measure of a country's export quality is significantly positively correlated with its GDP per capita.

data on observed export qualities. The rationale we develop suggests that this data might be censored from below. In particular, if countries with low skill levels are bounded by the minimum-quality constraint for complex products and can therefore not compete for them, then the fact that a country does not export a product could – and should – be exploited in an empirical analysis. As we will show next, this motivates the use of a censored regression model.

5.5.1. A censored regression model for a country's export quality

In an equilibrium with sufficient skills, a country with skill level $r \in \mathcal{R}$ is competitive only for products that it can produce with preferred quality, $\left[-\frac{1}{\lambda i \log(r)}\right]^{\frac{1}{\lambda}} \geq 1$, i.e. $\forall\, i \in \left[0, \tilde{i}(r)\right]$. Now suppose that each country exports all products that it is competitive for.[55] Then our theoretical set-up naturally leads to a censored regression model to estimate the link between a country's skill level r and the quality of its exports. In particular, taking logs of the preferred quality, we get:

$$\log\left(q_{i,t}^k\right) = \boldsymbol{d}_{i,t}\boldsymbol{\alpha} + \beta \log\left[-\log\left(r_t^k\right)\right] + u_{i,t}^k, \quad u_{i,t}^k\Big|\,\boldsymbol{d}_{i,t}, r_t^k \sim \mathrm{N}(0,\sigma^2) \tag{5.18a}$$

$$\log\left(\tilde{q}_{i,t}^k\right) = \begin{cases} \log\left(q_{i,t}^k\right) & \text{if } q_{i,t}^k \geq 1 \\ \text{NaN} & \text{otherwise} \end{cases}, \tag{5.18b}$$

where $q_{i,t}^k$ is the *latent* preferred quality of product i if produced in country k in period t, $\tilde{q}_{i,t}^k$ denotes the *observed* quality, r_t^k denotes the skill level of country k in period t, $\boldsymbol{d}_{i,t}$ is a $1 \times T \cdot N_p$ vector of product-time dummies capturing (time-varying) product characteristics, $\boldsymbol{\alpha}$ is a $T \cdot N_p \times 1$ vector of coefficients on these dummies, $u_{i,t}^k$ is an error term, and where we have assumed that the distribution of $\log\left(q_{i,t}^k\right)$ given $\boldsymbol{d}_{i,t}$ and r_t^k is homoskedastic normal.

It is not possible to take the censored regression model (5.18) directly to the data, as both $\tilde{q}_{i,t}^k$ and r_t^k are unobservable. However, we can estimate the link between a country's GDP per capita, $GDP_{cap,t}^k$, and the quality of its exports, and use export prices, $p_{i,t}^k$, as a proxy for quality. As we argue in detail in appendix C.6.1, this leads to the following censored regression model:

[55] In 2010, countries such as Austria, Australia, Belgium, Canada, China, France, Germany, Japan, Switzerland, and the US, for example, had some exports in more than 97% of the products at the hs4 classification level.

Hypothesis 5.1

$$\log\left(p_{i,t}^k\right) = \boldsymbol{d}_{i,t}\boldsymbol{\alpha} + \beta_i \log(GDP_{cap,t}^k) + u_{i,t}^k, \quad u_{i,t}^k \Big| \boldsymbol{d}_{i,t}, GDP_{cap,t}^k \sim N(0,\sigma_i^2) \tag{5.19a}$$

$$\log\left(\tilde{p}_{i,t}^k\right) = \begin{cases} \log\left(p_{i,t}^k\right) & \textit{if } p_{i,t}^k \geq \min_{k\in\{1,2,\ldots,N_c\}} p_{i,t}^k \\ NaN & \textit{otherwise} \end{cases} \tag{5.19b}$$

The latent variable model, equation (5.19a), is, in essence, regression model (2) in Schott (2004) and regression model (17) in Khandelwal (2010). Both papers estimate their models using OLS. The reasoning developed here suggests that using OLS on the subsample with $p_{i,t}^k \geq \min_{k\in\{1,2,\ldots,N_c\}} p_{i,t}^k$ is inconsistent, and that we should rather use maximum likelihood instead.[56,57] Precisely, we may expect OLS to underestimate the true link between a country's GDP per capita and the quality of its exports.[58]

5.5.2. Data description

Export data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013), which reports bilateral data on export values and export quantities for more than 200 countries at the hs6 classification level for the period from 1995 to 2011. From this dataset, we exclude countries with less than 1m inhabitants in 2008. We then sum up a country's exports over all destinations and summarize data at the hs4 classification level in our base-case scenario.[59]

Unit values are computed as the ratio of export values over export quantities. The resulting data is trimmed by excluding observations with extreme unit values. Let $uv_{i,t}^k$ denote the unit value of exports of product i by country k in period t. Then observations are dropped

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[56] Cf. Wooldridge (2002, p. 524).

[57] Consistency of the maximum-likelihood estimator relies on the distributional assumptions. In particular, heteroskedasticity and nonnormality would result in inconsistent estimators. As a more robust alternative, we could apply the censored least absolute deviations estimator proposed by Powell (1984), which is based on the assumption $Med\left(u_{i,t}^k \big| \boldsymbol{d}_{i,t}, GDP_{cap,t}^k\right) = 0$. We could also estimate a richer model. For example, country k may not export product i in period t even though it is competitive for that product, i.e. even though $q_{i,t}^k \geq 1$. We could introduce this possibility into our regression model by modeling the probability of not exporting a product conditional on being competitive.

[58] Schott (2004) considers what he calls LMH products only, i.e. products that are co-exported by low- and high-income countries to the US. Following the line of reasoning presented here, this should mitigate the OLS estimation bias.

[59] Our main findings are robust to classifying products at the hs6 level. Cf. appendix C.6.2.1.

whenever:

$$uv_{i,t}^{k} \geq 10 \times median_k(uv_{i,t}^{k}) \wedge uv_{i,t}^{k} \geq 5 \times median_t(uv_{i,t}^{k})$$
$$\vee$$
$$uv_{i,t}^{k} \leq \frac{1}{10} \times median_k(uv_{i,t}^{k}) \wedge uv_{i,t}^{k} \leq \frac{1}{5} \times median_t(uv_{i,t}^{k}) \ ,$$

i.e. observations are classified as outliers whenever they deviate strongly from the median observation across countries in the same year and from the median observation over time for the same country.[60]

Data on GDP per capita is taken from World Bank (2013). Following Hummels and Klenow (2005), we use data in purchasing power parities to avoid mechanical relationships between export prices and GDP stemming from market exchange rates.[61]

5.5.3. Estimation results

We start by estimating equation (5.19a) by OLS, using the subsample of data for which we observe an exporter's unit value. We run the estimation separately for each of the 1241 hs4 product categories included in our data. Standard errors are clustered by exporting country. The estimation results are summarized in Figure 5.2 and Table 5.1.

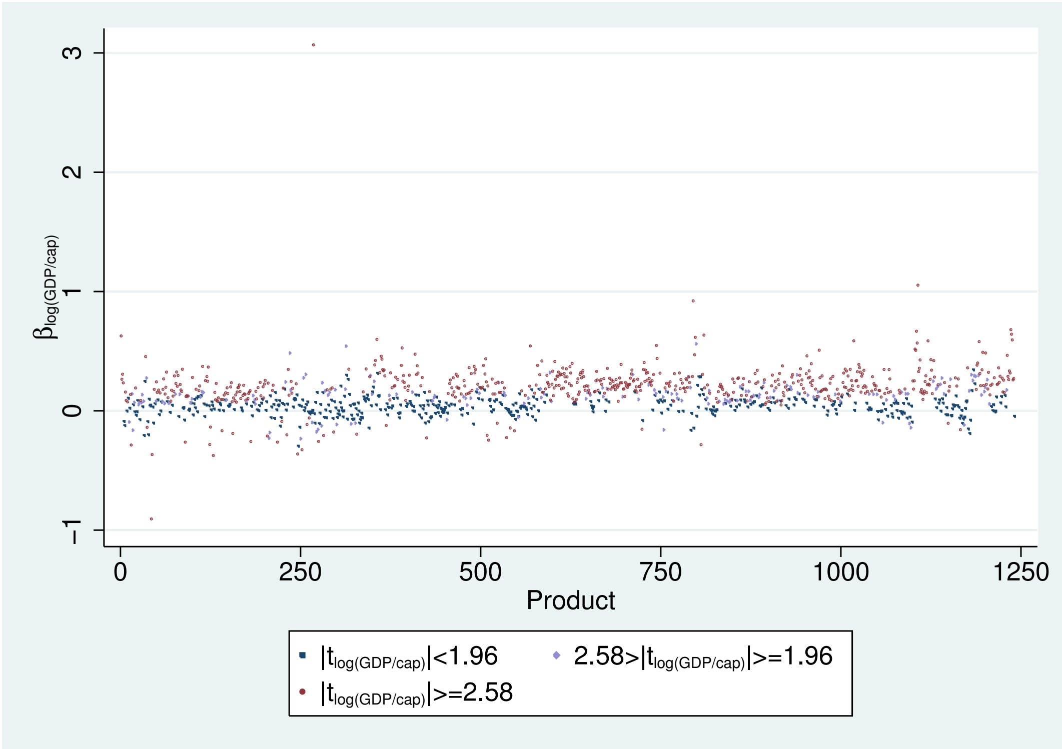
These results are remarkably close to the results of Schott (2004). A share of 57.5 % of the coefficients on $\log(GDP_{cap})$ is positive and significant at the 5% level. Moreover, the average of the β's indicates that a 10% increase in GDP per capita is associated with a 1.4% increase in unit values.

We next estimate the censored regression model (5.19) by maximum likelihood, using the full sample available. Again, we run the estimation separately for each of the 1241 hs4 product categories included in our data, and cluster standard errors by exporting country. The estimation results are summarized in Figure 5.3 and Table 5.2.

These results reveal a much stronger link from a country's GDP per capita to the unit values of its exports. The coefficient on $\log(GDP_{cap})$ is significantly positive even at the 1% level in more than 98% of the 1241 regressions. We obtain a negative coefficient in only 3 out of 1241 regressions, none of which is significant at any conventional level.[62] Furthermore, the estimated effect is substantially larger: The maximum likelihood esti-

[60] Our main findings are robust to using different selection criteria for outliers. Cf. appendix C.6.2.2.
[61] Our main findings are robust to using data at market exchange rates. Cf. appendix C.6.2.3.
[62] The three hs4 product categories with negative coefficients are: 8504 – Transformers; 6309 – Worn Textiles; 4403 – Wood.

Figure 5.2.: OLS estimates of $\beta_{\log(GDP_{cap})}$ – base case



Notes: This figure plots the OLS estimates of $\beta_{\log(GDP_{cap})}$ in equation (5.19a), using the subsamples with observed unit values. Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is in purchasing power parities and is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

Table 5.1.: OLS estimates of $\beta_{\log(GDP_{cap})}$ – base case

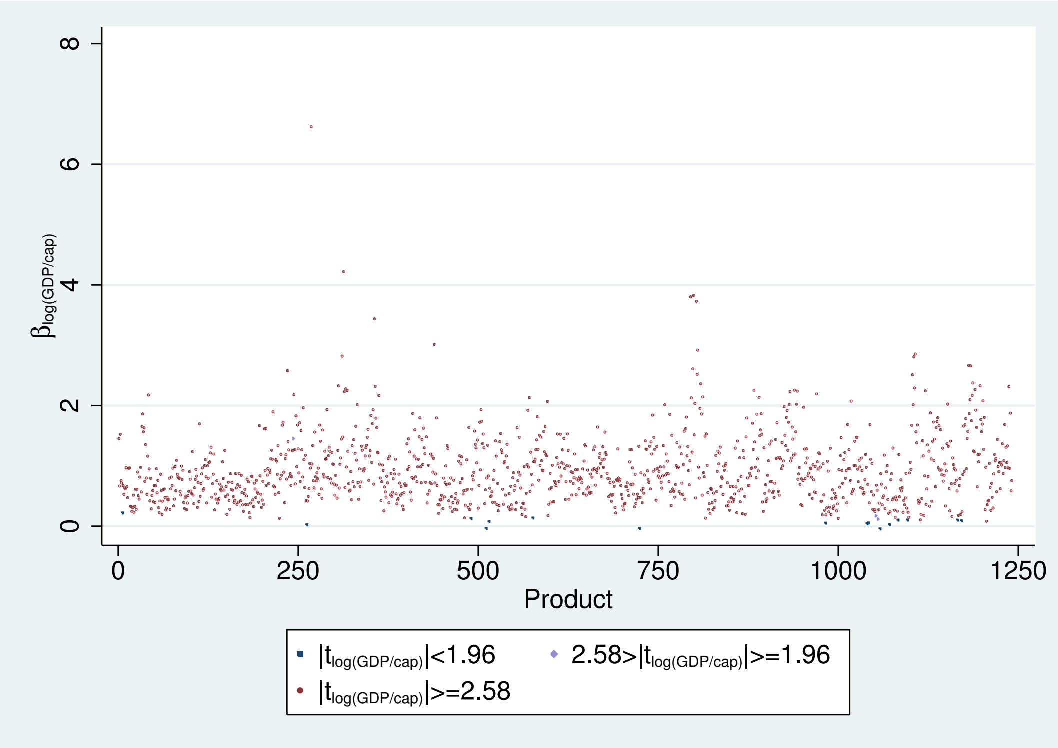
Mean $\beta_{\log(GDP_{cap})}$	0.136
Share $\beta_{\log(GDP_{cap})}$ significantly positive at 5% level	57.5%
Share $\beta_{\log(GDP_{cap})}$ significantly negative at 5% level	4.4 %
Product × year FEs	YES
Mean R-squared	0.643
Mean # observations	1460

Notes: This table reports summarizing statistics of the OLS estimates of equation (5.19a), using the subsamples with observed unit values. Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is in purchasing power parities and is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

mates suggest that on average across all product categories, a 10% higher GDP per capita is associated with a 9.1% higher unit value of the same product.

Our findings are in line with a downward bias of the OLS estimator. For each of the

Figure 5.3.: ML estimates of $\beta_{\log(GDP_{cap})}$ – base case



Notes: This figure plots the ML estimates of $\beta_{\log(GDP_{cap})}$ in equation (5.19a). Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is in purchasing power parities and is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

Table 5.2.: ML estimates of $\beta_{\log(GDP_{cap})}$ – base case

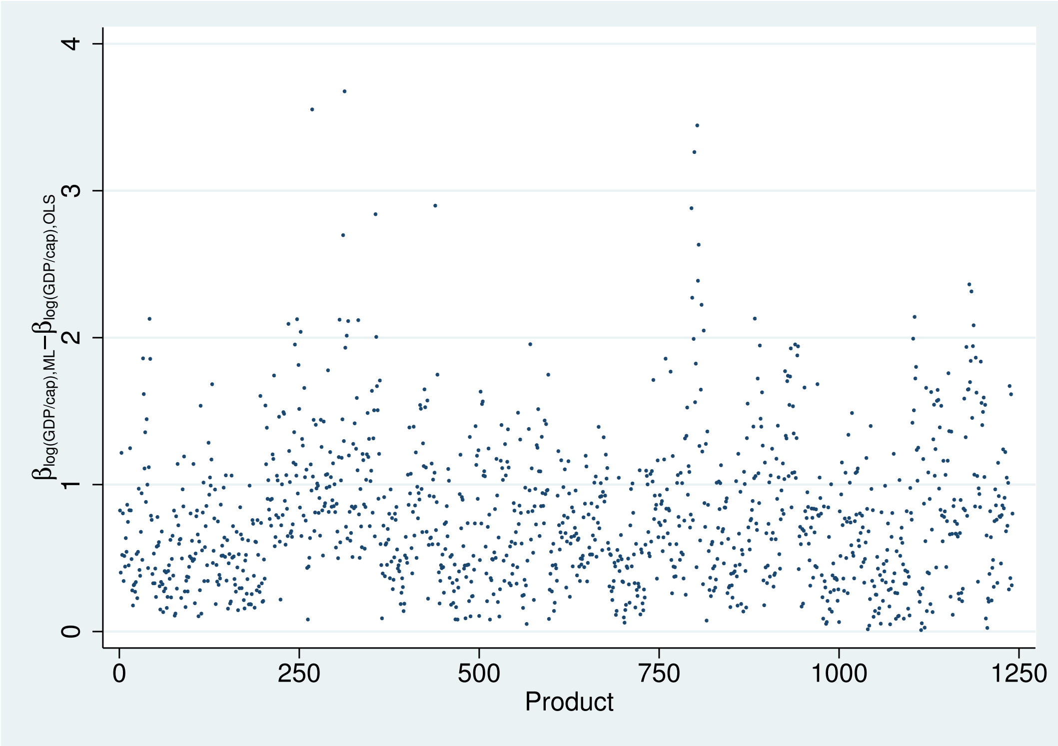
Mean $\beta_{\log(GDP_{cap})}$	0.915
Share $\beta_{\log(GDP_{cap})}$ significantly positive at 5% level	98.7%
Share $\beta_{\log(GDP_{cap})}$ significantly positive at 1% level	98.5 %
Share $\beta_{\log(GDP_{cap})}$ significantly negative at 5% level	0 %
Product $\times$ year FEs	YES
Mean # observations	2258

Notes: This table reports summarizing statistics of the ML estimates of regression model (5.19). Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is in purchasing power parities and is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

1241 hs4 product categories considered, we plot in Figure 5.4 the difference between the maximum likelihood and the OLS estimate of the coefficient on $\log(GDP_{cap})$. This difference is positive in all cases.[63]

[63] Of course, according to our regression model, the OLS estimate using the subsample of data with observed export prices is a linear approximation to $E\left[\log\left(p^k_{i,t}\right) \mid \boldsymbol{d}_{i,t}, GDP^k_{cap,t}, p^k_{i,t} \geq \rho_{i,t}\right]$ and hence,

Figure 5.4.: Comparison of estimated betas: $\beta_{\log(GDP_{cap}),ML} - \beta_{\log(GDP_{cap}),OLS}$



To summarize, our theoretical set-up motivates the use of a censored regression model to estimate the link between a country's GDP per capita and the quality of its exports. In line with our theory, this censored regression model takes into account the preferred quality of countries that are not exporting a given product. Taking this model to the data, we find a strong and significant relationship. The estimated link is much stronger than when using OLS on the subsample of countries exporting the product under scrutiny. This observation is in line with a downward bias of OLS, as expected based on our theory.

5.6. Conclusion

This chapter introduces a mechanism underlying the comparative advantages that is new to the literature. Our mechanism is centered on the interplay between product complexity and product quality. It is well known that industrialized countries are able to produce more complex products. Based on this observation, a classical Ricardian argument would suggest that the countries with highest level of human capital have a comparative disadvantage for the simplest products. Yet the situation changes if firms can choose product

technically, a direct comparison of the maximum likelihood and the OLS estimates is not meaningful. Yet, if we ignored the censoring structure in our data, we would typically interpret the OLS estimates as indicating the link between a country's GDP per capita and the unit values of its exports.

quality. In that case, industrialized countries compete in simple products through product quality. As we have shown, this results in a triangular structure of comparative advantages. The intuitive argument is that products such as nuclear reactors and high-tech machines are simply too difficult to produce and distribute for the least productive countries. This pattern of comparative advantages was found empirically and has come to the front of policy discussions. To the best of our knowledge, our work is the first to provide a theoretical underpinning.

The link from a country's GDP per capita to the quality of its exports was examined in many empirical studies. In our empirical section, we show how our rationale naturally leads to a censored regression model to estimate this link. Taking this model to the data, we find the said link to be much stronger than by using OLS.

In future work, it may be interesting to apply our rationale to development economics: Embedding our model in a dynamic framework may provide us with new insights on the drivers of the economic development of countries. It may also be interesting to analyze the implications of our work in the context of a richer model of international trade, allowing for outsourcing and trade in intermediate goods, for example. We will take a first step in this direction in the next chapter and introduce a homogeneous intermediate good into our model.

6. Introducing a Homogeneous Intermediate Good

6.1. Introduction

In the previous chapter, we analyzed the interplay between product-intrinsic complexity and product quality in international trade. We have shown how this interplay can give rise to an upper-triangular structure of comparative advantages in an equilibrium with sufficient skills. The basic intuition is that high-skill countries can always specialize on high-quality versions of simple products, but the inverse is not true. Low-skill countries cannot successfully compete for complex products because these products are just too difficult to produce, even in a basic, minimum-quality version.

In this chapter we present an extended version of our model which introduces an intermediate-good sector. In particular, we assume that final goods are produced by refining a homogeneous intermediate good, which we can think of as representing raw materials, for example. Every attempt to produce one unit of the final good requires α units of the intermediate good. The intermediate good is lost whenever final-good production fails. Final-good production is otherwise identical to the case described in chapter 5. It involves a continuum of tasks where the probability of successful accomplishment of each task is determined by the skill level of labor used in production. Also output quality can still be freely chosen by final-good firms, at the cost of rendering each task involved in final-good production more demanding, i.e. output quality does not depend on the intermediate good.

Both final-good production and intermediate-good production are footloose, i.e. firms are free to locate production wherever they deem best and supply the world market from there. Then. by introducing an intermediate-good sector, we enable international division of labor in production of a single good, in line with what we observe from the data.[1] As

[1] Trade in intermediate goods possibly accounts for more than 50% of total trade in goods (cf. Miroudot et al., 2009).

we will show, the upper-triangular pattern of specialization in final-good production also prevails in the variant of the model considered here.

We introduce the intermediate good as a standardized good that involves only routine production tasks. Formally, we assume that the skills of labor as measured by r are of no value in intermediate-good production. As we will show, the existence of a low-skill intermediate-good sector has interesting effects on the world distribution of wages. On the one hand, skills become more valuable in final-good production, as they reduce the risk of loosing the intermediate good due to a failure in final-good production. This tends to increase inequality. On the other, workers with the lowest skill levels are naturally employed in the intermediate-good sector. These workers all earn the same wage, irrespective of their skill level. Depending on the size of the intermediate-good sector, this may give rise to poverty traps, where investments in human capital have a positive return only above a certain threshold level.

Organisation of this chapter

The remainder of this chapter is organized as follows. Section 6.2 presents the extended version of our model. In section 6.3 we derive the equilibrium in our economy. In section 6.4 we discuss the equilibrium properties and conclude.

6.2. Model

6.2.1. Households

Households in the variant of our model considered here are just the same as the households in the model of chapter 5. We thus summarize our expositions of section 5.2.1 only briefly here.

Our economy is populated by a continuum of measure 1 of households who derive utility from consumption of a continuum of products, the final goods:

$$U^h\left(\left\{c_{i,q}^h\right\}_{(i,q)\in[0,N]\times[1,\bar{q}_i]}\right) = C^h \tag{6.1}$$

$$C^h := \left(\int_0^N \left(\int_1^{\bar{q}_i} q c_{i,q}^h \, dq\right)^{\frac{\sigma-1}{\sigma}} di\right)^{\frac{\sigma}{\sigma-1}}, \tag{6.2}$$

where, again, consumption of each product can be split across a continuum of varieties of different quality, and utility depends on the quantity and the quality consumed. Qualities of the same product are perfect substitutes. σ is the constant elasticity of substitution between products, where $1 < \sigma < 1 + \lambda$. Households live in one of N_c countries. They inelastically supply L units of labor to their domestic labor market. Labor is immobile across countries, but perfectly mobile across sectors, i.e. it can be used for production of the intermediate good as well as of any quality of any of the final goods.

Households differ in the skill level of their labor, r. In particular, a household living in country $k \in \{1, 2, ..., N_c\}$ has skill level $r^k \in [\underline{r}, \overline{r}]$, where $0 < \underline{r} < \overline{r} < 1$ and $r^k \neq r^l$, $\forall\, k, l \in \{1, 2, ..., N_c\}$.[2] As in chapter 5, we use $F_r(r)$ to denote the world distribution of skills and $\mathcal{R}$ to denote the set of skill levels of labor available. We will henceforth identify countries by the skill level of their labor, $r \in \mathcal{R}$.

We again solve the representative household's utility maximization problem to derive the demand for final good i:

$$\tilde{c}_i = C \left(\frac{\frac{p_i}{q_i}}{P} \right)^{-\sigma} \tag{6.3}$$

$$PC = L \int_{\underline{r}}^{\overline{r}} w_r \, dF_r(r) + \overline{I} \;, \tag{6.4}$$

$$\text{with} \quad P := \left(\int_0^N (\rho_i)^{1-\sigma} \, di \right)^{\frac{1}{1-\sigma}} \;. \tag{6.5}$$

6.2.2. Intermediate-good production

There is one homogeneous intermediate good, which we can think of as raw materials, for example. The market for this good is perfectly competitive. The intermediate good is produced by a one-to-one transformation of labor, irrespective of its skill level:

$$m = L_m \;, \tag{6.6}$$

where m is output of the intermediate good and L_m is the mass of labor used in production. As for final goods, we assume a footloose economy in the sense that firms are free to locate production wherever they deem best and supply the intermediate good to the world market from there, facing no barriers to trade. With perfect competition in the intermediate-good sector, the price of the intermediate good, p_m, is then equal to the unique wage paid to labor employed in the intermediate-good sector, w_m, and intermediate-good firms make

[2] As in chapter 5, we could, in principle, allow for an arbitrary distribution of skills.

zero profits.

6.2.3. Final-good production

Final-good firms take up the homogeneous intermediate good and refine it. As before, production of final good $i \in [0, N]$ involves a mass i of simultaneous tasks. Every attempt to produce one unit of a final good requires α units of the intermediate good. If workers fail, then not only is their work lost, but the intermediate goods used in production as well. Otherwise, the production technology is the same as described in section 5.2.2.1. In particular, firms can again freely choose quality, subject to a minimum-quality constraint, and higher quality renders every task involved in production more demanding. Let $m_{i,q}$ denote the mass of the intermediate good used in production of quality q of final good i. Then expected output is given by:[3]

$$E\left[x_{i,q}\right] = [r]^{iq^{\lambda}} \min\left\{L_i(r), \frac{m_{i,q}}{\alpha}\right\}, \quad q \geq 1 \ .$$

The only difference compared to production technology (5.7) is that the scale of production is now determined by the minimum of the mass of labor and $\frac{1}{\alpha}$ times the mass of the intermediate good employed.

In optimum, firms will always endow every unit of labor with α units of the intermediate good. Hence the firm's profit maximization problem is the same as in chapter 5, with the only exception that the costs of production are now given by $L_i(r)\left[w_r + \alpha p_m\right]$. It follows that Lemma 5.1 also applies here, i.e. we have:

$$q_i(r) = \max\left\{1, \left[-\frac{1}{\lambda i \log(r)}\right]^{\frac{1}{\lambda}}\right\} \ .$$

Also, the threshold complexity and skill levels, $\tilde{i}(r)$ and $\tilde{r}(i)$, are the same as in chapter 5. The effective price levels, ρ_i, and output levels, χ_i, deviate from chapter 5, but in a straightforward way. We thus postpone the exposition to the discussion of the equilibrium below.

[3] As in chapter 5, allowing the firm to hire workers with different skill levels to work on the different tasks involved in production would not affect our subsequent analyses.

6.3. Equilibrium

In this section, we derive the equilibrium in our economy. Its definition is analogous to chapter 5, but with some extra elements:

Definition 6.1 (Equilibrium)
An equilibrium is:

(i) a set of countries where the intermediate good is produced, $\mathcal{R}_m \subseteq \mathcal{R}$

(ii) for each country $r \in \mathcal{R}_m$*, an output level of the intermediate good,* $\{m_r\}_{r\in\mathcal{R}_m}$*, and a corresponding labor input level,* $\{L_{m,r}\}_{r\in\mathcal{R}_m}$

(iii) for each final-good firm $i \in [0, N]$*, a set of countries where the firm operates a production site,* $\{\mathcal{R}_i\}_{i\in[0,N]}$

(iv) for each production site of each final-good firm, a quality, $\{q_i(r)\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$*, an output level,* $\left\{x_{i,q_i(r)}\right\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$*, a mass of labor employed,* $\{L_i(r)\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$*, and a mass of the intermediate good used,* $\left\{m_{i,q_i(r)}\right\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$

(v) for each household $h \in [0, 1]$*, a set of consumption levels of each quality of each product,* $\left\{c^h_{i,q_i(r)}\right\}_{(i,r,h)\in[0,N]\times\mathcal{R}_i\times[0,1]}$

(vi) a set of final-good prices, $\left\{p_{i,q_i(r)}\right\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$ *and an intermediate good price* p_m

(vii) a set of wage rates $\{w_r\}_{r\in\mathcal{R}}$

such that:

(i) $\mathcal{R}_m$*,* $\{m_r\}_{r\in\mathcal{R}_m}$*, and* $\{L_{m,r}\}_{r\in\mathcal{R}_m}$ *maximize the intermediate-good firms' profits*

(ii) $\frac{p_{i,q_i(r)}}{q_i(r)} = \rho_i,\ \forall\,(i, r) \in [0, N] \times \mathcal{R}_i$ *and some* $\rho_i \geq 0$

(iii) $\mathcal{R}_i$*,* $\{q_i(r)\}_{r\in\mathcal{R}_i}$*,* $\left\{x_{i,q_i(r)}\right\}_{r\in\mathcal{R}_i}$*,* $\{L_i(r)\}_{r\in\mathcal{R}_i}$*,* $\left\{m_{i,q_i(r)}\right\}_{r\in\mathcal{R}_i}$*, and* ρ_i *solve firm* i*'s profit maximization problem,* $\forall\, i \in [0, N]$

(iv) $\left\{c^h_{i,q_i(r)}\right\}_{(i,r)\in[0,N]\times\mathcal{R}_i}$ *solve household* h*'s utility maximization problem* $\forall\, h \in [0, 1]$

(v) good markets clear for the intermediate good and for each quality of each final good

(vi) labor markets clear in all countries

As in chapter 5, we consider equilibrium wages first and turn to the other equilibrium values later.

6.3.1. Equilibrium wage

Skills have no value in the production of the intermediate good, whereas final-good production is strictly increasing in the skill level of labor employed. It follows that in equilibrium, the intermediate-good firms will produce in the countries with the lowest skill levels of their labor. Let us again use $w_{\underline{r}} = 1$ as the numéraire and suppose $\underline{r} \in \mathcal{R}$, for simplicity. Then this immediately implies $p_m = 1$.

Now suppose that final-good firm $i \in [0, N]$ operates in a country with skill level $r \geq \tilde{r}(i)$. Then, with an optimal choice of quality, its costs per unit of effective output are given by:

$$\left. \frac{L_i(r)\,[w_r + \alpha]}{\chi_i} \right|_{q_i(r)} = [-e\lambda i \log(r)]^{\frac{1}{\lambda}} \, [w_r + \alpha] \ .$$

It follows that firm i is indifferent between producing in either of two countries, $r^l, r^h \in \mathcal{R}$, with $r^l, r^h \geq \tilde{r}(i)$, whenever:

$$w_{r^h} = \left[\frac{\log(r^l)}{\log(r^h)} \right]^{\frac{1}{\lambda}} w_{r^l} + \alpha \frac{\log(r^l)^{\frac{1}{\lambda}} - \log(r^h)^{\frac{1}{\lambda}}}{\log(r^h)^{\frac{1}{\lambda}}} \ .$$

The wage premium paid to workers in the high-skill country now not only has to compensate for their higher productivity, but also for the reduction in the expected loss of intermediates.[4]

More generally, an argument along the lines of chapter 5 leads to the following lemma:

Lemma 6.1
Let wages satisfy $w_r = \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} + \alpha \frac{\log(\underline{r})^{\frac{1}{\lambda}} - \log(r)^{\frac{1}{\lambda}}}{\log(r)^{\frac{1}{\lambda}}}$ $\forall\, r \in \mathcal{R}$. *Then:*

(i) $\forall \left(i, r^l, r^h\right) \in [0, N] \times \mathcal{R} \times \mathcal{R}$ *such that* $r^h > r^l \geq \tilde{r}(i)$, *firm* i *is indifferent between producing in country* r^l *and in country* r^h*;*

(ii) $\forall \left(i, r^l, r^h\right) \in [0, N] \times \mathcal{R} \times \mathcal{R}$ *such that* $r^h > r^l$ *and* $r^l < \tilde{r}(i)$, *firm* i *strictly prefers producing in country* r^h *to producing in country* r^l.

To characterize the equilibrium on the labor market, we turn to the demand for labor in the intermediate-good sector next. Every final-good firm endows each unit of labor employed

[4] Precisely, with an interior solution for quality, the probability of success is always the same. Hence the wage increase compensates for the higher quality produced, and for the fact that with higher quality fewer intermediates are needed to produce the same amount of effective output.

with α units of the intermediate good, implying:

$$m_{i,q_i(r)} = \alpha L_i(r) \ .$$

Now the intermediate good is produced by a one-to-one transformation of labor. Hence total labor employed in the intermediate-good sector, L_m, is trivially α times total labor employed in the final-good sector. Labor-market clearing then implies:

$$L_m = \frac{\alpha}{1+\alpha} L \ . \tag{6.7}$$

As stated earlier, the fact that skills are of no value in the production of the homogeneous intermediate good implies that, in equilibrium, the intermediate good is produced in the countries with the lowest skill levels. Let r_m denote the minimum skill level of labor satisfying $LF_r(r) \geq L_m$, i.e. $r_m := \min \{r \in \mathcal{R} : LF_r(r) \geq L_m\}$. Then countries with skill level $r < r_m$ produce only the intermediate good, the country with skill level r_m produces both the intermediate good and some final goods,[5] and countries with skill level $r > r_m$ produce only some of the final goods. All labor employed in the intermediate-good sector must earn the same wage, i.e. in any equilibrium we have:

Lemma 6.2
$w_r = 1, \ \forall \, r \leq r_m$

We can now characterize the equilibrium wage along the lines of chapter 5, starting with the condition for sufficient skills. In the variant of the model discussed here, this condition has to take into account that a fraction of the population is employed in the intermediate-good sector. In this setting, it will be convenient to first define the distribution of the skill levels of labor available for final-good production, $F_f(r)$:

$$F_f(r) = \begin{cases} 0 & \text{if } r < r_m \\ F_r(r)(1+\alpha) - \alpha & \text{otherwise} \end{cases} \ .$$

In words, for any $\hat{r} \geq r_m$, the share of total labor available for final-good production that has skill level $r \leq \hat{r}$ is equal to:

$$\frac{\text{‘}\textit{total labor with } r \leq \hat{r}\text{’} \ - \ \text{‘}\textit{labor used in intermediate-good production}\text{’}}{\text{‘}\textit{total labor available for final-good production}\text{’}} \ .$$

This reduces to the expression above. Moreover, let us define effective labor in terms of the lowest-skilled labor available for final-good production here, i.e. in terms of labor

[5] Unless $LF_r(r_m) = L_m$, in which case the country also only produces the intermediate good.

with skill level r_m:

$$\tilde{L}(r) := L(r) \left[\frac{\log(r_m)}{\log(r)} \right]^{\frac{1}{\lambda}} .$$

With this notation, we can express the condition for sufficient skills in our economy as follows:

Definition 6.2 (Sufficient Skills)
We say that there are sufficient skills in the economy if the following condition is satisfied:

$$\frac{L}{1+\alpha} \int_{e^{-\frac{1}{\hat{i}\lambda}}}^{\overline{r}} \left[\frac{\log(r_m)}{\log(r)} \right]^{\frac{1}{\lambda}} dF_f(r) \geq \int_{\hat{i}}^{N} \tilde{L}_i \, di, \quad \forall \, \hat{i} \in [0, N] \,. \tag{SSC2}$$

Condition (SSC2) eventually enables us to characterize the equilibrium wage in our economy.[6]

Proposition 6.1
Let $\{\hat{w}_r\}_{r \in \mathcal{R}}$ *be a wage scheme satisfying:*

$$\hat{w}_r = \begin{cases} 1 & \textit{if } r \leq r_m \\ \left[\frac{\log(r_m)}{\log(r)} \right]^{\frac{1}{\lambda}} + \alpha \frac{\log(r_m)^{\frac{1}{\lambda}} - \log(r)^{\frac{1}{\lambda}}}{\log(r)^{\frac{1}{\lambda}}} & \textit{otherwise} \end{cases} .$$

Then:

(i) $\{\hat{w}_r\}_{r \in \mathcal{R}}$ *is the unique equilibrium wage scheme if and only if* $\left\{ \tilde{L}_i \left(\{\hat{w}_r\}_{r \in \mathcal{R}} \right) \right\}_{i \in [0,N]}$ *satisfies condition* (SSC2).

(ii) Otherwise, the equilibrium wage scheme, $\{w_r^\star\}_{r \in \mathcal{R}}$*, satisfies:*

$$w_r^\star \begin{cases} = 1 & \textit{if } r \leq r_m \\ = \left[\frac{\log(r_m)}{\log(r)} \right]^{\frac{1}{\lambda}} + \alpha \frac{\log(r_m)^{\frac{1}{\lambda}} - \log(r)^{\frac{1}{\lambda}}}{\log(r)^{\frac{1}{\lambda}}} & \textit{if } r_m \leq r \leq \hat{r} \\ > \left[\frac{\log(r_m)}{\log(r)} \right]^{\frac{1}{\lambda}} + \alpha \frac{\log(r_m)^{\frac{1}{\lambda}} - \log(r)^{\frac{1}{\lambda}}}{\log(r)^{\frac{1}{\lambda}}} & \textit{otherwise} \end{cases} ,$$

[6] To be precise, in Proposition 6.1 we assume that $L_m < F_r(r_m)$, i.e. that some labor with skill level r_m is available for final-good production. In case of $L_m = F_r(r_m)$ and sufficient skills, any wage scheme satisfying:

$$\hat{w}_r = \begin{cases} 1 & \text{if } r \leq r_m \\ 1 \leq w_r \leq \left[\frac{\log(r_m)}{\log(r)} \right]^{\frac{1}{\lambda}} + \alpha \frac{\log(r_m)^{\frac{1}{\lambda}} - \log(r)^{\frac{1}{\lambda}}}{\log(r)^{\frac{1}{\lambda}}} & \text{if } r = r^+ \\ w_r = \left[\frac{\log(r^+)}{\log(r)} \right]^{\frac{1}{\lambda}} w_{r^+} + \alpha \frac{\log(r^+)^{\frac{1}{\lambda}} - \log(r)^{\frac{1}{\lambda}}}{\log(r)^{\frac{1}{\lambda}}} & \text{otherwise} \end{cases}$$

is an equilibrium, where $r^+ := \min \{ r \in \mathcal{R} : \, LF_r(r) > L_m \}$.

for some $\hat{r} \in \mathcal{R}$ *such that* $r_m \leq \hat{r} < \max\{\mathcal{R}\}$*, and where*

$$w_{r^h} \geq \left[\frac{\log(r^l)}{\log(r^h)}\right]^{\frac{1}{\lambda}} w_{r^l} + \alpha \frac{\log(r^l)^{\frac{1}{\lambda}} - \log(r^h)^{\frac{1}{\lambda}}}{\log(r^h)^{\frac{1}{\lambda}}} \; \forall \, r^l, r^h \in \mathcal{R} : \; r^h \geq r^l \geq r_m \; .$$

Analogously to chapter 5, we subsequently focus on an economy with sufficient skills. It turns out that, in the variant of the model considered here, we have sufficient skills whenever the following assumption is satisfied:

Assumption 6.1

$$\frac{\int_{e^{-\frac{1}{\lambda i}}}^{\overline{r}} [-\log(r)]^{-\frac{1}{\lambda}} \; dF_f(r)}{\int_{\underline{r}}^{\overline{r}} [-\log(r)]^{-\frac{1}{\lambda}} \; dF_f(r)} \geq 1 - \left(\frac{i}{N}\right)^{\frac{1+\lambda-\sigma}{\lambda}} \;, \quad \forall \, i \in [0, N]$$

Note that, in the variant of the model considered here, sufficient skills are given for a broader range of world distributions of skills, $F_r(r)$. The reason for this is simply that low-skill labor is employed in the intermediate-good sector, implying that, on average, workers employed in the final-good sector have higher skills.[7]

6.3.2. Other equilibrium values

The derivation of the other equilibrium values closely follows the derivations as outlined in appendix C.3.4. It is therefore summarized only briefly here.

Final-good firms charge the same constant mark-up of $\frac{\sigma}{\sigma-1}$ over their marginal costs, and hence:

$$\rho_i^\star = \frac{\sigma}{\sigma - 1} \left[-e\lambda i \log(r_m)\right]^{\frac{1}{\lambda}} (1 + \alpha) \; . \tag{6.8}$$

Substituting equation (6.8) in equation (6.5) and solving the integral yields the equilibrium price index $P^\star$:

$$P^\star = (1 + \alpha) \frac{\sigma}{\sigma - 1} \left[-e\lambda \log(r_m)\right]^{\frac{1}{\lambda}} \left[\frac{\lambda}{1 - \sigma + \lambda}\right]^{\frac{1}{1-\sigma}} N^{\frac{1-\sigma+\lambda}{(1-\sigma)\lambda}} \; . \tag{6.9}$$

Total effective labor available for final-good production, $\tilde{L}_f$, is given by:

$$\tilde{L}_f := \frac{L}{1 + \alpha} \int_{r_m}^{\overline{r}} \left[\frac{\log(r_m)}{\log(r)}\right]^{\frac{1}{\lambda}} dF_f(r) \; .$$

[7] Formally, $F_f(r)$ first order stochastically dominates $F_r(r)$.

Labor market clearing requires that total demand for effective labor in the final-good sector equals total supply:

$$\begin{aligned}\tilde{L}_f &\stackrel{!}{=} \int_0^N \tilde{L}_i \, di \\ &= CP^{\sigma} \left[\frac{\sigma}{\sigma-1}(1+\alpha)\right]^{-\sigma} \left[-e\lambda \log(r_m)\right]^{\frac{1-\sigma}{\lambda}} \frac{\lambda}{1+\lambda-\sigma} N^{\frac{1+\lambda-\sigma}{\lambda}} \; .\end{aligned}$$

Solving for C and using equation (6.9) yields:

$$C^{\star} = \tilde{L}_f \left[-e\lambda \log(r_m)\right]^{-\frac{1}{\lambda}} \left[\frac{\lambda}{1+\lambda-\sigma}\right]^{\frac{1}{\sigma-1}} N^{\frac{1+\lambda-\sigma}{(\sigma-1)\lambda}} \; . \tag{6.10}$$

Equations (6.3), (6.8), (6.9), and (6.10) imply:

$$\chi_i^{\star} = \tilde{L}_f \left[-e\lambda \log(r_m)\right]^{-\frac{1}{\lambda}} \frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} \left[i\right]^{-\frac{\sigma}{\lambda}} \; , \tag{6.11}$$

and with the production technology, we get:

$$\tilde{L}_i^{\star} = \tilde{L}_f \frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} \left[i\right]^{\frac{1-\sigma}{\lambda}} \; . \tag{6.12}$$

As in chapter 5, we can use these equilibrium values to derive the counterpart of Assumption 5.1 for the variant of the model considered here. This yields the expression stated in Assumption 6.1 above.

We summarize our insights in the following proposition:

Proposition 6.2

Let Assumption 6.1 be satisfied. Then in any equilibrium it holds that:

(i) $p_m^{\star} = 1$

(ii) $m^{\star} = L_m^{\star} = \frac{\alpha}{1+\alpha} L$

(iii) $r_m^{\star} = \min \{r \in \mathcal{R} : \; LF_r(r) \geq L_m^{\star}\}$

(iv) $\tilde{L}_f^{\star} := \frac{L}{1+\alpha} \int_{\underline{r}}^{\overline{r}} \left[\frac{\log(r_m^{\star})}{\log(r)}\right]^{\frac{1}{\lambda}} \, dF_f(r)$

(v) $w_r^{\star} = \begin{cases} 1 & \text{if } r \leq r_m^{\star} \\ \left[\frac{\log(r_m^{\star})}{\log(r)}\right]^{\frac{1}{\lambda}} + \alpha \frac{\log(r_m^{\star})^{\frac{1}{\lambda}} - \log(r)^{\frac{1}{\lambda}}}{\log(r)^{\frac{1}{\lambda}}} & \text{otherwise} \end{cases} \;, \; \forall \, r \in \mathcal{R}$

(vi) $\mathcal{R}_i^{\star} \subseteq \{r \in \mathcal{R} : \; r \geq \max\{r_m^{\star}, \tilde{r}(i)\}\} \;\; \forall \, i \in [0, N]$

(vii) $q_i^{\star}(r) = \left[-\frac{1}{\lambda i \log(r)}\right]^{\frac{1}{\lambda}} \;\; \forall \, (i, r) \in [0, N] \times \mathcal{R}_i^{\star}$

(viii) $\rho_i^\star = \frac{\sigma}{\sigma-1}\left[-e\lambda i \log(r_m^\star)\right]^{\frac{1}{\lambda}}(1+\alpha)\ \forall\, i \in [0,N]$

(ix) $\chi_i^\star = \tilde{L}_f^\star \left[-e\lambda \log(r_m^\star)\right]^{-\frac{1}{\lambda}} \frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} [i]^{-\frac{\sigma}{\lambda}}\ \forall\, i \in [0,N]$

(x) $\tilde{L}_i^\star = \tilde{L}_f^\star \frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} [i]^{\frac{1-\sigma}{\lambda}}\ \forall\, i \in [0,N]$

(xi) $P^\star = (1+\alpha)\frac{\sigma}{\sigma-1}\left[-e\lambda \log(r_m^\star)\right]^{\frac{1}{\lambda}} \left[\frac{\lambda}{1-\sigma+\lambda}\right]^{\frac{1}{1-\sigma}} N^{\frac{1-\sigma+\lambda}{(1-\sigma)\lambda}}$

(xii) $C^\star = \tilde{L}_f^\star \left[-e\lambda \log(r_m^\star)\right]^{-\frac{1}{\lambda}} \left[\frac{\lambda}{1+\lambda-\sigma}\right]^{\frac{1}{\sigma-1}} N^{\frac{1+\lambda-\sigma}{(\sigma-1)\lambda}}$

6.4. Discussion

In chapter 5 we presented a general equilibrium framework to analyze comparative advantages of countries over a heterogeneous set of products. We have shown how the interplay between product-intrinsic complexity and endogenously chosen product quality can give rise to an upper-triangular structure of these comparative advantages if there are sufficient skills in the economy.

In this chapter, we consider a variant of our model where we introduce a homogeneous intermediate good, which is taken up and refined in final-good production. It turns out that the basic pattern of comparative advantages of countries for final goods also prevails in the extended framework considered here. In particular, a high-skill country $r \in \mathcal{R}$ with $r \geq r_m$ is still competitive for all final goods $i \in \left[0, \tilde{i}(r)\right]$. For countries active in final-good production, comparative advantages are still driven by whether or not these countries are bounded by the minimum-quality constraint.

Countries with the lowest skill levels $r < r_m$ are not competitive for any of the final goods. They rather specialize on producing the intermediate good. This, however, is not the case in general if we allow for heterogeneity of labor within countries. Suppose, for example, that in every country there are low-skill workers with $r = \underline{r}$ and high-skill workers with country-specific skill level $r^k > \underline{r}$. Suppose further that the total supply of low-skill workers is at least as high as the total labor employed in intermediate-good production, L_m. Then comparative advantages of countries over final goods exhibit the same upper-triangular structure as in the version of the model presented in chapter 5.

We consider the case of an intermediate good with no skill intensity, i.e. where all types of labor have the same productivity. This assumption trivially implies that the least productive labor is employed in intermediate-good production. For a more general case, where higher skilled labor is also more productive in intermediate-good production, the equilibrium split of labor between the two sectors may be more involved. However, the characterization of the demand for labor by final-good firms outlined in Lemma 6.1 applies more generally to a set-up with a homogeneous intermediate good, when α is replaced by the costs of endowing each unit of labor employed in final-good production with the required units of the intermediate good. Hence, with sufficient skills, we may still observe an upper-triangular structure of comparative advantages among those countries active in final-good production.

The introduction of a low-skill intermediate sector has interesting implications for the equilibrium distribution of wages. In particular, it can give rise to a polarization of the income distribution. At the one end, the distribution of wages becomes more unequal among those workers that are employed in final-good production. Intuitively, the more skilled the labor, the lower its risk of a failure in production. Without intermediate goods, a failure results simply in a loss of one's own work. By contrast, when final goods are produced by refining an intermediate good, then, in case of a failure, the investment in the intermediate good is lost as well. Hence reducing the risk of a failure has some extra value here. In the expression for the equilibrium wage above, this logic is reflected in the fact that among workers with skill level $r \geq r_m$, wages increase the more in r the higher α is, i.e. the more intermediate-good intense final-good production is. Hence the introduction of the homogeneous intermediate good gives rise to stronger incentives for investment in the skill levels of labor at the top.

At the other end, labor with skill level $r < r_m$ is employed in intermediate-good production. All these workers earn a wage of 1, irrespective of their skill level r. Hence an equilibrium with $r_m > \underline{r}$ exhibits a poverty-trap: Investments in the skill levels of labor yield a positive return only if skills are pushed beyond the threshold level of r_m.

In future work, it may be interesting to further explore the implications of the characterized polarization of the income distribution in a dynamic framework. It may also be interesting to consider international division of production of a single final good more generally, allowing firms to outsource parts of their production, for example.

Appendix

A. Appendix to Chapter 3

A.1. Robustness of taxation pecking order

A.1.1. Optimal policy without lump-sum taxes and transfers

In section 3.5.2 separating the choice of L_B from τ was feasible. We now ask whether this is always possible, even when lump-sum taxes or transfers are not available. It is possible when, for some given values of L_B and τ, we can always find values of t_L and t_P resulting in the desired value of τ and satisfying the budget constraint:

$$wL_B = wt_L\left[\bar{L} - L_E\right] + t_P\left[\pi_y + \eta(L_B)L_E\pi_{xm}\right]. \tag{A.1}$$

Using the equilibrium values of π_y, π_{xm}, and w, the budget constraint can be rewritten as:

$$L_B = t_L\left[\bar{L} - L_E\right] + t_P\left[\frac{\alpha}{1-\alpha}L_y - m + L_E\chi(L_B)\right]. \tag{A.2}$$

The right-hand side of equation (A.2) corresponds to the tax revenue in working-hour equivalents. It will subsequently be denoted by TR.

The definition of τ yields $t_L = 1 - \frac{1-t_P}{\tau}$. Inserting this expression into equation (A.2) and solving for t_P, we find that the choice of L_B and τ can be separated only if the resulting value of t_P, which we denote by $\tilde{t}_P$, is in the feasible range $[\underline{t}_P, \bar{t}_P]$ and $\tilde{t}_L = 1 - \frac{1-\tilde{t}_P}{\tau}$ is in $[\underline{t}_L, \bar{t}_L]$.[1] In the main text we saw that in the setting with lump-sum taxes either $\left(\bar{\tau}, \tilde{L}_B(\bar{\tau})\right)$ or $(\underline{\tau}, 0)$ is optimal. In this appendix we assume $\underline{t}_L = \underline{t}_P = 0$, as we want to allow the government not to provide basic research, if so desired. Then, by Assumption 3.1(ii), the policy choice $t_L = t_P = L_B = 0$ also allows the realization of a stagnant economy without lump-sum taxes. By contrast, $\left(\bar{\tau}, \tilde{L}_B(\bar{\tau})\right)$ is not feasible in general

[1] The exact formula for $\tilde{t}_P$ is:

$$\tilde{t}_P = \left(L_B + \frac{1-\tau}{\tau}(\bar{L} - L_E)\right) / \left(\frac{\alpha}{1-\alpha}L_y - m + L_E\chi(L_B) + \frac{\bar{L} - L_E}{\tau}\right).$$

in the setting without lump-sum taxes, as it would require that $\left(\bar{t}_L, \underline{t}_P, \tilde{L}_B(\overline{\tau})\right)$ exactly satisfies equation (A.2).

To examine optimal policies in an economy without lump-sum taxes or transfers, we proceed as in section 3.5.2 and solve the government's maximization problem in two steps. First, we consider the optimal tax policy given that a certain level of basic research needs to be financed. Consider the set of all tax policies $\mathcal{T}(L_B)$ consisting of vectors (t_P, t_L), with $0 \leq t_P \leq \bar{t}_P$, $0 \leq t_L \leq \bar{t}_L$, that satisfy the budget constraint (A.2).[2] We focus on affordable basic research investments, i.e. $\mathcal{T}(L_B) \neq \emptyset$. For each such L_B, the policies in $\mathcal{T}(L_B)$ define a feasible range of τ whose upper and lower bounds are denoted by $\overline{\tau}_O(L_B)$ and $\underline{\tau}_O(L_B)$, respectively. It transpires that the upper bound $\overline{\tau}_O(L_B)$ will be reached by using the labor income tax to finance basic research and levying a positive profit tax only if a *ceteris paribus* increase in t_L cannot be used to finance additional basic research, i.e. with a pecking order in which labor income tax comes first. With a pecking order in which profit taxes come first, we will obtain the lower bound $\underline{\tau}_O(L_B)$. We note that it may not be possible to finance additional basic research by a unilateral increase of the preferential tax measure for two reasons: either because the preferential tax instrument has reached its upper constitutional bound or because it is located at the decreasing part of the Laffer curve for TR.[3]

By definition, all policies in $\mathcal{T}(L_B)$ satisfy the government's budget constraint. However, depending on the implied level of τ, the tax policies entail different levels of entrepreneurship and consequently different output levels. Entrepreneurship increases aggregate consumption if $\chi(L_B) \geq 1$, i.e., if $L_B \geq L_{B,min}$. In this case, the government's tax policy will aim at maximizing entrepreneurship by maximizing τ with the pecking order in which labor income tax comes first. By contrast, the opposite pecking order will be applied to minimize entrepreneurship if $\chi(L_B) < 1$.[4] We formalize these insights in Proposition A.1.

Proposition A.1 (Taxation Pecking Order)
Consider a government that maximizes aggregate consumption and finances an amount L_B of basic research using (t_L, t_P) as its tax scheme. Suppose $\mathcal{T}(L_B) \neq \emptyset$. Then:

(i) If $L_B \geq L_{B,min}$, basic research should be financed using a pecking order with labor income tax coming first. In particular, $t_P > 0$ only if TR cannot be increased further by a unilateral increase of t_L.

[2] Note that for $L_B > 0$, the Positive Profit Condition (PPC) is a necessary condition for the government budget constraint to be satisfied.
[3] Cf. section 4.2 for a characterization of these Laffer curves.
[4] In principle, there could exist several tax schemes that fully deter entrepreneurship. If the government is indifferent between such tax policies, we assume that it will choose $\underline{\tau}_O(L_B)$.

(ii) If $L_B < L_{B,min}$, basic research should be financed using a pecking order with profit tax coming first. In particular, $t_L > 0$ only if TR cannot be increased further by a unilateral increase of t_P.

A proof of Proposition A.1 can be found in appendix A.3.7.

Proposition A.1 characterizes the optimal tax policies required to finance a given amount of basic research L_B. We will now use the optimal tax policies to determine the optimal provision of basic research. For this purpose, it is again convenient to consider first the constrained problem for $L_B \geq L_{B,min}$. In this case, the government's tax policy maximizes τ for each given L_B. Inserting $\overline{\tau}_O(L_B)$ into its objective function (see equation (3.13)), the government's problem boils down to:

$$\max_{\{L_B \geq L_{B,min}\}} \quad L_y(L_B, \overline{\tau}_O(L_B)) \,.$$

We obtain as a necessary condition for a maximum:

$$\frac{\partial L_y(L_B, \overline{\tau}_O(L_B))}{\partial L_B} + \frac{\partial L_y}{\partial L_E} \frac{\partial L_E}{\partial \tau} \frac{\partial \overline{\tau}_O(L_B)}{\partial L_B} \leq 0 \,, \tag{A.3a}$$

$$\left(\frac{\partial L_y(L_B, \overline{\tau}_O(L_B))}{\partial L_B} + \frac{\partial L_y}{\partial L_E} \frac{\partial L_E}{\partial \tau} \frac{\partial \overline{\tau}_O(L_B)}{\partial L_B} \right) (L_B - L_{B,min}) = 0. \tag{A.3b}$$

The first partial derivative of the objective function $L_y(\,\cdot\,,\,\cdot\,)$ with respect to L_B corresponds to the necessary condition for maximization of aggregate consumption when lump-sum taxes and transfers are feasible (3.16a). The second summand captures the effect of L_B on τ implying that a marginal increase of basic research additionally influences the number of entrepreneurs making use of it via the tax scheme. The sign of $\frac{\partial L_y}{\partial L_E}$ is positive for $L_B > L_{B,min}$. For $L_E > 0$, the term $\frac{\partial L_E}{\partial \tau}$ is positive, which follows from the equilibrium value of L_E given in (3.6). Finally, the last expression represents the marginal effect of basic research on $\overline{\tau}_O(L_B)$ as implied by the government budget constraint. The sign of this effect depends on two interdependent factors: first, it depends on whether or not an increase in L_B requires additional funding. An increase in L_B might in principle generate additional tax returns in working-hour equivalents exceeding the increase in L_B. Second, it depends on how precisely basic research is financed: via a change in labor income or via a change in profit taxes. Suppose, for example, that both tax measures are located at the increasing part of the Laffer curve and that an increase in basic research requires additional funding. Then, with the pecking order $\overline{\tau}_O(L_B)$, the government will use the labor tax to finance additional basic research, implying $\frac{\partial \overline{\tau}_O(L_B)}{\partial L_B} = \frac{\partial \tau}{\partial t_L} \frac{\partial t_L}{\partial L_B} > 0$. If, by contrast, an increase in L_B cannot be funded via an increase in the labor tax, either because it has reached its upper bound or because it is located at the decreasing part of the Laffer curve, then additional basic research will be financed by an increase in the profit taxes and/or a decrease in the labor tax, and the last expression becomes negative.

Let us use $L_{B,\overline{\tau}_O}$ to denote the solution of the government's problem, constrained by $L_B \geq L_{B,min}$, which implies a pecking order with labor income taxes coming first. Again, note that $L_{B,\overline{\tau}_O} > L_{B,min}$ implies that (A.3a) holds with equality.

Next, we consider the government's problem restricted to $L_B < L_{B,min}$ implying a pecking order with profit taxes coming first, $\underline{\tau}_O$. Since, in this case, entrepreneurship affects consumption negatively, the government will prevent inefficient entrepreneurship by providing no basic research.[5] Hence the solution to this restricted optimization problem will be $(L_{B,\underline{\tau}_O} = 0, \underline{\tau}_O(L_{B,\underline{\tau}_O}) = 1)$.

Consequently, the government will implement $L_{B,\overline{\tau}_O} > L_{B,min}$ if and only if basic research increases the entrepreneurs' innovation probability sufficiently to compensate for the investments in basic research and the labor diverted to entrepreneurship. That is, if and only if $L_{B,\overline{\tau}_O}$ satisfies:

$$-L_{B,\overline{\tau}_O} + \left[1 - \frac{1}{\overline{\tau}_O(L_{B,\overline{\tau}_O}) b\, \chi\left(L_{B,\overline{\tau}_O}\right)}\right] \left[\chi\left(L_{B,\overline{\tau}_O}\right) - 1\right] \geq 0\,. \tag{PLS2}$$

Otherwise, the government will implement policy $L_B = t_P = t_L = 0$. Proposition A.2 summarizes our findings.

Proposition A.2
Suppose the government maximizes aggregate consumption using (t_L, t_P, L_B) as policy instruments. Then:

(i) If and only if condition (PLS2) *is satisfied, there will be an entrepreneurial economy with $L_B^* = L_{B,\overline{\tau}_O}$, $\tau^* = \overline{\tau}_O(L_{B,\overline{\tau}_O})$, and $L_E = 1 - \frac{1}{\overline{\tau}_O(L_{B,\overline{\tau}_O}) b \chi\left(L_{B,\overline{\tau}_O}\right)}$.*

(ii) Otherwise, there will be a stagnant economy with $t_L^* = t_P^* = 0$, $L_B^* = 0$ and $L_E = 0$.

A.1.2. Maximization of aggregate welfare

In this part of the appendix we analyze the case of a government aiming to maximize aggregate utility rather than aggregate consumption. We reintroduce lump-sum taxes,

[5] Note that the government is able to deter inefficient entrepreneurship by forgoing any basic research investment according to Assumption 3.1. Via the budget constraint, $L_B = 0$ implies $t_P = t_L = 0$.

again allowing the government to separate the choice of the optimal amount of basic research from the optimal financing scheme. In our model aggregate utility, W, is given by:

$$W = (1-t_P)\pi_y + \int_0^{L_E} [(1-t_P)\lambda_k \eta(L_B)\pi_{xm} - t_H] \, dk + \int_{L_E}^{\bar{L}} [(1-t_L)w - t_H] \, dk \; . \quad \text{(A.4)}$$

Combining (A.4) with the government budget constraint, (3.4), the labor market clearing condition, (3.9), and the aggregate income identity, $y = \pi_y + \eta(L_B)L_E\pi_{xm} + (L_x + L_y)w$, yields:

$$W = y + (1-t_P)\eta(L_B)\pi_{xm} \int_0^{L_E} (\lambda_k - 1) \, dk \; .$$

Replacing y and π_{xm} by their respective equilibrium values given in part (i) of Proposition 3.1 and solving the integral using $\lambda_k = (1-k)b$ yields:

$$W = L_y^{1-\alpha} + (1-t_P)\chi(L_B)(1-\alpha)bL_y^{-\alpha}L_E \left[1 - \frac{1}{b} - \frac{L_E}{2}\right] \; . \quad \text{(A.5)}$$

The government's problem is to maximize (A.5) subject to the non-negativity constraint of the final-good producer's profits and equilibrium conditions (1) and (3) given in Proposition 3.1.

Comparing the expression for aggregate welfare given in equation (A.5) with the expression for aggregate consumption given in equation (3.13), makes it apparent that aggregate welfare corresponds to aggregate consumption plus the immaterial benefits (cost) of entrepreneurs. This immaterial utility term is scaled by $(1-t_P)$, i.e. profit taxes allow the government to directly affect this term. So when maximizing aggregate welfare, not only the relative size of $(1-t_P)$ compared to $(1-t_L)$ matters, but also its absolute size. The imposition of labor income taxes affects the occupational choice of potential entrepreneurs and hence the equilibrium number of entrepreneurs who use the basic research provided. The imposition of profit taxes also influences the occupational choice of potential entrepreneurs. In addition it affects the utility received by those who opt to become entrepreneurs. Proposition A.3 shows that this implies that, in any welfare optimum with strictly positive entrepreneurship, at least one tax measure is located at the boundary of its feasible set. The intuition is that for any strictly interior combination of tax measures, there is a continuum of combinations of t_L and t_P yielding the same τ and hence the same level of entrepreneurship in the economy. Now, if for a given τ the immaterial utility term in the aggregate welfare is positive, then the welfare-maximizing combination of t_L and t_P yielding this τ is the t_P-minimizing combination, which requires that either

$t_L = \underline{t}_L$ or $t_P = \underline{t}_P$ or both. A similar argument reveals that either $t_L = \overline{t}_L$ or $t_P = \overline{t}_P$ or both if the immaterial utility term in the aggregate welfare is negative.[6]

Proposition A.3
Let $(t_L^*, t_P^*, t_H^*, L_B^*)$ be a welfare optimum with $\tau^* := \frac{1-t_P^*}{1-t_L^*} > \frac{1}{\chi(L_B^*)b}$. Then at least one tax rate is at the boundary of its feasible set, i.e. $t_P^* = \underline{t}_P$, $t_P^* = \overline{t}_P$, $t_L^* = \underline{t}_L$ or $t_L^* = \overline{t}_L$.

Proposition A.3 follows directly from Proposition A.6 in appendix A.3.8. It implies that no interior optimum exists for tax policies. We next characterize the optimal tax policy for a given L_B in more detail. As we have argued previously, depending on whether or not the immaterial utility term in the aggregate welfare is positive, it is optimal to either implement the desired τ in the t_P-minimizing or the t_P-maximizing way. We now assume the opposite perspective and consider the optimal level of τ given t_P. We show that tax neutrality, i.e. a tax policy satisfying $t_L = t_P$, is not welfare-maximizing in general.

For t_P given, τ is determined by t_L, which only affects entrepreneurship in the economy. In particular, the following relationship between the marginal effect of labor income taxes and entrepreneurship on aggregate welfare holds:

$$\frac{\partial W}{\partial t_L} = \begin{cases} \frac{\partial W}{\partial L_E} \frac{1}{(1-t_P)\chi(L_B)b} & , \quad \text{if } \frac{1-t_L}{(1-t_P)\chi(L_B)b} \leq 1 \\ 0 & , \quad \text{if } \frac{1-t_L}{(1-t_P)\chi(L_B)b} > 1 \end{cases} .$$

We will make use of this relationship between τ, t_L, and L_E for given t_P and L_B and analyze welfare effects of entrepreneurship directly, which yields the most insights. The partial derivative of W with respect to L_E is given by:

$$\begin{aligned} \frac{\partial W}{\partial L_E} =& (1-\alpha)L_y^{-\alpha}\Big\{(\chi(L_B)-1) + (1-t_P)\chi(L_B)b \\ & \left[\left(1-\frac{1}{b}-L_E\right) - \alpha(\chi(L_B)-1)L_y^{-1}\left(1-\frac{1}{b}-\frac{L_E}{2}\right)L_E\right]\Big\} . \end{aligned}$$

Rearranging terms yields:

$$\begin{aligned} \frac{\partial W}{\partial L_E} =& -(1-\alpha)L_y^{-\alpha} + (1-\alpha)L_y^{-\alpha}\chi(L_B)b(1-L_E) \\ & - t_P(1-\alpha)L_y^{-\alpha}\chi(L_B)b\left(1-\frac{1}{b}-L_E\right) \\ & - (1-t_P)\alpha(1-\alpha)L_y^{-1-\alpha}\chi(L_B)b(\chi(L_B)-1)\left(1-\frac{1}{b}-\frac{L_E}{2}\right)L_E . \end{aligned} \tag{A.6}$$

[6] The case where the aggregate immaterial utility term is exactly equal to zero is somewhat more involved. The intuition here is that in this case aggregate welfare will reduce to aggregate consumption, which we have shown previously to be maximized at either $\overline{\tau}$ or $\underline{\tau}$.

Equation (A.6) characterizes the trade-offs faced by the social planner when considering a marginal increase of entrepreneurship in the economy. It reveals why tax neutrality, i.e. $t_L = t_P$, is not welfare-maximizing in our economy in general.

The first summand represents the marginal product of labor used in final-good production – which corresponds to the pre-tax wage in equilibrium, $(1-\alpha)L_y^{-\alpha}$. This is lost as the marginal entrepreneur is not available for production anymore. $(1-\alpha)L_y^{-\alpha}\chi(L_B)b(1-L_E)$ is the pre-tax expected utility for this marginal entrepreneur. Assume tax neutrality, i.e. $t_P = t_L$, then the first two summands exactly reflect the trade-off faced by the marginal entrepreneur, so they cancel. To see this, note that under tax neutrality each potential entrepreneur k compares his pre-tax wage earned in the labor market, $(1-\alpha)L_y^{-\alpha}$, with the pre-tax expected utility from being an entrepreneur, $(1-\alpha)L_y^{-\alpha}\chi(L_B)b(1-k)$. The result then follows from $k = L_E$ for the marginal entrepreneur.

By contrast, the remaining two summands in equation (A.6) do not necessarily vanish under tax neutrality. $-t_P(1-\alpha)L_y^{-\alpha}\chi(L_B)b\left(1-\frac{1}{b}-L_E\right)$ captures the immaterial utility of the marginal entrepreneur that is lost due to profit taxes. For the occupational choice of the marginal entrepreneur, only the relation of profit to labor income taxes matters, so it is not affected by tax-neutral policies. Furthermore, with regard to consumption, for a constant τ, t_L and t_P have purely distributional effects that do not matter for aggregate welfare in our economy. However, t_P does not only decrease the expected after-tax profits of the marginal entrepreneur but also his immaterial utility. This reduction in immaterial utility for the marginal entrepreneur lowers aggregate welfare. It could be eliminated by having $t_L = t_P = 0$.

The last summand captures the effect of the marginal entrepreneur on equilibrium wages, which affects the immaterial utility of all other entrepreneurs. The sign of this effect depends on two factors. First, it depends on $1-\frac{1}{b}-\frac{L_E}{2} \gtrless 0$, which determines whether the total sum of these immaterial utilities is positive or negative. Second, it depends on whether $\chi(L_B)$ is greater or smaller than one, which determines whether the marginal entrepreneur has a positive or a negative effect on equilibrium wages. This term does not vanish in general for $t_L = t_P = 0$.

In summary, we have argued that any given level τ should be implemented either in a t_P-minimizing or in a t_P-maximizing way and that tax neutrality is not optimal in general. Taken together, these two observations give rise to *taxation pecking orders* and hence reinforce our main insights from the analysis of aggregate consumption-maximizing policies. Proposition A.4 establishes the welfare-maximizing pecking orders formally, where (t_L^*, t_P^*, L_B^*) again denote optimal policy choices and L_E^* denotes the resulting equilibrium level of entrepreneurship in the economy.

Proposition A.4 (Welfare-Optimal Taxation Pecking Order)
The welfare optimal tax policy for economies with positive entrepreneurship, $L_E^* > 0$, can be characterized as follows:

(i) *if* $L_E^* < \min\left\{1 - \frac{1-\underline{t}_L}{(1-\underline{t}_P)\chi(L_B^*)b}, 2\left(1-\frac{1}{b}\right)\right\}$*, then* $t_P^* > \underline{t}_P$ *and* $t_L^* = \underline{t}_L$*;*

(ii) *if* $1 - \frac{1-\underline{t}_L}{(1-\underline{t}_P)\chi(L_B^*)b} < L_E^* < 2\left(1-\frac{1}{b}\right)$*, then* $t_P^* = \underline{t}_P$ *and* $t_L^* > \underline{t}_L$*;*

(iii) *if* $2\left(1-\frac{1}{b}\right) < L_E^* < 1 - \frac{1-\bar{t}_L}{(1-\bar{t}_P)\chi(L_B^*)b}$*, then* $t_P^* = \bar{t}_P$ *and* $t_L^* < \bar{t}_L$*;*

(iv) *if* $L_E^* > \max\left\{1 - \frac{1-\bar{t}_L}{(1-\bar{t}_P)\chi(L_B^*)b}, 2\left(1-\frac{1}{b}\right)\right\}$*, then* $t_P^* < \bar{t}_P$ *and* $t_L^* = \bar{t}_L$*.*

A proof including all cases of Proposition A.4 and knife-edge cases is given in appendix A.3.8.

Cases (i) and (iii) of Proposition A.4 give rise to a pecking order with profit taxes coming first in the sense that either t_L is at its lower bound and t_P is not, or t_P is at its upper bound and t_L is not. Conversely, cases (ii) and (iv) give rise to a pecking order with labor income tax coming first.

Note, however, that as opposed to the setting without lump-sum taxes considered in appendix A.1.1, the pecking order in this part of the appendix is not a result of the government seeking to raise additional funds in order to finance basic research once the preferred tax measure cannot be used any further. Optimal tax policies are rather driven by the endeavor to implement a preferred τ either in a t_P-maximizing or in a t_P-minimizing way, as discussed above. In cases (i) and (ii) of Proposition A.4, for example, the aggregate extra (dis)-utility of entrepreneurs is positive $\left(L_E^* < 2\left(1-\frac{1}{b}\right)\right)$, and hence the government seeks to have a minimal t_P in order not to lose this extra utility, primarily using t_L to induce the desired level of entrepreneurship. If entrepreneurship is desirable from a social-welfare perspective, the government will opt for $t_L^* > \underline{t}_L$ to incentivize entrepreneurship (case (ii)). If entrepreneurial activity becomes less attractive, the government first responds by decreasing t_L to discourage entrepreneurship and once t_L cannot be relied upon any further because it has reached its lower bound, it will increase t_P, thereby trading-off the social-welfare gain from continuing to discourage entrepreneurship against the cost of losing some of the extra utility earned by entrepreneurs (case (i)). As a side-effect, the pecking orders derived here are solely characterized by bounds of taxation. In particular, peaks of the Laffer Curves, which played a central role in the pecking orders derived in appendix A.1.1, do not matter in this part of the appendix.

Note further that the underlying motives for the two cases yielding the same pecking order according to Proposition A.4 are different. Consider for example case (iii) of Proposition A.4 as opposed to case (i), both of which motivate a pecking order with profit taxes coming first. In case (iii), the aggregate extra (dis)-utility term of entrepreneurs is negative ($L_E^* > 2\left(1 - \frac{1}{b}\right)$), so the government will choose $t_P^* = \bar{t}_P$ to minimize these welfare losses for any given level L_E. In addition, it will use t_L to further discourage entrepreneurship and hence choose $t_L < \bar{t}_L$.

Finally, although we have just identified differences between the pecking orders, it is important to note that from a more fundamental perspective they share the same motive: the pecking order with profit taxes coming first is preferable whenever the desired level of entrepreneurship is relatively low. By contrast, the pecking order with labor income tax coming first is preferable whenever the desired level of entrepreneurship is relatively high. In the setting considered here, a relatively high level of entrepreneurial activity means:

– a level larger than the one implied by $t_L = \underline{t}_L$ and $t_P = \underline{t}_P$ if aggregate immaterial utility from entrepreneurship is positive (case (ii));

– a level larger than the one implied by $t_L = \bar{t}_L$ and $t_P = \bar{t}_P$ if aggregate immaterial utility from entrepreneurship is negative (case (iv)).

We summarize these qualitative results in the following Corollary:

Corollary A.1
Suppose the government maximizes aggregate welfare, given by (A.5)*, using* (t_L, t_P, t_H, L_B) *as policy instruments. Then:*

(i) If the welfare-optimal level of entrepreneurial activity is relatively high, then the government will opt for the pecking order with labor income tax coming first.

(ii) If the welfare-optimal level of entrepreneurial activity is relatively low, then the government will opt for the pecking order with profit tax coming first.

The welfare-optimal level of entrepreneurial activity depends on a variety of different factors. In particular, it depends on the effectiveness of entrepreneurship in terms of labor saved in intermediate-good production, $\chi(L_B^*)$, and on the immaterial benefits from entrepreneurship as determined by b.

Proposition A.4 limits its attention to economies in which entrepreneurs are active, i.e. $L_E > 0$. Economically, this is not very restrictive for the purpose of our analysis, as in an economy where $L_E^* = 0$, trivially $L_B^* = 0$ combined with any tax policy ensuring that $L_E^* = 0$ would be welfare-maximizing. Proposition A.5 analyzes the circumstances when $L_E^* > 0$ is welfare-optimal for given L_B. Whether or not $L_E^* > 0$ is only interesting for cases where $L_E = 0$ and $L_E > 0$ are both feasible, which is why we limit our attention to these cases.[7]

Proposition A.5

Suppose that $L_B = L_B^*$ and let $L_E = 0$ and $L_E > 0$ both be feasible. Then $L_E^* > 0$, i.e. positive entrepreneurship is welfare-maximizing, if:

$$\chi(L_B^*) > \frac{1}{1 + (1 - \tilde{t}_P)(b - 1)} \,, \tag{A.7}$$

where

$$\tilde{t}_P = \begin{cases} \min\left(\bar{t}_P, 1 - \frac{1-\bar{t}_L}{\chi(L_B^*)b}\right) & \text{if } b \leq 1 \\ \max\left(\underline{t}_P, 1 - \frac{1-\underline{t}_L}{\chi(L_B^*)b}\right) & \text{if } b > 1 \end{cases} \,. \tag{A.8}$$

A proof of Proposition A.5 is given in appendix A.3.9. Proposition A.5 implies quite intuitively that $L_E^* > 0$ is welfare-optimal whenever $\chi(L_B^*)$ is large, i.e. whenever the expected labor saved for final-good production from increasing the number of entrepreneurs is large.

A.2. Details on political economy analysis

A.2.1. Applicability of median voter theorem

In this part of the appendix, we give sufficient conditions under which the median voter theorem holds in our model. We start by elaborating on whether the preferences of the individuals satisfy the single-crossing condition over the policy space.

Consider policy space $\mathcal{P}$ with policies $p = (t_L, t_P, t_H, L_B)$ that either reflect a stagnant economy with $L_B = 0$ or growth-oriented entrepreneurial policies with $L_B > 0$. We order the policies according to their implied net final-good profit, $(1 - t_P)\pi_y$, such that if $p_2 > p_1$ then $(1 - t_P^2)\pi_y^2 > (1 - t_P^1)\pi_y^1$. We further order the voters according to their shareholdings. The single-crossing condition requires that if $p > p'$ and $s < s'$, or if $p < p'$ and $s > s'$, then from $EU_s(p) > EU_s(p')$ it follows that $EU_{s'}(p) > EU_{s'}(p')$. In this condition, $EU_s(p)$ refers to the expected utility of an individual with shareholdings s

[7] Note that in our model feasibility of a given level L_E does not only require the existence of a combination of tax measures t_L and t_P that yield the desired level of entrepreneurial activity given L_B, but also that this results in non-negative profits for the final-good producer.

under policy $p \in \mathcal{P}$, which can be written as:

$$\begin{aligned} EU_s(p) =&(1-t_L)w - t_H + s(1-t_P)\frac{\pi_y}{\bar{L}} \\ &+ \mathbb{1}_{k\in[0,1]} \max\left\{(1-t_P)\pi_{xm}\eta(L_B)(1-k)b - (1-t_L)w, 0\right\} \ . \end{aligned} \tag{A.9}$$

We immediately observe that the single-crossing condition holds for the preferences of all individuals with $k \geq 1$, i.e. when we exclude all potential entrepreneurs. Consider two policies p_1 and p_2 with $p_2 > p_1$. If a worker with shareholdings s_1 prefers policy p_2, so will a worker with shareholdings $s_2 > s_1$. Further, if the person with shares s_2 prefers p_1 to p_2, so will the individual with shares s_1. Intuitively, the labor income and the lump-sum transfers are always the same for both workers, but the worker with the higher amount of shares benefits more from a policy involving higher net profits in final-good production. We summarize this finding in the following lemma:

Lemma A.1

The preferences of the individuals with $k \notin [0, 1)$ satisfy the single-crossing condition over the policy space $\mathcal{P}$.

When we consider the entire set of agents (i.e. including the set of potential entrepreneurs), the single-crossing condition does not hold. This can be illustrated by restricting the vote to one between a stagnant and an entrepreneurial policy, for instance by assuming that the stagnant economy is the status quo challenged by an entrepreneurial policy proposal. Recall that for the single crossing condition to hold in this case, the following must be true: If the individual with the median amount of share prefers (disfavors) the entrepreneurial policy, so will all individuals with weakly higher (lower) shareholdings. It follows directly from equation (A.9) and Lemma A.1 that the first statement, which we recall in the next lemma, is satisfied but the statement in parentheses is not.

Lemma A.2

Suppose a worker with shareholdings $\hat{s}$ prefers a growth-oriented entrepreneurial economy to the stagnant economy. Then so will all voters with shareholdings $s \geq \hat{s}$.

Intuitively, the higher a worker's shareholdings, the more he can benefit from the increase in final-good producers' profits associated with a growth-oriented entrepreneurial economy. (This is implied by Lemma A.1.) The result extends to potential entrepreneurs with shareholdings $s \geq \hat{s}$, as they will all be workers in the stagnant economy. Then if they remain workers in the entrepreneurial economy, their trade-off is just the same as the one faced by a worker with the same shareholdings. If, by contrast, they opt to become entrepreneurs, they must prefer this option to being workers and the result follows accordingly. Note that for agents with $0 \leq k \leq 1$ the decision whether to become an entrepreneur is captured by the maximum term in equation (A.9).

The reverse of Lemma A.2 is not true. In particular, if a worker with shareholdings s prefers the stagnant economy, a potential entrepreneur with shareholdings equal to or less than s will not necessarily support a stagnant economy. This follows immediately from the fact, incorporated in equation (A.9), that the utility gain from being an entrepreneur must be weakly positive.

Hence, the single-crossing condition regarding a stagnant policy and an entrepreneurial policy does not hold for the entire set of individuals. Moreover, note that the single-crossing condition does not necessarily hold when we consider the voting on two different entrepreneurial policies. The reason is the expected gain from being an entrepreneur, as described in (A.9). To illustrate the argument, consider two policies $p_1 > p_2$. Suppose that a worker with $\hat{s}$ shares prefers policy p_2 to policy p_1. Now consider an entrepreneur with $\hat{s}$ shares as well. Note that her absolute expected gain from being an entrepreneur as described in (A.9) may be larger for policy p_1 than for policy p_2. So, she may prefer policy p_1.

The type of preferences of potential entrepreneurs can imply that the amount of shares of the median voter may be different across different binary collective decisions. This inhibits the direct application of the median voter theorem. However, when we order individuals from 1 to $\bar{L}$ according to the amount of shares they own, starting with the lowest amount at $k = 1$, and if $\bar{L} > 2$, we will observe that the median voter on any collective decision between p_1 and p_2 is in $\left[\frac{\bar{L}}{2}, \frac{\bar{L}}{2} + 1\right]$. The preferences of potential entrepreneurs can affect the location of the median voter on some binary decisions in the interval $\left[\frac{\bar{L}}{2}, \frac{\bar{L}}{2} + 1\right]$.[8] All our results apply, as long as the shareholdings s of workers $\left[\frac{\bar{L}}{2}, \frac{\bar{L}}{2} + 1\right]$ fulfill the conditions required in section 3.6.[9]

To simplify the presentation, we assume that all workers in $\left[\frac{\bar{L}}{2}, \frac{\bar{L}}{2} + 1\right]$ have the same amount of shares s. Accordingly, if these workers prefer policy p_1 to p_2, at least half of the electorate will have the same preference ordering. The single-crossing property of the preferences of individuals $\left[1, \bar{L}\right]$ then implies the median voter theorem. The votes of potential entrepreneurs in $[0, 1]$ will not affect the outcome of any binary collective decision p_1 against p_2.

[8] Note that if the worker with $k = \frac{\bar{L}}{2}$ prefers an entrepreneurial to a stagnant policy, all individuals in $\left[\frac{\bar{L}}{2}, \bar{L}\right]$ will support the former.

[9] Even if collective decisions displayed cycles, these would remain in the set of most-preferred policies for workers in $\left[\frac{\bar{L}}{2}, \frac{\bar{L}}{2} + 1\right]$.

A.2.2. Most-preferred policy of the median voter

In this section we consider the median voter's problem and derive her most-preferred policy. As described in the main text, we start with a given (τ, L_B) and derive the optimal choice of t_P and t_L. Then we elaborate on the desired levels of (τ, L_B).

With τ given, we can replace t_L by $1-(1-t_P)/\tau$ in expression (3.19) for the net transfers. Then taking the derivative of the net transfers with respect to t_P yields:

$$DNT := \left.\frac{\partial NT}{\partial t_P}\right|_{\tau} = w\left[(\frac{\alpha}{1-\alpha}l_y - m_l)(1-s) + \chi(L_B)l_E - \frac{l_E}{\tau}\right] , \qquad \text{(A.10)}$$

where we use $l_y := \frac{L_y}{L}$, $m_l := \frac{m}{L}$, and $l_E := \frac{L_E}{L}$ to denote per-capita variables. Note that with lump-sum transfers, a marginal increase in profit tax constitutes a redistribution of profits (from entrepreneurs and the final-good firm) to workers, while an increase in the labor tax redistributes from workers to entrepreneurs.[10] The redistribution of profits is captured by the first two summands in (A.10). The first summand reflects the additional redistribution of the final-good firm's profits, the second represents the additional redistribution of entrepreneurial profits. As the median voter is a worker, she will prefer redistribution of entrepreneurial profits. Factor $1-s$ indicates that the redistribution of the final-good firm's profits is only favorable if she owns less than the per-capita shares in the final-good firm. Finally, keeping τ constant, an increase in the profit tax t_P by a marginal unit must be matched by an increase in the labor tax t_L of $1/\tau$. The resulting amount of redistribution of labor income to entrepreneurs is captured by the last summand in DNT.

If DNT is positive, net transfers for the median voter are maximized by the highest possible profit tax rate, while the opposite is true if DNT is negative. However, the optimal choice of t_P (and t_L) will depend on the particular value of τ. Table A.1 shows the optimal levels of t_P and t_L depending on DNT and τ. Note that since profits of the final-good firm are non-negative (as $w\left(\frac{\alpha}{1-\alpha}l_y - m_l\right) \geq 0$), the case where $DNT < 0$ and $\tau \geq 1$ can only occur if entrepreneurship is inefficient (i.e. $\chi(L_B) < 1$) and/or $s > 1$.

Table A.1.: Median voter's preferred labor and profit tax rates, given τ and L_B

	$\tau \geq 1$	$\tau < 1$
$DNT \geq 0$	$t_L = \bar{t}$, $t_P = 1 - \tau(1-\bar{t})$	$t_L = 1 - (1-\bar{t})/\tau$, $t_P = \bar{t}$
$DNT < 0$	$t_L = 1 - (1-\underline{t})/\tau$, $t_P = \underline{t}$	$t_L = \underline{t}$, $t_P = 1 - \tau(1-\underline{t})$

[10] The increase in labor tax does not per se constitute a redistribution towards the owners of the shares of the final-good firm, as these are also either workers or entrepreneurs.

We use $\tilde{t}_L(\tau, L_B)$ and $\tilde{t}_P(\tau, L_B)$ to refer to the optimal labor and profit tax rates for given τ and L_B. Using these tax rates, we can write the net transfers, and consequently the median voter's income, as a continuous function of τ and L_B.

Lemma A.3

Using $\tilde{t}_L(\tau, L_B)$ and $\tilde{t}_P(\tau, L_B)$, the median voter's income is a continuous function of (τ, L_B) on $[\underline{\tau}, \overline{\tau}] \times [0, \bar{L}]$.

The proof is given in appendix A.3.10. Note that the median voter's income is not differentiable at the values of τ and L_B where $DNT = 0$. With these results, we now move on to the second part of the median voter's maximization problem concerning the level of τ and the amount of basic research investments. Using Lemma A.3, the median voter will seek the maximum of a continuous function over a compact set. Hence, by the Weierstrass extreme value theorem, the maximum will be attained in $[\underline{\tau}, \overline{\tau}] \times \left[0, \bar{L}\right]$. However, the set of maximizers may not be single-valued. For this purpose, it is instructive to discuss some properties of the median voter's income maximization problem by approaching it in the two-step procedure used in the main text.

Consider the optimization of the median voter's income (3.17) with respect to τ for given basic research investments L_B:

$$\max_{\tau \in [\underline{\tau}, \overline{\tau}]} \quad I(\tau, L_B) = w(\tau, L_B)\left[1 + s\left(\frac{\alpha}{1-\alpha} l_y(\tau, L_B) - m_l\right)\right] + NT(\tau, L_B)\ . \quad \text{(A.11)}$$

Regarding a marginal increase in τ at values of τ (and L_B), where $DNT \neq 0$, the median voter's income is affected as follows:[11]

$$\frac{dI(\tau, L_B)}{d\tau} = \frac{\partial NT}{\partial \tilde{t}_P}\frac{\partial \tilde{t}_P(\tau, L_B)}{\partial \tau} + \frac{\partial NT}{\partial \tilde{t}_L}\frac{\partial \tilde{t}_L(\tau, L_B)}{\partial \tau} + \frac{\partial I(\tau, L_B)}{\partial l_E}\frac{\partial l_E}{\partial \tau}\ . \quad \text{(A.12)}$$

Note that for an interior solution τ of the problem displayed in (A.11) $\frac{dI(\tau, L_B)}{d\tau}$ must be zero, if it is not equal to the critical values of τ associated with $DNT = 0$. An increase in τ has two effects: it increases the relation between labor and profit taxes and it (weakly) increases the number of entrepreneurs. The first two summands in (A.12) reflect the decline of redistribution from profits to labor income due to the comparatively lower profit taxes. Note that one of the summands is zero, as either $\tilde{t}_P$ or $\tilde{t}_L$ remains at the boundary of the feasible set $[\underline{t}, \overline{t}]$. The last term in (A.12) captures the effect of an increase in the

[11] Note that the terms $\frac{\partial \tilde{t}_P(\tau, L_B)}{\partial \tau}$ and $\frac{\partial \tilde{t}_L(\tau, L_B)}{\partial \tau}$ differ according to the different cases in Table A.1. At the critical values τ_c, as defined in the proof of Lemma A.3, and $\tau = 1$, equation (A.12) can still be used when we refer to the right-sided derivatives.

number of entrepreneurs on the median voter's income.[12] In the case where entrepreneurship is efficient, i.e. $\chi(L_B) > 1$, an increase in entrepreneurship will increase profits and total output but will lead to a lower wage rate. Consequently, a median voter with a small amount of stocks faces the following trade-off regarding τ: On the one hand, a marginally higher level of τ via a decline of t_P will lower her gross income (as the wage payments are the major income source) and lower the share of profits redistributed.[13] On the other, a larger τ will increase total output and with it the tax base for profit tax. This reflects a standard Laffer-curve trade-off.

As the set of maximizers may contain several values for τ, we cannot proceed as in section 3.5.2 and appendix A.1.1 by defining a function $\tau(L_B)$, inserting it back into the objective function, and then solving for the optimal value of L_B. Instead, we have to derive the correspondence $L_B(\tau)$ that maximizes the median voter's income with respect to L_B for a given level of τ. Optimal policy candidates for the median voter will lie in the intersection between the two correspondences $\tau(L_B)$ and $L_B(\tau)$. Those with the highest income level will then constitute the median voter's preferred policies.

A.2.3. Details on the numerical illustration

We consider an economy with population $\bar{L} = 20$, which represents the total labor force. To calibrate our model, we assume the following concave functional form for $\eta(L_B)$: $\eta(L_B) = (L_B/\bar{L})^{\beta}$. For a complete numerical specification, five parameter values need to be specified: α, β, γ, b, and m. We calibrate these parameters such that an entrepreneurial economy with positive basic research and entrepreneurship exhibits some average key characteristics of OECD member states observed from the data. We start by requiring that total investments in basic research amount to a share of 0.33% of GDP, which corresponds to the simple average of basic research intensities in OECD member states.[14] This yields the following condition:

$$(1-\alpha)\frac{L_B}{L_y} = 0.0033 \ . \tag{A.13}$$

Next we turn our attention to entrepreneurship. In our model entrepreneurship is innovative. We therefore choose L_E according to:

$$L_E = 0.0425\bar{L} \ , \tag{A.14}$$

[12] Note that for small values of L_B and τ, L_E will remain at zero in response to a marginal increase in τ.

[13] Obviously, if τ is increased via an increase of t_L rather than a decrease of t_P, a higher share of labor income is redistributed to entrepreneurs.

[14] *Source*: Own calculations based on OECD (2012a). The data refers to centered 5-year moving averages in 2006 and was downloaded in June 2013.

where 4.25% is the average share of the labor force engaged in opportunity-driven entrepreneurial activities.[15] We combine these requirements with information on output shares of intermediate goods and of labor to derive the standard production technology for intermediates in our economy. In particular, we follow Jones (2011) in requiring that in our entrepreneurial economy the output share of intermediates be 0.5. With all intermediates selling at price $p(i) = mw$, this corresponds to the following condition:

$$(1-\alpha)\frac{m}{L_y} = 0.5 \; . \tag{A.15}$$

Concerning labor income shares, we refer to data provided by the EU KLEMS project and require that:[16,17]

$$(1-\alpha)\frac{L_y + L_x + L_B}{L_y + (1-\alpha)L_B} = 0.628 \; . \tag{A.16}$$

From the labor market clearing condition we obtain:

$$L_y + L_x + L_B = \bar{L} - L_E \; .$$

Combining this result with equations (A.13) to (A.16) and solving for m, yields:

$$m \approx 15.2 \; .$$

Next we require that output in the entrepreneurial economy be 5.7% larger than in the stagnant economy:[18]

$$\left[\frac{L_y}{\bar{L} - m}\right]^{1-\alpha} = 1.057 \; . \tag{A.17}$$

From equation (A.15) we can replace L_y by $2m(1-\alpha)$, yielding:

$$\left[\frac{2(1-\alpha)m}{\bar{L} - m}\right]^{1-\alpha} = 1.057 \; .$$

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[15] *Source*: Own calculations based on Global Entrepreneurship Monitor (2013). The data refers to centered 5-year moving averages in 2006. The definition by GEM: 'improvement-driven opportunity entrepreneurial activity'. The data was downloaded in July 2013.

[16] *Source*: Own calculations based on EU KLEMS (2011). The value of 0.628 is the average labor income share in OECD countries considered in the EU KLEMS database in year 2005 (centered 5-year moving averages have been used). The labor income share has been computed as $\frac{\text{labor compensation}}{\text{labor compensation + capital compensation}}$. The data was downloaded in July 2013.

[17] To mimic labor shares observed from the data, we add basic research investments to both labor income and final-good production when computing the labor share in our model, as basic research represents government expenditures. We note that using the labor share in the private sector alone, $\frac{w[L_y+L_x]}{y}$, would yield a very similar calibration.

[18] A 5.7% increase corresponds to the average total factor productivity growth for the OECD members included in the EU KLEMS database for the period 1996 to 2006. *Source*: Own calculations based on EU KLEMS 2011. The data was downloaded in July 2013.

With the solution for m given above, we can solve this equation numerically for α to obtain:

$$\alpha \approx 0.79 \ .$$

We now turn to b, β, and γ, the parameters characterizing entrepreneurship and innovation in our economy. We need three conditions to calibrate these parameters. An initial condition follows directly from the use of our previously derived results in the labor market clearing condition:

$$L_y = \bar{L} - L_B - m + L_E \left[\chi(L_B) - 1\right] \ . \tag{A.18}$$

With the previous parameter values, this condition pins down the expected amount of labor savings by an additional entrepreneur, $\chi(L_B)$. Setting $\tau = 1.01$, which is in line with effective tax rates for OECD member countries,[19] we obtain the value for $b \approx 2.31$ from the equilibrium condition for L_E:[20]

$$L_E = 1 - \frac{1}{\tau\chi(L_B)b} \ . \tag{A.19}$$

Finally, we have to specify β and γ. Those parameter values are calculated to match both the value of $\chi(L_B)$ derived previously and empirical evidence on mark-ups presented by Roeger (1995) and Martins et al. (1996). In line with this evidence, we require intermediate-good producers to charge on average a mark-up of 1.2, i.e. we require:

$$\frac{1}{\gamma} L_E \eta(L_B) = 1.2 \ .$$

This gives us the values $\gamma \approx 0.16$ and $\beta \approx 0.28$.

A.2.4. Alternative numerical illustrations

In this part of the appendix we report alternative numerical scenarios. In the main text we have argued that higher upper bounds on tax rates make it easier to align efficiency and equality in our economy, thereby increasing political support for growth-oriented entrepreneurial policies. We have illustrated this result with the numerical example shown in Figure 3.2.

Higher tax bounds increase political support for growth policies because they allow for a stronger redistribution of the gains from innovation. Of course, if the median voter has

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[19] *Source*: Own calculations based on Djankov et al. (2010). The data was downloaded in April 2014.

[20] Note that this value for b implies that the aggregate immaterial utility from being an entrepreneur is positive, i.e. that, on average, entrepreneurs like being entrepreneurs, although some entrepreneurs dislike being entrepreneurs, in line with empirical evidence previously cited (cf. footnote 14 in chapter 3).

Figure A.1.: Illustration of politically feasible entrepreneurial policies: $s = 0$

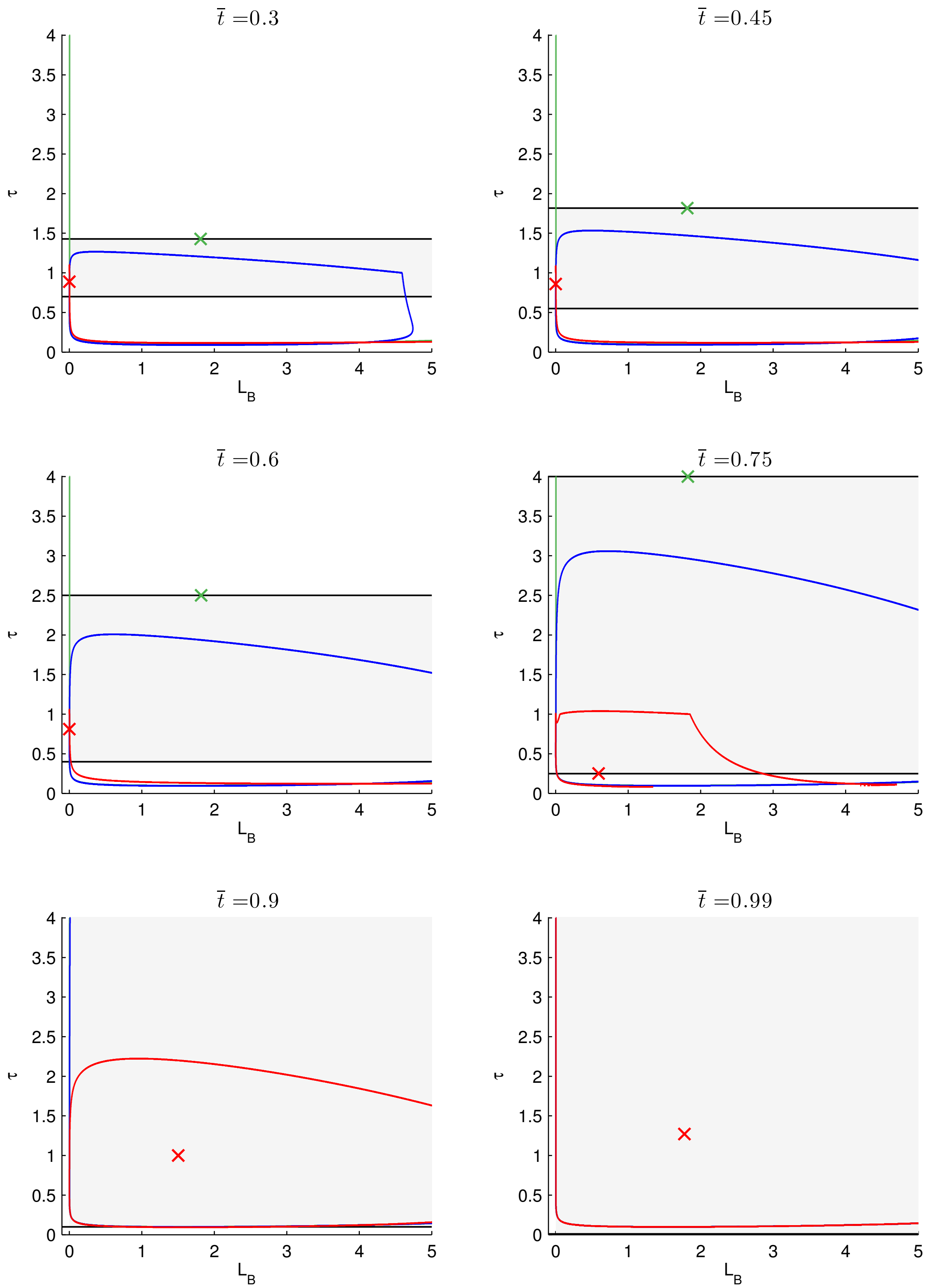
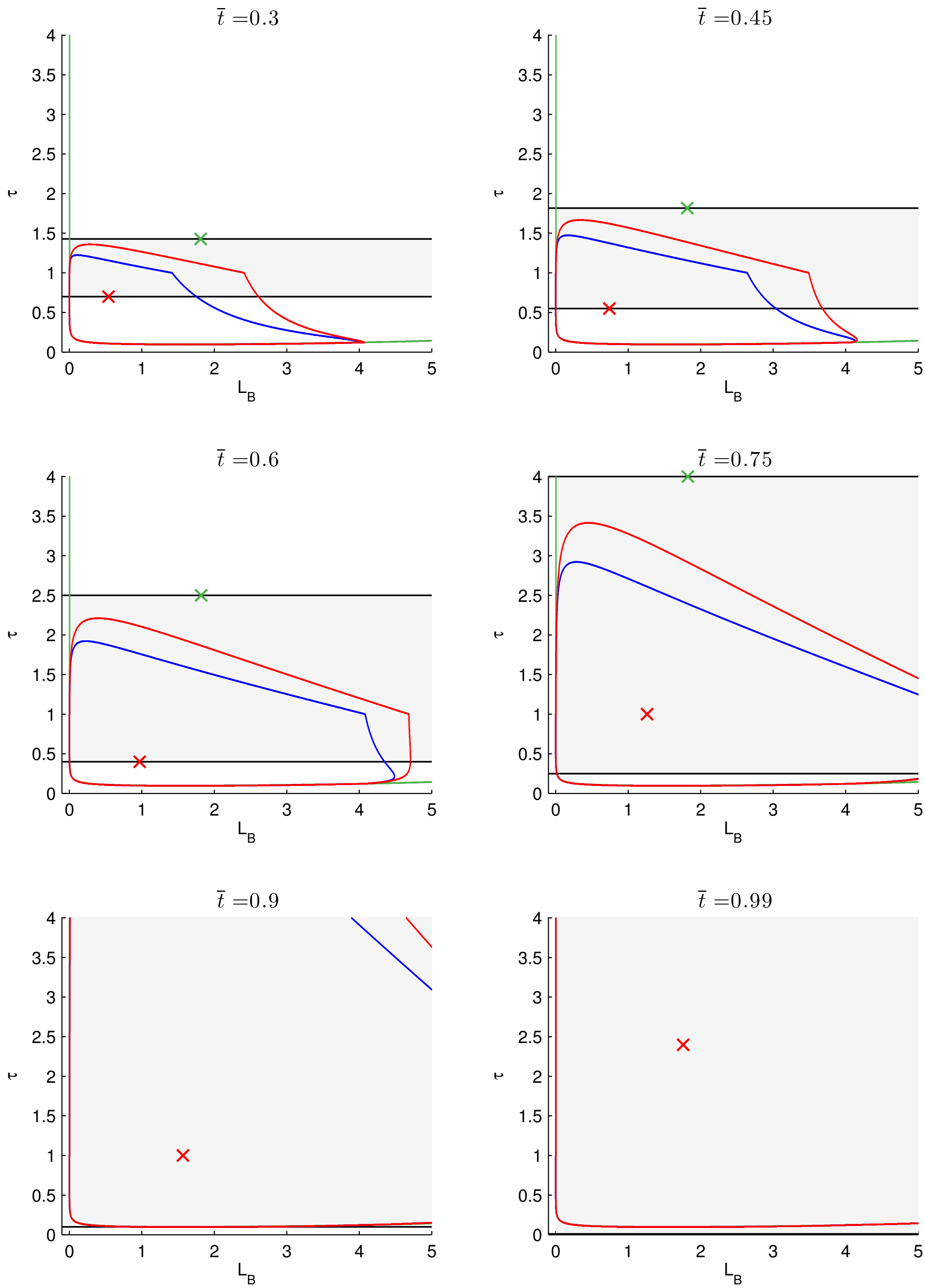


Figure A.2.: Illustration of politically feasible entrepreneurial policies: $s = 1$



more shareholdings, then she has greater direct participation in the gains from innovation, and there is less need for redistribution via tax policies. Hence, as the shares of the median voter increase, she will support more growth-oriented policies for the same level of upper tax bounds $\bar{t}$. We illustrate this observation in Figures A.1 and A.2, where we assume values of $s = 0$ and $s = 1$, respectively. Indeed, a voter with no shares will only prefer some growth-oriented policy over the stagnant economy for high levels of $\bar{t}$. In fact, for low levels of $\bar{t}$, her most-preferred policy is an inefficient entrepreneurial policy, where aggregate output is lower than in the stagnant economy and thus wages are higher. By contrast, a voter with $s = 1$ (i.e. a voter with per-capita shares) will prefer a broad range of growth-oriented entrepreneurial policies to the stagnant economy. Moreover, her most-preferred policy is one with growth-stimulating investments in basic research, even for very low levels of $\bar{t}$.

A.2.5. Constitutional design

In this part of the appendix, we discuss constitutional design behind the veil of ignorance. Specifically, suppose that households decide on $\bar{t}$ without knowing their individual shareholdings but only the distribution from which these shareholdings will be drawn. This distribution is the same for all households, i.e. households own the per-capita shares in expectation. For simplicity, suppose further that they are aware of their immaterial utilities from being an entrepreneur. Let $\bar{L} > 2$, i.e. let the majority of the population be workers. Then workers will choose $\bar{t}$ to maximize their expected income under the policy preferred by the median voter.[21] As before, let $s < 1$, i.e. after the veil of ignorance has been resolved the median voter owns less than the per-capita shares. Then ex-ante workers will not care about the distribution of final-good producer's profits, only about aggregate income and the distribution thereof between workers and entrepreneurs. By contrast, the ex-post median voter will also care about distribution of final-good producer's profits. In essence, agents with (expected) $s = 1$ set $\bar{t}$ to guide the subsequent policy choice by a median voter with $s < 1$. In principle, we have to distinguish two cases, depending on whether or not the median voter with $s \leq 1$ can earn $\bar{y}_{opt}$, the per-capita income in the output-maximizing entrepreneurial economy, or even more. We limit our attention to the more realistic case where this is not feasible.[22]

[21] Recall that households are risk-neutral.

[22] If the median voter owns less than the per-capita shares of the final-good producer, she can only receive an income of $\bar{y}_{opt}$ or more if entrepreneurs receive less income than workers on average (she can never have an income exceeding the average worker's income). Formally, we must have $(1 - t_P)\chi(L_B)w < (1 - t_L)w$, i.e. entrepreneurs are taxed sufficiently more heavily than workers such that net income is redistributed from entrepreneurs to workers. With $\chi(L_B) > 1$ in any growth-oriented entrepreneurial economy, this requires $\tau < 1$, i.e. tax policies dis-incentivize entrepreneurship, so this economy is

Suppose $\bar{t}$ is chosen arbitrarily close to 1 at the constitutional stage, i.e. $\bar{t} = 1 - \varepsilon$ for some arbitrarily small $\varepsilon > 0$. Then, by choosing t_L, t_P arbitrarily close to 1 with $t_L > t_P$, the ex-post median voter can earn an income that is arbitrarily close to $\bar{y}_{opt}$. Given that it is not possible for her to earn $\bar{y}_{opt}$, she will implement this policy. This is ex-ante desired by the worker as it maximizes the cake and fully redistributes entrepreneurial profits. We conclude that in the constitutional design phase workers will choose $\bar{t} = 1 - \varepsilon$, the largest possible upper bound on taxation. As in Proposition 3.4, choosing $\bar{t} = 1 - \varepsilon$ helps resolve the conflict between efficiency and equality. For $\bar{t} = 1 - \varepsilon$, the higher redistribution incentive for a voter with $s < 1$ will not compromise efficiency.[23] The optimality of maximal constitutional freedom for tax policies adds a new perspective to the literature, which has hitherto emphasized constitutional tax constraints.[24]

A.3. Proofs

A.3.1. Proof of Lemma 3.1

We prove each part of Lemma 3.1 separately.

(i) We consider innovative and non-innovative intermediate-good producers separately.

Intermediate goods in non-innovative industries are produced using the freely available standard technology. Perfect competition implies that these intermediate goods are sold at cost in equilibrium, i.e. non-innovative intermediate-good producers will offer their goods at price $p(i) = mw$.

The production costs of innovative intermediate-good producers are reduced to γmw.

inefficient when compared to the output-maximizing economy yielding $\bar{y}_{opt}$. Hence, for the median voter to receive income larger than $\bar{y}_{opt}$, the redistribution of net income from entrepreneurs to workers must be large enough to overcompensate for the loss in efficiency arising from the decrease in productive entrepreneurship due to $\tau < 1$. If b is very large, this is possible in principle, as then the decrease in τ has only a small negative effect on entrepreneurship. However, this may not be the most realistic scenario, and we therefore ignore it here.

[23] Note that this rationale also implies that in the constitutional design phase workers will choose $\bar{t} = 1 - \varepsilon$, the largest possible upper bound on taxation. The lower $\bar{t}$ is, the more the median voter will compromise efficiency for more redistribution of the (final-good producer's) profits in her optimal policy choice.

[24] Cf. Brennan and Buchanan (1977) and Gradstein (1999) and the discussion in section 3.2. Note, however, that in our model $\bar{t} = 1 - \varepsilon$ is no longer optimal in general if the ex-post median voter can receive income larger than $\bar{y}_{opt}$ or if she holds s shares with $s > 1$. Then the median voter's ex-post interest in the redistribution of final-good producers' profits is different from the optimal solution for a worker with $s = 1$. Similarly, additional effects have to be taken into account if entrepreneurial talent is also behind the veil of ignorance in the constitutional stage. In this case, households care about maximizing aggregate welfare including the immaterial costs and benefits of being an entrepreneur (cf. section A.1.2) when choosing $\bar{t}$. Depending on parameter values, $\bar{t} = 1 - \varepsilon$ may or may not be optimal in this case.

These firms are still confronted with competition from non-innovative intermediate-good producers in their industry. Taken together, this implies that an innovative intermediate-good producer will charge a price $p(i) = \delta_i mw$ with $\delta_i \in [\gamma, 1]$. We show by contradiction that $\delta_i \in [\gamma, 1)$ cannot be optimal. In particular, we show that no symmetric equilibria exist in which all innovative intermediate-good producers charge the common price $p(i) = \delta mw$, with $\delta \in [\gamma, 1)$.[25]

Let us define $\tilde{X} := \int_{i|p(i)=\delta mw} x(i)^\alpha di$ and $\hat{X} := \int_{i|p(i)=mw} x(i)^\alpha di$. This enables us to write the maximization problem of the final-good producer as:

$$\begin{aligned} \max_{L_y, X} \pi_y &= L_y^{1-\alpha}(\tilde{X} + \hat{X}) - wL_y - \delta mw\tilde{X} - mw\hat{X} \\ &= \tilde{X}(L_y^{1-\alpha} - \delta mw) + \hat{X}(L_y^{1-\alpha} - mw) - wL_y \,. \end{aligned} \tag{A.20}$$

As $\delta < 1$, $L_y^{1-\alpha} - \delta mw > 0$ is a necessary condition for non-negative profits for the final-good producer with positive output. $L_y^{1-\alpha} - \delta mw$ is the net marginal benefit of the final-good producer from using intermediate good $x(i)$ offered at price $p(i) = \delta mw$ in production. Hence $L_y^{1-\alpha} - \delta mw > 0$ implies first that if the final-good producer is operating, he will always demand $x(i) = 1$ of every intermediate offered at price $p(i) = \delta mw$, and second, that the innovative intermediate-good producer i would want to set a price $\tilde{p}(i) = \delta mw + \epsilon$, $\epsilon > 0$ but small, such that $L_y^{1-\alpha} - \tilde{p}(i) > 0$. Then the net marginal benefit of the final-good producer from using intermediate good $x(i)$ in production remains positive. Furthermore, given that each intermediate-good producer has measure 0, it would not affect the profitability of the representative final-good firm. Hence the final-good firm would still demand $x(i) = 1$, a contradiction to $p(i) = \delta mw$ being profit-maximizing for intermediate-good producer i.

The contradiction establishes the result.

(ii) Let us define $X := \int_0^1 x(i)^\alpha di$. X assumes the value 0 if $x(i) = 0 \, \forall \, i$, 1 if $x(i) = 1 \, \forall \, i$, and values between 0 and 1 only if a subset of the varieties is used. If $p(i) = mw \, \forall \, i$, the maximization problem of the final-good producer can be written as:

$$\max_{L_y, X} \pi_y = L_y^{1-\alpha} X - wL_y - mwX = X(L_y^{1-\alpha} - mw) - wL_y \,. \tag{A.21}$$

Hence the profit function is linear in X. A necessary condition for non-negative profits is $L_y^{1-\alpha} - mw > 0$. Hence $X = 1$ is profit-maximizing if the final-good producer is operating.

□

[25] It is straightforward to verify that no non-symmetric equilibrium exists with $\delta_i < 1$ for any value of i.

A.3.2. Proof of Proposition 3.1

From Lemma 3.1 and the explanations in the main text we know that, if condition (PPC) is satisfied, the final-good producer is operating and using all varieties of the intermediate goods in production. Conversely, if condition (PPC) is not satisfied, he is not operating. From this follows $L_E^e = L_x^e = L_y^e = 0$ and zero profits. We now need to show that in case (i) the other variables take on the unique equilibrium values stated in the Proposition.

(i) Conditions (1), (2), (4), and (7) have been derived in the main text. Condition (3) follows from using L_E^e and L_x^e in the labor market clearing condition. Combining w^e with the observation that $p(i) = mw \; \forall \, i$ yields condition (5). Condition (6) follows from $x(i) = 1 \; \forall \, i$ and the production technology in the final-good sector. Finally, condition (8) follows from using w^e in the expression for profits of a monopolistic intermediate-good producer.

□

A.3.3. Proof of Corollary 3.1

By Proposition 3.3 there will be an entrepreneurial economy if and only if condition (PLS) is satisfied. In response to a change in m, b, $\overline{\tau}$, or γ, the government could leave $\tilde{L}_B(\overline{\tau})$ unaffected. Hence, if it opts for a $\hat{\tilde{L}}_B(\overline{\tau}) \neq \tilde{L}_B(\overline{\tau})$, then we must have $c\left(\overline{\tau}, \hat{\tilde{L}}_B(\overline{\tau})\right) \geq c\left(\overline{\tau}, \tilde{L}_B(\overline{\tau})\right)$, which implies:

$$\begin{aligned} &-\hat{\tilde{L}}_B(\overline{\tau}) + \left[1 - \frac{1}{\overline{\tau}\chi\left(\hat{\tilde{L}}_B(\overline{\tau})\right)b}\right]\left[\chi\left(\hat{\tilde{L}}_B(\overline{\tau})\right) - 1\right] \geq \\ &-\tilde{L}_B(\overline{\tau}) + \left[1 - \frac{1}{\overline{\tau}\chi\left(\tilde{L}_B(\overline{\tau})\right)b}\right]\left[\chi\left(\tilde{L}_B(\overline{\tau})\right) - 1\right] \, . \end{aligned}$$

A proof then follows from the fact that for a given $\tilde{L}_B(\overline{\tau})$:

$$\left[1 - \frac{1}{\overline{\tau}\chi\left(\tilde{L}_B(\overline{\tau})\right)b}\right]\left[\chi\left(\tilde{L}_B(\overline{\tau})\right) - 1\right]$$

is increasing in m, b, and $\overline{\tau}$ and decreasing in γ as $\chi\left(\tilde{L}_B\left(\overline{\tau}\right)\right) = m(1-\gamma)\eta\left(\tilde{L}_B\left(\overline{\tau}\right)\right)$.

□

A.3.4. Proof of Proposition 3.4

By using (3), (4), and (6) from Proposition 3.1(i), income per capita can be written as:

$$\bar{y} := \frac{y}{\bar{L}} = w\left[1 + \frac{\alpha}{1-\alpha}l_y - m_l + l_E(\chi(L_B) - 1) - l_B\right] , \tag{A.22}$$

where we use $l_y := \frac{L_y}{\bar{L}}$, $m_l := \frac{m}{\bar{L}}$, and $l_E := \frac{L_E}{\bar{L}}$ to denote per-capita variables. In the stagnant economy, this reduces to:

$$\bar{y}^S = \frac{y^S}{\bar{L}} = w^S\left[1 + \frac{\alpha}{1-\alpha}l_y^S - m_l\right] , \tag{A.23}$$

where we use a superscript ^{S} to denote variable values in the stagnant economy. Substituting (3.19) in (3.17), the value of the median voter's income is:

$$I = w\left[1 + (\frac{\alpha}{1-\alpha}l_y - m_l)(s + t_P(1-s)) + l_E(t_P\chi(L_B) - t_L) - l_B\right] ,$$

which reduces to:

$$I^S = w^S\left[1 + \left(\frac{\alpha}{1-\alpha}l_y^S - m_l\right)(s + t_P^S(1-s))\right]$$

in the stagnant economy. Due to the assumption $s < 1$, the median voter maximally redistributes profits $t_P^S = \bar{t}$ in the stagnant economy.[26]

Consider any policy $(\hat{\tau}, \hat{L}_B)$ for which $\hat{\bar{y}} > \bar{y}^S$ (such a policy necessarily implies $\hat{L}_B > 0$ and $\hat{L}_E > 0$). With $s < 1$, we have a condition where $I^S \leq \bar{y}^S$. Hence it suffices to show that for $(\hat{\tau}, \hat{L}_B)$ we can find a $\bar{t}$ such that $\hat{I} > \bar{y}^S$. Note that $\lim_{t_P \to 1, t_l \to 1} \hat{I} = \hat{\bar{y}}$. Since $\hat{\bar{y}} > \bar{y}^S$, the assertion of Proposition 3.4 follows from the fact that for any $\delta > 0$ we can find a pair $(t_P, t_L) \ll (1, 1)$ yielding $\hat{\tau}$ and satisfying $\hat{\bar{y}} - \hat{I} \leq \delta$.

□

A.3.5. Proof of Proposition 3.5

To show the result, note first that the restriction $s \leq \frac{\bar{L}}{\bar{L}+(1-\gamma)m}$ is a sufficient condition for the negative derivative of the median voter's gross income with respect to L_y. The restriction $s \leq \frac{\bar{L}}{\bar{L}+(1-\gamma)m}$ follows from the fact that $L_y < \bar{L} - \gamma m$.

Now suppose that $\bar{t} = 0$. Then the median voter's income corresponds to her gross income

[26] Note that labor tax does not affect the median voter's income in the stagnant economy as all individuals are workers. The population only differs with respect to their shareholdings in the final-good firm.

minus her share of the cost involved in providing basic research. In such circumstances, she will strictly prefer the stagnant economy over the entrepreneurial economy.[27] The result then follows from the continuity of the median voter's income, implying that she will also prefer the stagnant economy for sufficiently small $\bar{t} > 0$.

□

A.3.6. Proof of Proposition 3.6

Fix any entrepreneurial policy $(\hat{\tau}, \hat{L}_B)$ with $\hat{L}_y \geq L_y^S$. From Proposition 3.4 we know that for $\bar{t} = 1 - \varepsilon$, the following two conditions are satisfied:

1. $\hat{\tau} \in [\underline{\tau}, \overline{\tau}]$,
2. the median voter with $s \leq \frac{\bar{L}}{\bar{L}+(1-\gamma)m}$ will prefer the entrepreneurial policy $(\hat{\tau}, \hat{L}_B)$ over the stagnant economy.

From Proposition 3.5 we know that for $\bar{t}$ small the median voter supports the stagnant economy, implying that at least one of the two conditions above is no longer satisfied. Accordingly, it remains to be shown that for every entrepreneurial policy $(\hat{\tau}, \hat{L}_B)$ there exists a unique threshold level $\bar{t}_c$ such that both conditions above are satisfied if and only if $\bar{t} \geq \bar{t}_c$.

For every $\hat{\tau} \in (0,1)$ there exists a unique $\bar{t}_c^1$ such that $\hat{\tau} \in [\underline{\tau}, \overline{\tau}]$ if and only if $\bar{t} \geq \bar{t}_c^1$. Hence we can limit our attention to $\bar{t} \geq \bar{t}_c^1$, and the result follows if we can show that $\hat{I} - I^S$ is monotonic in $\bar{t}$.[28] Note that a decrease in $\bar{t}$ such that $\bar{t} \geq \bar{t}_c^1$ will only change net transfers but not the median voter's gross income. Thus we can limit our attention to the derivative of NT with respect to $\bar{t}$ for $\hat{\tau}$ and $\hat{L}_B$ given. In the stagnant economy we have:[29]

$$\frac{\partial NT^S}{\partial \bar{t}} = w^S \left[\left(\frac{\alpha}{1-\alpha} l_y^S - m_l \right) (1-s) \right] \geq 0 \, .$$

Note that $\frac{\partial NT^S}{\partial \bar{t}}$ is constant. The monotonicity of $\hat{I} - I^S$ then follows from $\left. \frac{\partial NT}{\partial \bar{t}} \right|_{\substack{\hat{\tau} \\ \hat{L}_B \\ \bar{t} \geq \bar{t}_c^1}}$ being constant as well. We will show that this holds for each of the four cases outlined in Table A.1 of appendix A.2.2.

---

[27] Note that in the entrepreneurial economy $L_y \geq L_y^S$ and $L_B > 0$.

[28] As we show below, $\hat{I} - I^S$ can be monotonically increasing or decreasing. Obviously, if it is monotonically decreasing then we must have $\bar{t}_c = \bar{t}_c^1$.

[29] Note that we always have $1 \in [\underline{\tau}, \overline{\tau}]$. Hence, by Assumption 3.1, the stagnant economy is always feasible, irrespective of $\bar{t}$.

$\boldsymbol{DNT < 0, \hat{\tau} \geq 1}$ Not possible as $\hat{L}_y \geq L_y^S$ implies $\chi(\hat{L}_B) > 1$ and $s \leq \frac{\bar{L}}{\bar{L}+(1-\gamma)m} < 1$.

$\boldsymbol{DNT < 0, \hat{\tau} < 1}$ The median voter optimally chooses $\hat{t}_L = \underline{t} = 0$ and $\hat{t}_P = 1 - \hat{\tau}$ implying that:

$$\left.\frac{\partial NT}{\partial \bar{t}}\right|_{\substack{\hat{\tau} \\ \hat{L}_B \\ \bar{t} \geq \bar{t}_c^1}} = 0 \, ,$$

so $\hat{I} - I^S$ is monotonically decreasing in $\bar{t}$.[30]

$\boldsymbol{DNT \geq 0, \hat{\tau} \geq 1}$ The median voter optimally chooses $\hat{t}_L = \bar{t}$ and $\hat{t}_P = 1 - \hat{\tau}(1 - \bar{t})$. Hence the derivative of net transfers in the entrepreneurial economy with respect to $\bar{t}$ writes:

$$\left.\frac{\partial NT}{\partial \bar{t}}\right|_{\substack{\hat{\tau} \\ \hat{L}_B \\ \bar{t} \geq \bar{t}_c^1}} = \hat{w}\left[\hat{\tau}\left((\frac{\alpha}{1-\alpha}\hat{l}_y - m_l)(1-s) + \chi(\hat{L}_B)\hat{l}_E\right) - \hat{l}_E\right] \, ,$$

which is constant, implying that $\hat{I} - I^S$ is monotonic in $\bar{t}$.[31]

$\boldsymbol{DNT \geq 0, \hat{\tau} < 1}$ The median voter optimally chooses $\hat{t}_L = 1 - (1 - \bar{t})/\hat{\tau}$ and $\hat{t}_P = \bar{t}$, yielding the following derivative of net transfers in the entrepreneurial economy:

$$\left.\frac{\partial NT}{\partial \bar{t}}\right|_{\substack{\hat{\tau} \\ \hat{L}_B \\ \bar{t} \geq \bar{t}_c^1}} = \hat{w}\left[\left(\frac{\alpha}{1-\alpha}\hat{l}_y - m_l\right)(1-s) + \chi(\hat{L}_B)\hat{l}_E - \frac{\hat{l}_E}{\hat{\tau}}\right] \, .$$

Again, $\left.\frac{\partial NT}{\partial \bar{t}}\right|_{\substack{\hat{\tau} \\ \hat{L}_B \\ \bar{t} \geq \bar{t}_c^1}}$ is constant, implying that $\hat{I} - I^S$ is monotonic in $\bar{t}$.

□

[30] Note that $\left.\frac{\partial NT}{\partial \bar{t}}\right|_{\substack{\hat{\tau} \\ \hat{L}_B \\ \bar{t} \geq \bar{t}_c^1}} = 0$, $\frac{\partial NT^S}{\partial \bar{t}} \geq 0$ and Proposition 3.4 imply that in the case considered here the median voter will prefer the entrepreneurial economy over the stagnant economy whenever both are feasible, i.e. we have $\bar{t}_c = \bar{t}_c^1 = 1 - \hat{\tau}$.

[31] In fact, we have $\bar{t}_c > \bar{t}_c^1$. This follows from $t_P = 0$ and hence $NT < 0$ for $\hat{\tau} = \overline{\tau}$. Note that this also implies that $\hat{I} - I^S$ is monotonically increasing.

A.3.7. Proof of Proposition A.1

To prove Proposition A.1, we need to show that $\overline{\tau}_O(L_B)$ and $\underline{\tau}_O(L_B)$ correspond to the taxation pecking orders described in the main text. We prove Proposition A.1 (i) by contradiction. Part (ii) can be shown using a similar argument.

(i) We first note that $L_B > L_{B,min}$ implies that if $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ satisfies condition (PPC), then so does any $\left(t'_L, t'_P, \hat{L}_B\right)$ satisfying $\frac{1-t'_P}{1-t'_L} \geq \frac{1-\hat{t}_P}{1-\hat{t}_L}$.

Let $TR(t_L, t_P, L_B)$ denote tax revenues in working hour equivalents given t_L, t_P, and L_B. Consider a policy choice $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ that satisfies (PPC) with $\hat{t}_P > 0$ and $\hat{L}_B > L_{B,min}$. Suppose there exists $\hat{\hat{t}}_L > \hat{t}_L$ such that $TR\left(\hat{\hat{t}}_L, \hat{t}_P, \hat{L}_B\right) > TR\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$. Then, by continuity of TR in t_L and t_P, it is possible to finance $\hat{L}_B$ using some alternative financing scheme (t'_L, t'_P) satisfying:

$$\begin{aligned} t'_L &= \hat{t}_L + \Delta_1\,, \quad \Delta_1 \geq 0, \text{ but small enough for } t'_L \leq \bar{t}_L \\ t'_P &= \hat{t}_P - \Delta_2\,, \quad \Delta_2 \geq 0, \text{ but small enough for } t'_P \geq 0 \\ \frac{1-t'_P}{1-t'_L} &> \frac{1-\hat{t}_P}{1-\hat{t}_L}\,. \end{aligned}$$

In particular, depending on whether $\frac{\partial TR}{\partial t_L}$ and $\frac{\partial TR}{\partial t_P}$, respectively, are smaller or larger than 0, the following alternative financing schemes satisfy the above conditions:

1. Suppose $\left.\frac{\partial TR}{\partial t_L}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} < 0$ or $\left(\left.\frac{\partial TR}{\partial t_L}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} = 0 \text{ and } \left.\frac{\partial^2 TR}{(\partial t_L)^2}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} < 0\right)$. By our assumption there exists $\hat{\hat{t}}_L > \hat{t}_L$ such that $TR\left(\hat{\hat{t}}_L, \hat{t}_P, \hat{L}_B\right) > TR\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$. Then by continuity of TR in t_L there exists a $t'_L > \hat{t}_L$ satisfying $TR\left(t'_L, \hat{t}_P, \hat{L}_B\right) = TR\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$. We conclude that there exists $\Delta_1 > 0$ and $\Delta_2 = 0$ satisfying the conditions stated above.

2. Suppose $\left.\frac{\partial TR}{\partial t_P}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} < 0$ or $\left(\left.\frac{\partial TR}{\partial t_P}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} = 0 \text{ and } \left.\frac{\partial^2 TR}{(\partial t_P)^2}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} > 0\right)$. We show that for given $\hat{t}_L$ and $\hat{L}_B$, TR is minimized at $t_P = 0$. Then it follows from continuity of TR in t_P that there exists a $t'_P < \hat{t}_P$ satisfying $TR\left(\hat{t}_L, t'_P, \hat{L}_B\right) = TR\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$. Hence there exist $\Delta_1 = 0$ and $\Delta_2 > 0$ satisfying the conditions stated above.

   To show that TR is minimized at $t_P = 0$ for given $\hat{t}_L$ and $\hat{L}_B$, note first that L_E is non-increasing in t_P. Hence the term $(\bar{L} - L_E)t_L$ is non-decreasing in t_P. Furthermore, all values $t_P < \hat{t}_P$ satisfy condition (PPC), so we have:

$$t_P \left[\frac{\alpha}{1-\alpha} L_y - m + L_E \chi(L_B) \right] \geq 0 \ .$$

We conclude that TR is indeed minimized at $t_P = 0$ for given $\hat{t}_L$ and $\hat{L}_B$.

3. Finally, suppose $\left.\frac{\partial TR}{\partial t_L}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} > 0$ or $\left(\left.\frac{\partial TR}{\partial t_L}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} = 0 \text{ and } \left.\frac{\partial^2 TR}{(\partial t_L)^2}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} > 0 \right)$ and
$\left.\frac{\partial TR}{\partial t_P}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} > 0$ or $\left(\left.\frac{\partial TR}{\partial t_P}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} = 0 \text{ and } \left.\frac{\partial^2 TR}{(\partial t_P)^2}\right|_{\substack{t_L=\hat{t}_L \\ t_P=\hat{t}_P \\ L_B=\hat{L}_B}} < 0 \right)$.
Then by continuity of TR in t_L and t_P there exists a tax rate $t'_L > \hat{t}_L$ and $t'_P < \hat{t}_P$ satisfying $TR\left(t'_L, t'_P, \hat{L}_B\right) = TR\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$. We conclude that there exist $\Delta_1 > 0$ and $\Delta_2 > 0$ satisfying the conditions stated above.

As $\frac{1-t'_P}{1-t'_L} > \frac{1-\hat{t}_P}{1-\hat{t}_L}$, $L'_E > \hat{L}_E$.[32] Since $\hat{L}_B > L_{B,min}$ and hence $\chi(\hat{L}_B) > 1$, it follows that $L'_y > \hat{L}_y$, a contradiction to $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ being optimal.

□

A.3.8. Proof of Propositions A.3 and A.4

We prove an extended version of Proposition A.4, also including relevant knife-edge cases. Proposition A.3 follows immediately.

[32] Note that it can never be optimal to finance $L_B > 0$ when occupational choices would lead to $L_E = 0$.

Proposition A.6

The welfare-optimal tax policy can be characterized as follows:

	Case			Tax Policy
1	$L_E^* > 0$	-	-	$t_P^* = \underline{t}_P$, $t_P^* = \bar{t}_P$, $t_L^* = \underline{t}_L$ or $t_L^* = \bar{t}_L$
1.1		$1 - \frac{1}{b} - \frac{L_E^*}{2} > 0$	-	$t_P^* = \underline{t}_P$ and/or $t_L^* = \underline{t}_L$
1.1.1			$L_E^* > 1 - \frac{1-\underline{t}_L}{(1-\underline{t}_P)\chi(L_B^*)b}$	$t_P^* = \underline{t}_P$ and $t_L^* > \underline{t}_L$
1.1.2			$L_E^* = 1 - \frac{1-\underline{t}_L}{(1-\underline{t}_P)\chi(L_B^*)b}$	$t_P^* = \underline{t}_P$ and $t_L^* = \underline{t}_L$
1.1.3			$L_E^* < 1 - \frac{1-\underline{t}_L}{(1-\underline{t}_P)\chi(L_B^*)b}$	$t_P^* > \underline{t}_P$ and $t_L^* = \underline{t}_L$
1.2		$1 - \frac{1}{b} - \frac{L_E^*}{2} = 0$	-	$t_P^* = \underline{t}_P$ and $t_L^* = \bar{t}_L$ or $t_P^* = \bar{t}_P$ and $t_L^* = \underline{t}_L$
1.3		$1 - \frac{1}{b} - \frac{L_E^*}{2} < 0$	-	$t_P^* = \bar{t}_P$ and/or $t_L^* = \bar{t}_L$
1.3.1			$L_E^* > 1 - \frac{1-\bar{t}_L}{(1-\bar{t}_P)\chi(L_B^*)b}$	$t_P^* < \bar{t}_P$ and $t_L^* = \bar{t}_L$
1.3.2			$L_E^* = 1 - \frac{1-\bar{t}_L}{(1-\bar{t}_P)\chi(L_B^*)b}$	$t_P^* = \bar{t}_P$ and $t_L^* = \bar{t}_L$
1.3.3			$L_E^* < 1 - \frac{1-\bar{t}_L}{(1-\bar{t}_P)\chi(L_B^*)b}$	$t_P^* = \bar{t}_P$ and $t_L^* < \bar{t}_L$
2	$L_E^* = 0$	-	-	any feasible t_L^*, t_P^* with $\frac{1-t_L^*}{(1-t_P^*)\chi(L_B^*)b} \geq 1$

A.3.8.1. Proof of Proposition A.6: Part 1

Implied by Proposition A.6.1.1-3.

A.3.8.2. Proof of Proposition A.6: Part 1.1

We prove the result by contradiction.

$0 < L_E < 2(1 - \frac{1}{b})$ implies that the immaterial utility of entrepreneurs in aggregate welfare, $(1 - t_P)\chi(L_B)(1 - \alpha)bL_y^{-\alpha}L_E\left[1 - \frac{1}{b} - \frac{L_E}{2}\right]$, is positive. Now consider a policy choice $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ such that $\hat{t}_L > \underline{t}_L$, $\hat{t}_P > \underline{t}_P$ and $\chi(\hat{L}_B)(2 - b) < \frac{1-\hat{t}_L}{1-\hat{t}_P} < \chi(\hat{L}_B)b$, which is equivalent to $0 < L_E < 2(1 - \frac{1}{b})$. Then the following deviation is feasible:

$$t'_P = \hat{t}_P - \Delta_1\,, \quad \Delta_1 > 0\text{, but small enough for } t'_P \geq \underline{t}_P$$

$$t'_L = \hat{t}_L - \Delta_2\,, \quad \Delta_2 > 0\text{, but small enough for } t'_L \geq \underline{t}_L$$

$$L'_B = \hat{L}_B\,,$$

and where Δ_1 and Δ_2 are chosen to satisfy:

$$\frac{1-\hat{t}_P}{1-\hat{t}_L} = \frac{1-t'_P}{1-t'_L} \, .$$

Then $L'_E = \hat{L}_E$, $L'_y = \hat{L}_y$, and hence $W(t'_L, t'_P, L'_B) > W(\hat{t}_L, \hat{t}_P, \hat{L}_B)$, a contradiction to $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ being a welfare optimum.

□

A.3.8.3. Proof of Proposition A.6: Parts 1.1.1, 1.1.2, 1.1.3

Immediately follow from Proposition A.6.1.1.

A.3.8.4. Proof of Proposition A.6: Part 1.2

We prove the result by contradiction.

Consider a policy choice $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ such that $0 < L_E = 2(1-\frac{1}{b})$ and where $\hat{t}_L$ and $\hat{t}_P$ are not located at opposing boundaries of their respective feasible sets. Then it must be possible to either increase or decrease both tax measures, t_L and t_P. Furthermore, for $L_E = 2(1-\frac{1}{b})$, the following relationship between the partial derivatives of W with respect to t_L, t_P, and L_E holds:

$$\frac{\partial W}{\partial t_P} = -\frac{\partial W}{\partial t_L}\frac{1}{\tau} = -\frac{\partial W}{\partial L_E}\frac{1-t_L}{(1-t_P)^2\chi(L_B)b} \, .$$

As a consequence, $\left.\frac{\partial W}{\partial L_E}\right|_{\substack{\hat{t}_L\\ \hat{t}_P\\ \hat{L}_B}} = 0$ is a necessary condition for $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ to be a welfare optimum. Using $\hat{L}_E = 2(1-\frac{1}{b})$, $\frac{\partial W}{\partial L_E}$ reduces to:

$$\left.\frac{\partial W}{\partial L_E}\right|_{\substack{\hat{t}_L\\ \hat{t}_P\\ \hat{L}_B}} = (1-\alpha)L_y^{-\alpha}\left[(\chi(\hat{L}_B)-1)-(1-\hat{t}_P)\chi(\hat{L}_B)(b-1)\right] \, . \qquad \text{(A.24)}$$

Next, consider the following deviation:

$$\begin{aligned}
t'_P &= \hat{t}_P + \Delta_1 \, , \quad \Delta_1 \neq 0, \text{ but small enough for } \underline{t}_P \leq t'_P \leq \bar{t}_P \\
t'_L &= \hat{t}_L + \Delta_2 \, , \quad \Delta_2 \neq 0, \text{ but small enough for } \underline{t}_L < t'_L < \bar{t}_L \\
L'_B &= \hat{L}_B \, ,
\end{aligned}$$

i.e. t'_L and t'_P are not located at opposing boundaries of there feasible sets, and where Δ_1 and Δ_2 are chosen to satisfy:[33]

$$\frac{1-\hat{t}_P}{1-\hat{t}_L} = \frac{1-t'_P}{1-t'_L} \ .$$

Then $L'_E = \hat{L}_E$, $L'_y = \hat{L}_y$, and hence $W(t'_L, t'_P, L'_B) = W(\hat{t}_L, \hat{t}_P, \hat{L}_B)$, i.e. if $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ is a welfare optimum, so is (t'_L, t'_P, L'_B). Now $\hat{L}_E = 2(1-\frac{1}{b}) > 0$ implies that $b > 1$. Hence, we know from equation (A.24) that if $\left.\frac{\partial W}{\partial L_E}\right|_{\substack{\hat{t}_L \\ \hat{t}_P, \\ \hat{L}_B}} = 0$, then $\left.\frac{\partial W}{\partial L_E}\right|_{\substack{t'_L \\ t'_P \\ L'_B}} \neq 0$ must hold.

This is a contradiction to $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ being a welfare optimum.

□

A.3.8.5. Proof of Proposition A.6: Part 1.3

We prove the result by contradiction.

With $L_E > \max\left\{0, 2(1-\frac{1}{b})\right\}$, the immaterial utility of entrepreneurs in the aggregate welfare, $(1-t_P)\chi(L_B)(1-\alpha)bL_y^{-\alpha}L_E\left[1-\frac{1}{b}-\frac{L_E}{2}\right]$, is negative. Now consider a policy choice $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ such that $\hat{t}_L < \bar{t}_L$, $\hat{t}_P < \bar{t}_P$, and $\frac{1-\hat{t}_L}{1-\hat{t}_P} < \min\left\{\chi(\hat{L}_B)b, \chi(\hat{L}_B)(2-b)\right\}$, which is equivalent to $L_E > \max\left\{0, 2(1-\frac{1}{b})\right\}$. Then the following policy choice is feasible:

$$\begin{aligned}
t'_P &= \hat{t}_P + \Delta_1\,, \quad && \Delta_1 > 0\text{, but small such that } t'_P \leq \bar{t}_P \\
t'_L &= \hat{t}_L + \Delta_2\,, \quad && \Delta_2 > 0\text{, but small such that } t'_L \leq \bar{t}_L \\
L'_B &= \hat{L}_B\ ,
\end{aligned}$$

where Δ_1 and Δ_2 are chosen to satisfy:

$$\frac{1-\hat{t}_P}{1-\hat{t}_L} = \frac{1-t'_P}{1-t'_L} \ .$$

Then $L'_E = \hat{L}_E$, $L'_y = \hat{L}_y$, and hence $W(t'_L, t'_P, L'_B) > W(\hat{t}_L, \hat{t}_P, \hat{L}_B)$, a contradiction to $\left(\hat{t}_L, \hat{t}_P, \hat{L}_B\right)$ being a welfare optimum.

□

[33] Note that by $\bar{t}_j \leq 1-\varepsilon$, $j \in \{L, P\}$ we have $\frac{1-\hat{t}_P}{1-\hat{t}_L} \in (0, \infty)$.

A.3.8.6. Proof of Proposition A.6: Parts 1.3.1, 1.3.2, 1.3.3

Immediately follow from Proposition A.6.1.3.

A.3.8.7. Proof of Proposition A.6: Part 2

For $L_E^* = 0$, all tax policies associated with $L_E = 0$ are welfare-optimal, i.e. all tax policies satisfying $\frac{1-t_L}{(1-t_P)\chi(L_B^*)b} \geq 1$. This proves the last row in Proposition A.6.

□

A.3.9. Proof of Proposition A.5

For $L_E = 0$, W does not depend on the choice of t_L and t_P. Hence, $L_E > 0$ is optimal if there exists a tax policy, $\hat{t}_L$ and $\hat{t}_P$ such that L_E is just equal to 0, i.e. $1 - \frac{1-\hat{t}_L}{(1-\hat{t}_P)\chi(L_B^*)b} = 0$, and $\frac{\partial W}{\partial L_E}\Big|_{\substack{\hat{t}_L \\ \hat{t}_P}} > 0$. In what follows we show that this is the case if and only if the condition stated in Proposition A.5 is satisfied.

Differentiating W with respect to L_E yields:

$$\frac{\partial W}{\partial L_E} = (1-\alpha)L_y^{-\alpha}\Bigg\{(\chi(L_B^*) - 1) + (1-t_P)\chi(L_B^*)b \\ \left[\left(1 - \frac{1}{b} - L_E\right) - \alpha(\chi(L_B^*) - 1)L_y^{-1}\left(1 - \frac{1}{b} - \frac{L_E}{2}\right)L_E\right]\Bigg\} .$$

Evaluated at $L_E = 0$, this reduces to:

$$\frac{\partial W}{\partial L_E}\bigg|_{L_E=0} = (1-\alpha)\left(\bar{L} - L_B^* - m\right)^{-\alpha}\left[\chi(L_B^*) - 1 + (1-t_P)\chi(L_B^*)(b-1)\right] .$$

The non-negativity condition for profits in the final-good producer combined with the feasibility of $L_E = 0$ imply that $\bar{L} - L_B^* \geq \frac{m}{\alpha}$ and hence $(\bar{L} - L_B^* - m) > 0$. We conclude:

$$\frac{\partial W}{\partial L_E}\bigg|_{L_E=0} > 0 \quad \text{if and only if} \quad \chi(L_B^*) > \frac{1}{1 + (1-t_P)(b-1)} .$$

Whether or not $\frac{\partial W}{\partial L_E}\Big|_{L_E=0} > 0$ depends on the choice of t_P. In particular, for $(\bar{L} - L_B^* -$

$m) > 0$:

$$\left.\frac{\partial W}{\partial L_E}\right|_{L_E=0} \text{ is } \begin{cases} \text{increasing in } t_P & \text{if } b < 1 \\ \text{independent of } t_P & \text{if } b = 1 \\ \text{decreasing in } t_P & \text{if } b > 1 \end{cases} .$$

We conclude that for $b \leq 1$, $\frac{\partial W}{\partial L_E} > 0$ for some choice of t_L and t_P satisfying $1 - \frac{1-t_L}{(1-t_P)\chi(L_B^*)b} = 0$ if and only if $\chi(L_B^*) > \frac{1}{1+(1-t_P)(b-1)}$ for the largest possible t_P satisfying $1-\frac{1-t_L}{(1-t_P)\chi(L_B^*)b} = 0$. Conversely, if $b > 1$, $\frac{\partial W}{\partial L_E} > 0$ for some choice of t_L and t_P satisfying $1 - \frac{1-t_L}{(1-t_P)\chi(L_B^*)b} = 0$ if and only if $\chi(L_B^*) > \frac{1}{1+(1-t_P)(b-1)}$ for the smallest possible t_P satisfying $1 - \frac{1-t_L}{(1-t_P)\chi(L_B^*)b} = 0$. $\tilde{t}_P$ in condition (A.7) has been chosen accordingly.

□

A.3.10. Proof of Lemma A.3

We first show the continuity of the median voter's income I with respect to τ, for given L_B, and then the continuity of I with respect to L_B, for given τ.

(1) Since the median voter's gross income is a continuous function of τ and L_B, it is sufficient to focus on net transfers $NT(\tau, L_B)$.

(2) We use Table A.1, which describes optimal labor and profit taxes for given (τ, L_B). We observe that the net transfers are continuous within each of the different subsets of (τ, L_B) defined by the four different cases. Potential discontinuities may exist at the transitions from one case to another. In this respect, we define the critical values $\tau^c(L_B)$ and $L_B^c(\tau)$ by $DNT(\tau^c, L_B) = 0$ for a given L_B in the feasible set and by $DNT(\tau, L_B^c) = 0$ for a given τ, respectively.

(3) As can be observed from Table A.1, there are two critical values of τ for a given L_B: $\tau^c(L_B)$ and $\tau = 1$. The former is only interesting if $\tau^c(L_B) \in [\underline{\tau}, \overline{\tau}]$, while by our assumptions in section 3.4 the latter will always be in the feasible set. Now consider any two sequences $\{\tau_m\}$ and $\{\tau_n\}$ with $\lim_{m\to\infty} \tau_m = \tau^c$, $\tau_m \leq \tau^c$, and $\lim_{n\to\infty} \tau_n = \tau^c$, $\tau_n \geq \tau^c$. As $DNT(\tau^c, L_B) = 0$ means that a change in tax rates t_P, t_L does not affect net transfers $[NT(\tau^c, L_B)]$ as long as τ^c remains unchanged, we must obtain $\lim_{m\to\infty} NT(\tau_m, L_B) = \lim_{n\to\infty} NT(\tau_n, L_B)$. Hence, $NT(\tau, L_B)$ is continuous at τ^c for a given L_B.

(4) At the critical value $\tau = 1$, both tax rates t_P and t_L are identical. Consequently, for two sequences with $\lim_{m\to\infty} \tau_m = 1$, $\tau_m \leq 1$, and $\lim_{n\to\infty} \tau_n = 1$, $\tau_n \geq 1$, we also obtain $\lim_{m\to\infty} NT(\tau_m, L_B) = \lim_{n\to\infty} NT(\tau_n, L_B) = NT(1, L_B)$. Thus, net transfers

are continuous in τ at $\tau = 1$.

(5) We can use the same argument as in (3) with respect to sequences $\{L_{B,m}\}$ and $\{L_{B,n}\}$ with limit L_B^c for given τ to establish continuity of I with respect to L_B.

□

B. Appendix to Chapter 4

B.1. Proofs

B.1.1. Proof of Proposition 4.1

We prove parts (i) and (ii) of Proposition 4.1 separately.

Proof of Proposition 4.1 (i)

Note first that for $L_E = 0$, TR is trivially increasing in t_P as equilibrium outcomes – and hence the tax base – do not depend on taxes.[1] This immediately proves the second part of Proposition 4.1(i)(c), and it proves that Proposition 4.1(i)(a-b) holds true in the range of t_P satisfying $t_P \geq 1 - \frac{1-t_L}{\chi(L_B)b}$.

We next consider the case of $L_E > 0$. We show that for $L_E > 0$ and $t_L \geq \frac{\chi(L_B)-\alpha}{1-\alpha}$, TR is also increasing in t_P, which proves part (i)(a). We finally show that for $L_E > 0$ and $t_L < \frac{\chi(L_B)-\alpha}{1-\alpha}$, TR follows a Laffer Curve that peaks at $t_{P,max}$. Parts (i)(b-c) then follow from a discussion of when $t_{P,max}$ will be reached.

Tax revenues in working-hour equivalents, TR, are given by the right-hand side of equation (A.2):

$$TR = (\bar{L} - L_E)t_L + t_P \left[\frac{\alpha}{1-\alpha} L_y - m + L_E \chi(L_B)\right] . \tag{B.1}$$

[1] More precisely, TR is linear in t_P with the slope coefficient given by the final-good producer's profits divided by the wage rate.

Taking first and second derivatives with respect to t_P yields:

$$\begin{aligned}\frac{\partial TR}{\partial t_P} =& - t_L \frac{\partial L_E}{\partial t_P} + \frac{\alpha}{1-\alpha} L_y - m + L_E \chi(L_B) \\ &+ t_P \frac{\partial L_E}{\partial t_P} \left[\frac{\alpha}{1-\alpha} (\chi(L_B) - 1) + \chi(L_B) \right] \end{aligned} \tag{B.2}$$

$$\begin{aligned}\frac{\partial^2 TR}{(\partial t_P)^2} =& \frac{\partial^2 L_E}{(\partial t_P)^2} \left[\left(\frac{\alpha}{1-\alpha} (\chi(L_B) - 1) + \chi(L_B) \right) t_P - t_L \right] \\ &+ 2 \frac{\partial L_E}{(\partial t_P)} \left[\frac{\alpha}{1-\alpha} (\chi(L_B) - 1) + \chi(L_B) \right] . \end{aligned} \tag{B.3}$$

For $L_E > 0$, we have:

$$\begin{aligned} L_E =& 1 - \frac{1 - t_L}{(1 - t_P)\chi(L_B) b} \\ \frac{\partial L_E}{\partial t_P} =& - \frac{1 - t_L}{(1 - t_P)^2 \chi(L_B) b} \\ \frac{\partial^2 L_E}{(\partial t_P)^2} =& - 2 \frac{1 - t_L}{(1 - t_P)^3 \chi(L_B) b} . \end{aligned}$$

Using these expressions in equations (B.2) and (B.3) and simplifying terms yields:

$$\frac{\partial TR}{\partial t_P} = \frac{\alpha}{1-\alpha} \left[\bar{L} - L_B - \frac{m}{\alpha} \right] + \frac{\chi(L_B) - \alpha}{1-\alpha} + \frac{1 - t_L}{(1 - t_P)^2 \chi(L_B) b} \left[t_L - \frac{\chi(L_B) - \alpha}{1-\alpha} \right] \tag{B.4}$$

$$\frac{\partial^2 TR}{(\partial t_P)^2} = 2 \frac{1 - t_L}{(1 - t_P)^3 \chi(L_B) b} \left[t_L - \frac{\chi(L_B) - \alpha}{1-\alpha} \right] . \tag{B.5}$$

We rearrange equation (B.4) to obtain:

$$\begin{aligned}\frac{\partial TR}{\partial t_P} =& \frac{\alpha}{1-\alpha} \left[\bar{L} - L_B - \frac{m}{\alpha} \right] + \frac{\alpha}{1-\alpha} (\chi(L_B) - 1) \left[1 - \frac{1 - t_L}{(1 - t_P)\chi(L_B) b} \right] \\ &+ \chi(L_B) \left[1 - \frac{1 - t_L}{(1 - t_P)\chi(L_B) b} \right] - \frac{\chi(L_B) - \alpha}{1-\alpha} \frac{1 - t_L}{(1 - t_P)\chi(L_B) b} \frac{t_P}{1 - t_P} \\ &+ \frac{1 - t_L}{(1 - t_P)^2 \chi(L_B) b} t_L . \end{aligned}$$

By condition (PPC), $\frac{\alpha}{1-\alpha} \left[\bar{L} - L_B - \frac{m}{\alpha} \right] + \frac{\alpha}{1-\alpha} (\chi(L_B) - 1) \left[1 - \frac{1-t_L}{(1-t_P)\chi(L_B)b} \right] \geq 0$. Furthermore, clearly $\chi(L_B) \left[1 - \frac{1-t_L}{(1-t_P)\chi(L_B)b} \right] > 0$ and $\frac{1-t_L}{(1-t_P)^2\chi(L_B)b} t_L \geq 0$. We conclude $\left. \frac{\partial TR}{\partial t_P} \right|_{t_P=0} > 0$.

From equation (B.5) we observe that $\frac{\partial^2 TR}{(\partial t_P)^2} \geq 0$ for $t_L \geq \frac{\chi(L_B)-\alpha}{1-\alpha}$. Hence, for $t_L \geq \frac{\chi(L_B)-\alpha}{1-\alpha}$, $\left. \frac{\partial TR}{\partial t_P} \right|_{t_P=0} > 0$ is sufficient for TR to be monotonically increasing in t_P. This completes the proof of part (a).

Next consider the case of $t_L < \frac{\chi(L_B)-\alpha}{1-\alpha}$. From equation (B.5) we know that $\frac{\partial^2 TR}{(\partial t_P)^2} < 0$ in this case. Hence, for $L_E > 0$, TR is maximized at the solution to $\frac{\partial TR}{\partial t_P} = 0$. Setting the right-hand side of equation (B.4) equal to 0 and solving for t_P yields:[2]

$$t_{P,max} := 1 - \left[\frac{\frac{1-t_L}{\chi(L_B)b}\left(\frac{\chi(L_B)-\alpha}{1-\alpha} - t_L\right)}{\frac{\alpha}{1-\alpha}\left(\bar{L} - L_B - \frac{m}{\alpha}\right) + \frac{\chi(L_B)-\alpha}{1-\alpha}} \right]^{\frac{1}{2}} .$$

Now, for $L_E > 0$, TR is increasing in t_P for $t_P < t_{P,max}$ and decreasing for $t_P > t_{P,max}$. Two cases need to be distinguished.

If prior to reaching the peak of the Laffer Curve, t_P reaches its upper bound, $\bar{t}_P$, and/or it reaches values such that $L_E = 0$, i.e. $t_P \geq 1 - \frac{1-t_L}{\chi(L_B)b}$, then TR is monotonically increasing in t_P, which proves part (b).

If, by contrast, t_P reaches $t_{P,max}$ first, then TR initially follows a Laffer Curve that peaks at $t_{P,max}$. If $t_{P,max} < 1 - \frac{1-t_L}{\chi(L_B)b} < \bar{t}_P$, then TR starts to rise again from $t_P = 1 - \frac{1-t_L}{\chi(L_B)b}$ onwards. This proves part (c).

□

Proof of Proposition 4.1 (ii)

Again, for $L_E = 0$, TR is trivially monotonically increasing in t_L. It remains to show that for $L_E > 0$ TR follows a Laffer Curve that peaks at $t_L = t_{L,max}$. The proof concludes with a discussion of when $t_{L,max}$ can be reached.

Taking first and second derivatives of TR with respect to t_L yields:

$$\frac{\partial TR}{\partial t_L} = \bar{L} - L_E - t_L\frac{\partial L_E}{\partial t_L} + t_P\frac{\partial L_E}{\partial t_L}\left[\frac{\alpha}{1-\alpha}(\chi(L_B)-1) + \chi(L_B)\right] \quad \text{(B.6)}$$

$$\frac{\partial^2 TR}{(\partial t_L)^2} = \frac{\partial^2 L_E}{(\partial t_L)^2}\left[t_P\left(\frac{\alpha}{1-\alpha}(\chi(L_B)-1) + \chi(L_B)\right) - t_L\right] - 2\frac{\partial L_E}{\partial t_L} . \quad \text{(B.7)}$$

[2] Note that $t_L < \frac{\chi(L_B)-\alpha}{1-\alpha}$ implies that $t_{P,max} \in (0,1)$.

For $L_E > 0$, we have:

$$\begin{aligned} L_E =& 1 - \frac{1 - t_L}{(1 - t_P)\chi(L_B)b} \\ \frac{\partial L_E}{\partial t_L} =& \frac{1}{(1 - t_P)\chi(L_B)b} \\ \frac{\partial^2 L_E}{(\partial t_L)^2} =& 0 \ . \end{aligned}$$

Using these expressions in equations (B.6) and (B.7) yields:

$$\begin{aligned} \frac{\partial TR}{\partial t_L} =& \bar{L} - 1 + \frac{1 - t_L}{(1 - t_P)\chi(L_B)b} - \frac{t_L}{(1 - t_P)\chi(L_B)b} \\ &+ \frac{t_P}{(1 - t_P)\chi(L_B)b}\left[\frac{\alpha}{1 - \alpha}(\chi(L_B) - 1) + \chi(L_B)\right] \qquad \text{(B.8)} \\ \frac{\partial^2 TR}{(\partial t_L)^2} =& -\frac{2}{(1 - t_P)\chi(L_B)b} < 0 \ . \qquad \text{(B.9)} \end{aligned}$$

$\frac{\partial^2 TR}{(\partial t_L)^2} < 0$ implies that TR has a unique peak at the solution to $\frac{\partial TR}{\partial t_L} = 0$. Setting the right-hand side of equation (B.8) equal to 0 and solving for t_L yields:

$$t_{L,max} := \frac{1}{2}\left[(\bar{L} - 1)(1 - t_P)\chi(L_B)b + 1 + t_P\frac{\chi(L_B) - \alpha}{1 - \alpha}\right] \ .$$

It follows that for $t_L < \max\{t_{L,max}, 1 - (1 - t_P)\chi(L_B)b\}$, TR is increasing in t_L either because $L_E = 0$ or because $L_E > 0$ and t_L is located on the increasing part of the Laffer Curve. By contrast, if $t_L > \max\{t_{L,max}, 1 - (1 - t_P)\chi(L_B)b\}$, then TR is decreasing in t_L because $L_E > 0$ and t_L is located on the decreasing part of the Laffer Curve. These insights, along with the boundary conditions for t_L, are summarized in the characterization of the maximum of TR stated in Proposition 4.1(ii).

□

B.1.2. Proof of Proposition 4.2

Maximizing I_{sw} is equivalent to maximizing $\bar{L}\tilde{\mu}I_{sw}$:

$$\begin{aligned} \bar{L}\tilde{\mu}I_{sw} =& \tilde{\mu}y + (1 - t_P)\pi_y(1 - \tilde{\mu}) + \tilde{\mu}(1 - t_L)wL_E - \tilde{\mu}(1 - t_P)\chi(L_B)wL_E \\ =& (1 - t_P)\pi_y + \tilde{\mu}\,[y - (1 - t_P)\pi_y + (1 - t_L)wL_E \\ &- (1 - t_P)\chi(L_B)wL_E] \ . \end{aligned}$$

Final good production is uniquely maximized in the entrepreneurial economy with $t_L = \bar{t}_L$, $t_P = \underline{t}_P$, $L_B = \tilde{L}_B(\overline{\tau})$. Hence $(1-t_P)\pi_y$ is also uniquely maximized in this entrepreneurial economy. A policy choice (t_L, t_P, L_B) that does not satisfy the non-negativity constraint of the final-good producer can never be I_{sw}-optimal. Hence we limit our attention to policy choices satisfying this constraint. Then $(1-t_P)\pi_y$ is a continuous function of (t_L, t_P, L_B) defined on the compact set:

$$\Omega = \left\{ t_L, t_P, L_B : (t_L, t_P, L_B) \in [\underline{t}_L, \bar{t}_L] \times [\underline{t}_P, \bar{t}_P] \times \left[0, \bar{L}\right], L_y(\tau, L_B) \geq m\frac{1-\alpha}{\alpha} \right\} .$$

Let $B_\epsilon(\tilde{x})$ denote an open ball around $\tilde{x} \in \Omega$ defined as $B_\epsilon(\tilde{x}) := \{x \in \Omega : \|x - \tilde{x}\| < \epsilon\}$ for some $\epsilon > 0$. Then the set $\Omega \backslash B_\epsilon(\bar{t}_L, \underline{t}_P, \tilde{L}_B(\overline{\tau}))$ is compact. Hence, by the extreme value theorem, function $(1-t_P)\pi_y$ attains a maximum on $\Omega \backslash B_\epsilon(\bar{t}_L, \underline{t}_P, \tilde{L}_B(\overline{\tau}))$. We denote this maximum by $M(\epsilon)$. Let x^* and $\hat{x}$ denote the values that variable x assumes in the output-maximizing entrepreneurial economy and in some economy with $(\hat{t}_L, \hat{t}_P, \hat{L}_B)$, respectively. Then, for every $(\hat{t}_L, \hat{t}_P, \hat{L}_B) \in \Omega \backslash B_\epsilon(\bar{t}_L, \underline{t}_P, \tilde{L}_B(\overline{\tau}))$, we have $(1-\hat{t}_P)\hat{\pi}_y \leq M(\epsilon)$. And by the uniqueness of the maximum of $(1-t_P)\pi_y$ in Ω, we have $M(\epsilon) < (1-t_P^*)\pi_y^*$.

Furthermore, $[y - (1-t_P)\pi_y + (1-t_L)wL_E - (1-t_P)\chi(L_B)wL_E]$ is bounded for every $(t_L, t_P, L_B) \in \Omega$. We denote the upper and lower bounds by $\overline{K}$ and $\underline{K}$, respectively. Then, for every $(\hat{t}_L, \hat{t}_P, \hat{L}_B) \in \Omega \backslash B_\epsilon(\bar{t}_L, \underline{t}_P, \tilde{L}_B(\overline{\tau}))$ we have:

$$\begin{gathered}
I_{sw}^* - \hat{I}_{sw} \\
= \\
(1-t_P^*)\pi_y^* - (1-\hat{t}_P)\hat{\pi}_y \\
+\tilde{\mu}\Big\{ \left[y^* - (1-t_P^*)\pi_y^* + (1-t_L^*)w^*L_E^* - (1-t_P^*)\chi(L_B^*)w^*L_E^*\right] \\
- \left[\hat{y} - (1-\hat{t}_P)\hat{\pi}_y + (1-\hat{t}_L)\hat{w}\hat{L}_E - (1-\hat{t}_P)\chi(\hat{L}_B)\hat{w}\hat{L}_E\right] \Big\} \\
\geq \\
(1-t_P^*)\pi_y^* - M(\epsilon) \\
+\tilde{\mu}\Big\{ \left[y^* - (1-t_P^*)\pi_y^* + (1-t_L^*)w^*L_E^* - (1-t_P^*)\chi(L_B^*)w^*L_E^*\right] \\
- \left[\hat{y} - (1-\hat{t}_P)\hat{\pi}_y + (1-\hat{t}_L)\hat{w}\hat{L}_E - (1-\hat{t}_P)\chi(\hat{L}_B)\hat{w}\hat{L}_E\right] \Big\} \\
\geq \\
(1-t_P^*)\pi_y^* - M(\epsilon) + \tilde{\mu}\left(\underline{K} - \overline{K}\right) .
\end{gathered}$$

Now, for every $\tilde{\mu} < \overline{\mu}$ with:

$$\overline{\mu} = \frac{(1 - t_P^*)\pi_y^* - M(\epsilon)}{\overline{K} - \underline{K}} ,$$

we have $I_{sw}^* - \hat{I}_{sw} > 0$ and hence shareholder-workers will strictly prefer the entrepreneurial economy to $(\hat{t}_L, \hat{t}_P, \hat{L}_B)$.

□

B.1.3. Proof of Corollary 4.1

We show that for $\bar{t}_L \geq \frac{m(1-\gamma)-1}{\bar{L}-1}$ the unconstrained optimum, i.e. the solution to the decision problem analyzed in section 3.5.2, satisfies the non-negativity constraint for investments in g:

$$t_L \left(\bar{L} - L_E\right) w + t_P \left[\pi_y + \eta(L_B) L_E \pi_{xm}\right] - w L_B \geq 0 . \tag{B.10}$$

From Proposition 3.3 we know that either an entrepreneurial economy with $\tau = \overline{\tau}$ and $L_B = \tilde{L}_B(\overline{\tau})$ or an economy with $\tau = \underline{\tau}$ and $L_B = 0$ is the unconstrained optimum. If the latter is optimal, the non-negativity constraint (B.10) is trivially satisfied.

Suppose next that the entrepreneurial economy $(\bar{t}_L, \underline{t}_P, \tilde{L}_B(\overline{\tau}))$ is the unconstrained optimum and let x^* denote the value that variable x assumes in the associated equilibrium. We show that $\bar{t}_L \geq \frac{m(1-\gamma)-1}{\bar{L}-1}$ implies that $\bar{t}_L \left(\bar{L} - L_E^*\right) w^* \geq w^* L_B^*$. Furthermore, $\underline{t}_P \left[\pi_y^* + \eta(L_B^*) L_E^* \pi_{xm}^*\right] \geq 0$. Hence, for $\bar{t}_L \geq \frac{m(1-\gamma)-1}{\bar{L}-1}$, condition (B.10) is satisfied in the unconstrained optimum.

$\bar{t}_L \left(\bar{L} - L_E^*\right) w^* \geq w^* L_B^*$ if and only if:

$$\bar{t}_L \geq \frac{L_B^*}{\bar{L} - L_E^*} . \tag{B.11}$$

Assumption 3.1 implies that an economy with $L_B = 0$ and $L_E = 0$ is feasible. Hence, in the optimal entrepreneurial economy, we must have $L_B^* \leq (\chi(L_B^*) - 1) L_E^*$, which in turn implies $\chi(L_B^*) > 1$. We combine these insights with $\eta(L_B^*) < 1$ and $L_E^* < 1$ to obtain:

$$\frac{L_B^*}{\bar{L} - L_E^*} \leq \frac{\left[\chi(L_B^*) - 1\right] L_E^*}{\bar{L} - L_E^*} < \frac{\chi(L_B^*) - 1}{\bar{L} - 1} < \frac{m(1-\gamma) - 1}{\bar{L} - 1}$$

and hence:

$$\bar{t}_L \geq \frac{m(1-\gamma)-1}{\bar{L}-1}$$

implies that:

$$\bar{t}_L \geq \frac{L_B^*}{\bar{L}-L_E^*} \, .$$

This proves sufficiency of $\bar{t}_L \geq \frac{m(1-\gamma)-1}{\bar{L}-1}$.

□

C. Appendix to Chapter 5

C.1. Revealed comparative advantages of countries

As argued in the main text, empirical evidence presented by Hausmann and Hidalgo (2011) and Tacchella et al. (2012) indicates an upper-triangular structure of specialization of countries on products. In this part of the appendix, we briefly discuss and summarize this evidence.

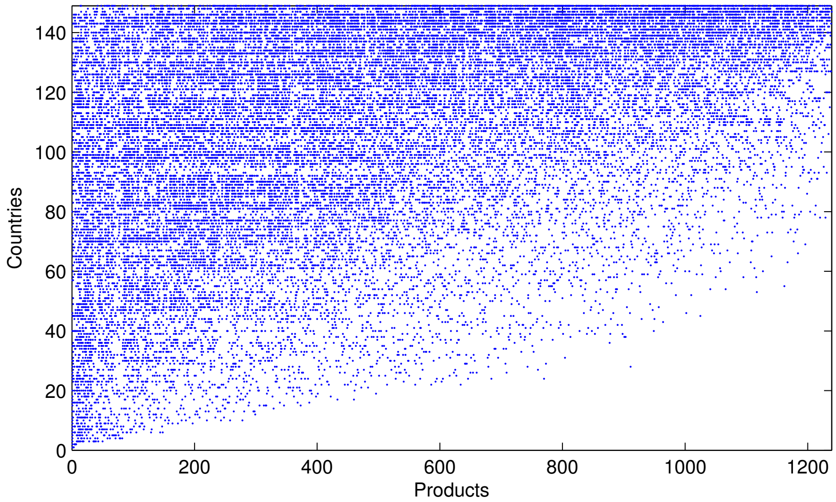
Hausmann and Hidalgo (2011) and Tacchella et al. (2012) summarize *revealed comparative advantages* of countries for products in a binary country-product matrix that indicates for each country the products for which it has a revealed comparative advantage of at least 1. Their new idea is to rank countries from the weakest to the strongest economically, and products from the least to the most complex, according to the new measures developed by Hidalgo and Hausmann (2009) and Tacchella et al. (2012).

We follow their approach and visualize the ordered country-product matrix in Figures C.1 to C.3. In Figure C.1 countries and products are ranked according to the measures proposed by Tacchella et al. (2012); in Figure C.2 they are ranked according to the measures of economic complexity proposed by Hidalgo and Hausmann (2009); and in Figure C.3 they are ranked according to their diversification and their ubiquity, respectively.[1,2]

[1] Hidalgo and Hausmann (2009) define a country's *diversification* as the number of products for which it has a revealed comparative advantage of at least 1. A product's *ubiquity* is defined as the number of countries exporting this product with revealed comparative advantage of at least 1.

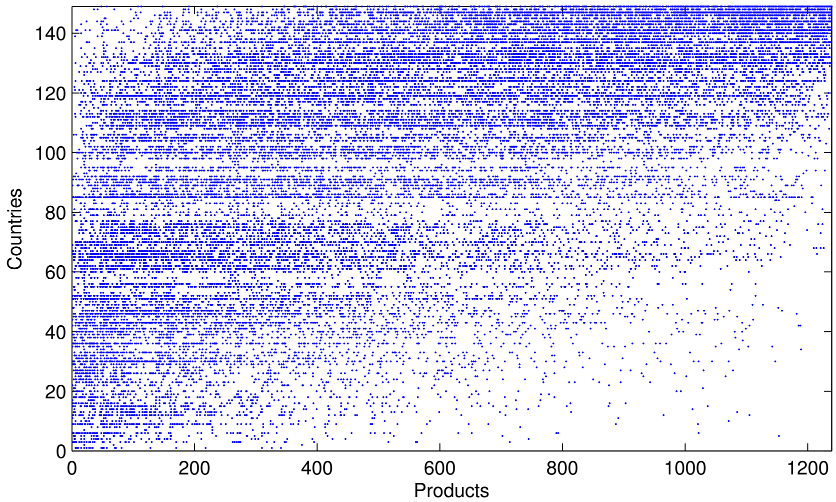
[2] Note, however, that the measures as proposed by Hidalgo and Hausmann (2009) and Tacchella et al. (2012) tend to accentuate the observed upper-triangular structure. In essence, these algorithms classify products as simple when they are strongly exported by weak countries.

Figure C.1.: Revealed comparative advantages – ranking according to Tacchella et al. (2012)



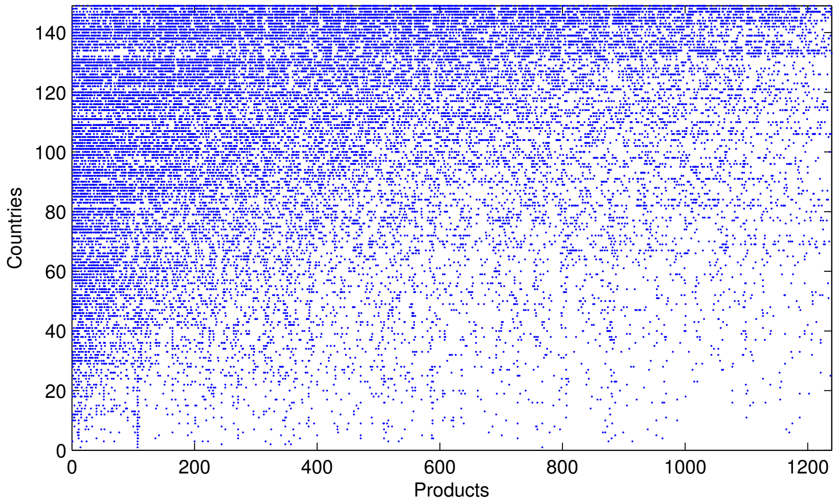
Source: Own illustration, based on Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). Products are grouped according to the 'hs4' classification codes. Countries and products are ranked according to the measures of *fitness of countries* and *complexity of products*, respectively, proposed by Tacchella et al. (2012). For every country-product pair, a dot indicates that the country has *revealed comparative advantage* of at least 1 for that product. The data refers to 2010 and was downloaded in August 2013.

Figure C.2.: Revealed comparative advantages – ranking according to Hidalgo and Hausmann (2009)



Source: Own illustration, based on Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). Products are grouped according to the 'hs4' classification codes. Countries and products are ranked according to the measures proposed by Hidalgo and Hausmann (2009). For every country-product pair, a dot indicates that the country has *revealed comparative advantage* of at least 1 for that product. The data refers to 2010 and was downloaded in August 2013.

Figure C.3.: Revealed comparative advantages – ranking according to diversification and ubiquity



Source: Own illustration, based on Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). Products are grouped according to the 'hs4' classification codes. Countries and products are ranked according to their diversification and their ubiquity, respectively. For every country-product pair, a dot indicates that the country has *revealed comparative advantage* of at least 1 for that product. The data refers to 2010 and was downloaded in August 2013.

C.2. Generalized production function

In the main text, we limit our attention to the case where all households living in a country have the same skill level of their labor. As labor is immobile across countries and as all tasks have to be accomplished simultaneously within a single production site, this also implies that all workers working in a team have the same skill level. In this part of the appendix, we consider the firm's decision problem for an arbitrary distribution of skills across countries. We further allow the firm to organize teams such that workers with different skill levels work on different tasks involved in production. We show that the firm will always form homogeneous teams in which all workers have the same skill level. It follows that, in equilibrium, output can always be described by the simplified production function stated in equation (5.7) in the main text. Also, the distribution of skill levels across countries does not matter for aggregate outcomes.

C.2.1. Production technology

Suppose firm i can choose the skill level of labor working on task j, r_j, for every task $j \in [0, i]$. Let otherwise the production technology be the same as described in the main text. Then firm i's expected output is given by:

$$E[x_{i,q}] = \left(\prod_0^i \left[(r_j)^{q^\lambda} \right]^{dj} \right) L_{i,q}, \quad q \geq 1 \,, \tag{C.1}$$

where $\left(\prod_a^b [f(x)]^{dx} \right) = \exp \left(\int_a^b \log(f(x))\, dx \right)$ denotes the geometric integral. Again, labor is organized in a continuum of identical teams. However, now each team is composed of labor with different skill levels as implied by the choice of $\{r_j\}_{j \in [0,i]}$. Hence $L_{i,q}$ is a labor-input aggregator combining labor of different skill levels to match the composition of each team. The probability of successful operation of each team is $\left(\prod_0^i \left[(r_j)^{q^\lambda} \right]^{dj} \right)$. Its expected output is given by this probability times the mass of labor employed in the team. With a continuum of teams, we can again apply the law of large numbers and henceforth ignore the expectation operator in the production function.

Example 5.1 (continued)

Suppose Paula hires a worker with skill level $r_{w,j}$ to work on task $j \in \{1, 2, 3\}$. Then her expected output is given by:

$$E[x_{w,q_w}] = (r_{w,1})^{q_w} (r_{w,2})^{q_w} (r_{w,3})^{q_w} L_w \,,$$

where L_w is the total mass of labor employed in workdays.

C.2.2. Optimal composition of teams

In appendix C.3.5 we show that it will always be optimal for the firm to build teams of workers with the same skill level:

Lemma C.1

Firm i always forms teams of workers with the same skill level to accomplish all tasks involved in production.

Lemma C.1 is a standard result following Kremer (1993). We illustrate the basic intuition by reference to our simple example.

Example 5.1 (continued)

Suppose Paula hires Amy, Thomas, and John to produce standard watches. If they work together in a team, then their daily (expected) output is ~ 1.1 standard watches. If, by contrast, Amy, Thomas, and John separately produce standard watches, then their daily (expected) output increases to $\left(r^A\right)^3 + \left(r^T\right)^3 + \left(r^J\right)^3 \approx 1.2$. Intuitively, Amy's work is the most valuable. Letting her work on all production steps minimizes the risk of losing her work on one production step due to a failure *of some other production step.*

C.2.3. Discussion

Lemma C.1 implies that considering the simplified production function (5.7) does not impact the equilibrium in our economy. We simplify the exposition further by assuming that in every country $k \in \{1, 2, ..., N_c\}$ there is only one skill level of labor available, r^k. As stated in the main text, we make this assumption because we are mostly interested in analyzing how countries' economic strengths – which we attribute to the skill levels of their labor – translate into comparative advantages over a heterogeneous set of products. Note, however, that this assumption – and the allocation of skills to countries in general – imposes no restrictions on aggregate outcomes. Put simply, with constant returns to scale, a footloose economy, and no barriers to trade, firms can follow the desired skill level of labor. Hence our model has an immediate closed-economy interpretation with heterogeneous workers. Of course, this also implies that workers with the same skill level must earn the same wage rate, irrespective of their country of residence.

C.3. Proofs

C.3.1. Proof of Lemma 5.1

Solving the first order condition stated in the main text, equation (5.9), yields:

$$q_i(\hat{r}) = \left[-\frac{1}{\lambda i \log(\hat{r})}\right]^{\frac{1}{\lambda}} ,$$

the expression stated in Lemma 5.1. Furthermore,

$$\frac{\partial \frac{\chi_i}{L_i(\hat{r})}}{\partial q} = [\hat{r}]^{iq^\lambda} \left[1 + \lambda i q^\lambda \log(\hat{r})\right] \begin{cases} < 0 & \text{if } q > q_i(\hat{r}) \\ > 0 & \text{if } q < q_i(\hat{r}) \end{cases} ,$$

and hence, the effective output is strictly decreasing as we move away from $q_i(\hat{r})$ in either direction. We conclude that $q_i(\hat{r})$ uniquely maximizes the effective output per worker.

Taking into account the minimum-quality constraint $q \geq 1$, yields the result as stated in Lemma 5.1.

□

C.3.2. Proof of Lemma 5.2

We prove Lemma 5.2(ii) for the case of $r^h < \tilde{r}(i)$. The remainder of Lemma 5.2 follows immediately from the discussions in the main text.

To prove the result, we show that $\forall\, i \in \left(\tilde{i}(r^h), N\right]$, firm i's costs per unit of effective output are strictly larger when producing in country r^l than when producing in country r^h. For the case of $\tilde{r}(i) > r^h > r^l$ we have:

$$\left.\frac{L_i(r^j)w_{r^j}}{\chi_i}\right|_{q_i(r^j)} = \left[r^j\right]^{-i} w_{r^j}\,, \quad j \in \{l, h\}\ ,$$

and $\left.\frac{L_i(r^l)w_{r^l}}{\chi_i}\right|_{q_i(r^l)} > \left.\frac{L_i(r^h)w_{r^h}}{\chi_i}\right|_{q_i(r^h)}$ follows from the fact that:

$$\frac{d\left[r^{-i}w_r\right]}{dr} = \left[-\log(\underline{r})\right]^{\frac{1}{\lambda}} r^{-i-1}\left[-\log(r)\right]^{-\frac{1+\lambda}{\lambda}}\left[-\frac{1}{\lambda} + i\log(r)\right] < 0\ .$$

□

C.3.3. Proof of Proposition 5.1 (i)

We proof necessity (i) and sufficiency (ii) of condition (SSC) separately.

(i) Suppose that for some $\hat{i} > \tilde{i}\left(\min\{\mathcal{R}\}\right)$ condition (SSC) is not satisfied.[3] Then it must hold:

$$L\int_{e^{-\frac{1}{\hat{i}\lambda}}}^{\overline{r}}\left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} dF_r(r) < \int_{\hat{i}}^{N}\tilde{L}_i\left(\{\hat{w}_r\}_{r\in\mathcal{R}}\right) di\ . \tag{C.2}$$

Condition (C.2) implies that total supply of effective labor in countries with skill level $r \geq e^{-\frac{1}{\hat{i}\lambda}}$ is less than total demand of effective labor by firms $i \in [\hat{i}, N]$. However, from Lemma 5.2 we know that firms $i \in [\hat{i}, N]$ will employ labor with skill level $r \geq \tilde{r}(\hat{i}) = e^{-\frac{1}{\hat{i}\lambda}}$ only. Hence total demand for labor with skill level $r \geq e^{-\frac{1}{\hat{i}\lambda}}$ exceeds total supply thereof, a contradiction to $\{\hat{w}_r\}_{r\in\mathcal{R}}$ being the equilibrium wage scheme.

The contradiction establishes necessity of condition (SSC).

(ii) If for some wage scheme $\{\hat{w}_r\}_{r\in\mathcal{R}}$ condition (SSC) is satisfied $\forall\,\hat{i} \in [0, N]$, then $\{\hat{w}_r\}_{r\in\mathcal{R}}$ is an equilibrium, as discussed in the main text. We prove uniqueness by contradiction.

[3] Note that for $i \leq \tilde{i}\left(\min\{\mathcal{R}\}\right)$ condition (SSC) is always satisfied for any feasible allocation of total effective labor.

Suppose the equilibrium is not unique. Then there exists an alternative equilibrium wage scheme $\{\breve{w}_r\}_{r\in\mathcal{R}} \neq \mu \{\hat{w}_r\}_{r\in\mathcal{R}}, \forall \mu > 0$. By Corollary 5.1, $\{\breve{w}_r\}_{r\in\mathcal{R}}$ satisfies:

$$\breve{w}_r \begin{cases} = \left[\frac{\log(\hat{r})}{\log(r)}\right]^{\frac{1}{\lambda}} \breve{w}_{\hat{r}} & \text{if } r \geq \hat{r} \\ < \left[\frac{\log(\hat{r})}{\log(r)}\right]^{\frac{1}{\lambda}} \breve{w}_{\hat{r}} & \text{otherwise} \end{cases} ,$$

for some $\hat{r} \in (\min\{\mathcal{R}\}, \max\{\mathcal{R}\}]$. Then by Lemma 5.2 all firms $i \in \left[0, \tilde{i}(\hat{r})\right)$ strictly prefer producing in a country with skill level $r < \hat{r}$ to producing in a country with skill level $r \geq \hat{r}$.[4] Now it is clear that firms $i \in \left[\tilde{i}(\hat{r}), N\right]$ decrease their demand for effective labor vis-à-vis the equilibrium with $\{\hat{w}_r\}_{r\in\mathcal{R}}$. But then, there must be excess supply of effective labor with skill level $r \geq \hat{r}$, a contradiction to $\{\breve{w}_r\}_{r\in\mathcal{R}}$ being an equilibrium.

□

C.3.4. Proof of Proposition 5.2

We proceed in two steps. We first derive the equilibrium values, assuming that we have sufficient skills. We then use the expression for the equilibrium demand for effective labor by firm $i \in [0, N]$, $\tilde{L}_i^\star$, in condition (SSC) to observe when we have sufficient skills in equilibrium.

As discussed in the main text, with $w_r^\star = \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} \forall r \in \mathcal{R}$, the allocation of total effective output of product i to countries $r \in \mathcal{R}$ with $r \geq \tilde{r}(i)$ is a matter of indifference. To simplify the exposition, we will assume here that firm i produces its entire effective output in one country $r_i \geq \tilde{r}(i)$.

Using $\{w_r^\star\}_{r\in\mathcal{R}}$ along with the fact that $r_i \geq \tilde{r}(i)$ in equation (5.11) yields:

$$\begin{aligned} \rho_i^\star &= \frac{\sigma}{\sigma - 1} w_r \left[-e\lambda i \log(r_i)\right]^{\frac{1}{\lambda}} \\ &= \frac{\sigma}{\sigma - 1} \left[-e\lambda i \log(\underline{r})\right]^{\frac{1}{\lambda}} . \end{aligned} \tag{C.3}$$

The quality-adjusted price of firm i is given by its marginal costs of producing effective output times a constant mark-up of $\frac{\sigma}{\sigma-1}$. The marginal costs, and hence $\rho_i^\star$, are increasing in the complexity of the product, i, reflecting the fact that the more complex a product, the more difficult it is to produce.[5]

[4] To be precise, our reasoning is based on $F_r(r)$ being continuous in the neighborhood of $\hat{r}$. However, the reasoning can easily be adapted to discrete distributions. With $F_r(r)$ being discrete, all firms $i \in \left[0, \tilde{i}(r^-)\right]$, $r^- := \max\{r \in \mathcal{R} : r < \hat{r}\}$, strictly prefer producing in a country with skill level $r < \hat{r}$ to producing in a country with skill level $r \geq \hat{r}$.

[5] In a variant of our model where products differ only in the minimum quality, but not in the number of

Substituting equation (C.3) in equation (5.6) and solving the integral yields the equilibrium price index $P^\star$:

$$P^\star = \frac{\sigma}{\sigma-1}\left[-e\lambda\log(\underline{r})\right]^{\frac{1}{\lambda}}\left[\frac{\lambda}{1-\sigma+\lambda}\right]^{\frac{1}{1-\sigma}} N^{\frac{1-\sigma+\lambda}{(1-\sigma)\lambda}} . \tag{C.4}$$

Note that here we used the assumption $\sigma < 1+\lambda$.

To derive $C^\star$, we first have to analyze labor-market clearing for the overall market for effective labor. Using equation (C.3) in the demand for product i, we obtain:

$$\chi_i = CP^\sigma\left[\frac{\sigma}{\sigma-1}\right]^{-\sigma}\left[-e\lambda i\log(\underline{r})\right]^{\frac{-\sigma}{\lambda}} . \tag{C.5}$$

Combining this result with equation (5.16) and solving for $L_i(r_i)$ yields:

$$L_i(r_i) = CP^\sigma\left[e\lambda i\right]^{\frac{1-\sigma}{\lambda}}\left[\frac{\sigma}{\sigma-1}\right]^{-\sigma}\left[-\log(r_i)\right]^{\frac{1}{\lambda}}\left[-\log(\underline{r})\right]^{-\frac{\sigma}{\lambda}} ,$$

which implies:

$$\tilde{L}_i = CP^\sigma\left[-e\lambda i\log(\underline{r})\right]^{\frac{1-\sigma}{\lambda}}\left[\frac{\sigma}{\sigma-1}\right]^{-\sigma} . \tag{C.6}$$

Now condition (SSC) guarantees that there is no excess demand for skills in our economy. In addition, labor-market clearing requires that total demand for effective labor equals total supply:

$$\begin{aligned}\tilde{L} &\overset{!}{=} \int_0^N \tilde{L}_i\,di\\ &= CP^\sigma\left[-e\lambda\log(\underline{r})\right]^{\frac{1-\sigma}{\lambda}}\left[\frac{\sigma}{\sigma-1}\right]^{-\sigma}\frac{\lambda}{1+\lambda-\sigma}N^{\frac{1+\lambda-\sigma}{\lambda}} ,\end{aligned}$$

where the second equality follows from using firm i's demand for effective labor, and where $\tilde{L}$ denotes the aggregate supply of effective labor in the economy as defined by:

$$\tilde{L} := L\int_{\underline{r}}^{\overline{r}}\left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} dF_r(r) . \tag{C.7}$$

Solving for C and using equation (C.4) yields:

$$C^\star = \tilde{L}\left[-e\lambda\log(\underline{r})\right]^{-\frac{1}{\lambda}}\left[\frac{\lambda}{1+\lambda-\sigma}\right]^{\frac{1}{\sigma-1}} N^{\frac{1+\lambda-\sigma}{(\sigma-1)\lambda}} . \tag{C.8}$$

The consumption aggregator C is increasing in the number of products N and in the total

tasks involved in production, quality-adjusted prices are the same for all products in an equilibrium with sufficient skills. Cf. appendix C.7.

effective labor available in the economy, $\tilde{L}$. $\tilde{L}$ is increasing in both hours worked per household, L, and the skills available in the economy, as summarized in their distribution $F_r(r)$.

Using equations (C.4) and (C.8) in equation (C.5), we obtain:

$$\chi_i^\star = \tilde{L} \left[-e\lambda \log(\underline{r})\right]^{-\frac{1}{\lambda}} \frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} \left[i\right]^{-\frac{\sigma}{\lambda}} \ .$$

$\chi_i^\star$ is decreasing in i, implying that the increased difficulty associated with producing more complex products is reflected in lower effective output in equilibrium, as we would expect.

Finally, using equations (C.4) and (C.8) in equation (C.6) yields:

$$\tilde{L}_i^\star = \tilde{L} \frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} \left[i\right]^{\frac{1-\sigma}{\lambda}} \ . \tag{C.9}$$

Effective labor used in production is also decreasing in i. Hence the lower effective output of more complex products is not only a consequence of the higher difficulty of production, but also of less labor input used in production.

Our equilibrium analysis outlined so far was conditional on $\left\{\tilde{L}_i\left(\{w_r^\star\}_{r\in\mathcal{R}}\right)\right\}_{i\in[0,N]}$ satisfying condition (SSC). We can now use the equilibrium demand for effective labor by firm i, equation (C.9), to further analyze when this is the case:

$$L \int_{e^{-\frac{1}{\hat{i}\lambda}}}^{\overline{r}} \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} dF_r(r) \geq \int_{\hat{i}}^{N} \tilde{L} \frac{1+\lambda-\sigma}{\lambda} N^{-\frac{1+\lambda-\sigma}{\lambda}} \left[i\right]^{\frac{1-\sigma}{\lambda}} di, \quad \forall \, \hat{i} \in [0,N] \ .$$

Solving the integral on the right-hand side, using the definition of $\tilde{L}$ given in equation (C.7), and rearranging terms, we get a condition for sufficient skills in the economy based on parameter values alone:

$$\frac{\int_{e^{-\frac{1}{\lambda i}}}^{\overline{r}} \left[-\log(r)\right]^{-\frac{1}{\lambda}} dF_r(r)}{\int_{\underline{r}}^{\overline{r}} \left[-\log(r)\right]^{-\frac{1}{\lambda}} dF_r(r)} \geq 1 - \left(\frac{i}{N}\right)^{\frac{1+\lambda-\sigma}{\lambda}} , \quad \forall \, i \in [0,N] \ .$$

This is exactly the condition stated in Assumption 5.1.

□

C.3.5. Proof of Lemma C.1

A necessary condition for profit maximization by firm $i \in [0, N]$ is that it produces any amount of effective output $\hat{\chi}_i$ at minimal costs. Now suppose firm i produces quality $q \geq 1$ using a mass $L_{i,q}$ of labor. Labor is organized in identical teams and satisfies $r_{j_1} \neq r_{j_2}$ for some $j_1, j_2 \in [0, i]$, i.e. we rule out that all workers have the same skill level. Without loss of generality, assume $qL_{i,q} = 1$. Then firm i's effective output is given by:

$$\chi_i = \left(\prod_0^i \left[(r_j)^{q^\lambda} \right]^{dj} \right) .$$

Next suppose, by contrast, that firm i uses the same labor input, but rearranges teams in such a way that in each team only workers with the same skill level work together, i.e. the firm forms a continuum of measure i of teams where team $j \in [0, i]$ is composed of workers with skill level r_j only. Then effective output per labor input of team j is given by $q \left[r_j \right]^{iq^\lambda}$, and total effective output is given by the integral of effective outputs across all teams:

$$\tilde{\chi}_i = \frac{L_{i,q}}{i} \int_0^i q \left[r_j \right]^{iq^\lambda} \, dj = \frac{1}{i} \int_0^i \left[r_j \right]^{iq^\lambda} \, dj .$$

Now, by Jensen's Inequality, we have:

$$\log(\tilde{\chi}_i) = \log \left(\frac{1}{i} \int_0^i \left[r_j \right]^{iq^\lambda} \, dj \right) > \int_0^i q^\lambda \log(r_j) \, dj = \log(\chi_i) ,$$

and hence:

$$\tilde{\chi}_i > \chi_i .$$

The firm can increase effective output at constant costs by forming teams of workers with the same skill level only. By continuity of the production function in the mass of teams, it follows that it can produce the same amount of effective output at lower costs, a contradiction to forming teams of workers with different skill levels being cost-minimizing.

□

C.4. Details on the numerical example

In this part of the appendix, we outline the details of the random allocation of products to countries underlying our numerical example of section 5.4.1.

We divide production of product i into small production steps. Each such step consists of a fixed amount of effective labor and is randomly allocated to countries. We require that this random allocation satisfies the following two conditions:

1. Each firm $i \in \{1, 2, ..., N_p\}$ produces in countries with skill level $r \geq \tilde{r}\left(\frac{N}{N_p}\left[i - \frac{1}{2}\right]\right)$ only.[6]

2. $\forall\, r^l, r^h \in \mathcal{R}$, with $r^l < r^h$, the relative odds of allocating a production step to country r^l or r^h are the same $\forall\, i \leq \tilde{i}\left(r^l\right)\frac{N_p}{N} + \frac{1}{2}$.[7]

The first condition is satisfied by recursive allocation of production, starting from the most complex product. The second condition is satisfied by randomly allocating the production of product $\hat{i} \in \{1, 2, ..., N_p\}$ based on the effective labor available in expectation for the production of products $i = 1, 2, ..., \hat{i}$. In particular, let $\tilde{L}_{\hat{i},\hat{r}}$ denote effective labor available in expectation in country $\hat{r} \in \mathcal{R}$ for use in production of products $i = 1, 2, ..., \hat{i}$. Then a production step of product $\hat{i} \in \{1, 2, ..., N_p\}$ is allocated to country $\hat{r}$ with probability:

$$pr_{\hat{i},\hat{r}} = \begin{cases} \frac{\tilde{L}_{\hat{i},\hat{r}}}{\sum_{r\in\mathcal{R}:\, r\geq\tilde{r}\left(\frac{N}{N_p}\left[\hat{i}-\frac{1}{2}\right]\right)} \tilde{L}_{\hat{i},r}} & \text{if } \hat{r} \geq \tilde{r}\left(\frac{N}{N_p}\left[\hat{i} - \frac{1}{2}\right]\right) \\ 0 & \text{otherwise} \end{cases} . \tag{C.10}$$

Now for $\hat{i} = N_p$ we have:[8]

$$\tilde{L}_{N_p,\hat{r}} = \frac{\log(\underline{r})}{\log(\hat{r})} . \tag{C.11}$$

Effective labor available in expectation in country $\hat{r}$ for use in production of products $i = 1, 2, ..., N_p$ is simply the total effective labor available in country $\hat{r}$. Using $\tilde{L}_{N_p,\hat{r}}$ in equation (C.10) yields $pr_{N_p,\hat{r}}$. Combining this information with total effective labor used in equilibrium in production of product N_p, $\tilde{L}^{\star}_{N_p}$, allows to derive $\tilde{L}_{N_p-1,\hat{r}}$ via the following recursive formula:[9]

$$\tilde{L}_{N_p-1,\hat{r}} = \begin{cases} \tilde{L}_{N_p,\hat{r}} - pr_{N_p,\hat{r}}\tilde{L}^{\star}_{N_p} & \text{if } \hat{r} \geq \tilde{r}\left(\frac{N}{N_p}\left[N_p - \frac{1}{2}\right]\right) \\ \tilde{L}_{N_p,\hat{r}} & \text{otherwise} \end{cases} .$$

6 In the model as presented in section 5.2, the complexity of firm i's product is i. In the discrete example considered here, firm i's product has complexity $\frac{N}{N_p}\left[i - \frac{1}{2}\right]$ and, hence, the minimum skill level needed to produce product i with preferred quality is given by $\tilde{r}\left(\frac{N}{N_p}\left[i - \frac{1}{2}\right]\right)$.

7 The maximum complexity that country r^l can produce with preferred quality is given by $\tilde{i}\left(r^l\right)$, i.e. country r^l can produce all products $i \leq \tilde{i}\left(r^l\right)\frac{N_p}{N} + \frac{1}{2}$ with preferred quality.

8 Remember that $\lambda = L = 1$.

9 To compute $\tilde{L}^{\star}_i$, we use the formulas for the model with a continuum of countries and products as outlined in the main text. In the discrete counterpart considered here, we have divided the continuum of complexities from 0 to N in N_p equally sized intervals, and attributed to product i a complexity level which corresponds to the midpoint of the i^{th} interval. $\tilde{L}_i$ is strictly convex in the complexity of the product. It follows that we underestimate total demand for effective labor when using the formulas from the continuous model. We correct for this error by proportionally scaling the demand for effective labor of each firm $i \in \{1, 2, ..., N_p\}$.

In words, effective labor available in expectation in country $\hat{r}$ for use in production of products $i = 1, 2, ..., N_p - 1$ is equal to total effective labor available in country $\hat{r}$ minus effective labor used in expectation for production of product N_p. In general, we can derive $\tilde{L}_{\hat{i},\hat{r}}$, $\hat{i} \in \{1, 2, ..., N_p - 1\}$ recursively as follows:

$$\tilde{L}_{\hat{i},\hat{r}} = \begin{cases} \tilde{L}_{\hat{i}+1,\hat{r}} - pr_{\hat{i}+1,\hat{r}} \tilde{L}^{\star}_{\hat{i}+1} & \text{if } \hat{r} \geq \tilde{r}\left(\frac{N}{N_p}\left[\hat{i} + \frac{1}{2}\right]\right) \\ \tilde{L}_{\hat{i}+1,\hat{r}} & \text{otherwise} \end{cases} . \tag{C.12}$$

Combining equations (C.10) and (C.12) with the initial values (C.11) yields probabilities for the random allocation of products to countries. These probabilities are based on expected levels of labor available. In the numerical implementation, we use these probabilities, but subject to the constraint that total allocation of production to country $\hat{r}$ may not exceed its total effective labor available.[10]

C.5. Measuring economic complexity in a world as described by our model

In this part of the appendix, we present a simple experiment to illustrate that in a world as described by our model, the algorithms proposed by Hidalgo and Hausmann (2009) and Tacchella et al. (2012) can indeed reveal important information on the economic strength of countries and on the complexity of products. In particular, we apply the proposed algorithms to binary country-product matrices that are generated according to our simple numerical example of section 5.4.1. We then compare the derived rankings of countries and products to the fundamental rankings underlying our model. Table C.1 shows the mean and the standard deviations for the according rank correlations as observed from a Monte Carlo simulation with 1000 random draws of the equilibrium in our economy. These rank correlations are generally high, suggesting that the proposed algorithms perform well indeed in uncovering the economic strength of countries and the complexity of

[10] Note that the resulting probabilities do indeed satisfy the second condition as specified above. To see this, consider two countries $r^l, r^h \in \mathcal{R}$, with $r^l < r^h$ and product $\hat{i} \leq \tilde{i}\left(r^l\right) \frac{N_p}{N} + \frac{1}{2} < \tilde{i}\left(r^h\right) \frac{N_p}{N} + \frac{1}{2}$. Then we have:

$$\frac{pr_{\hat{i},r^l}}{pr_{\hat{i},r^h}} = \frac{\tilde{L}_{\hat{i},r^l}}{\tilde{L}_{\hat{i},r^h}} = \frac{\tilde{L}_{\hat{i},r^l}\left[1 - \frac{\tilde{L}^{\star}_{\hat{i}}}{\sum_{r \in \mathcal{R}:\, r \geq \tilde{r}\left(\frac{N}{N_p}\left[\hat{i} - \frac{1}{2}\right]\right)} \tilde{L}_{\hat{i},r}}\right]}{\tilde{L}_{\hat{i},r^h}\left[1 - \frac{\tilde{L}^{\star}_{\hat{i}}}{\sum_{r \in \mathcal{R}:\, r \geq \tilde{r}\left(\frac{N}{N_p}\left[\hat{i} - \frac{1}{2}\right]\right)} \tilde{L}_{\hat{i},r}}\right]} = \frac{\tilde{L}_{\hat{i}-1,r^l}}{\tilde{L}_{\hat{i}-1,r^h}} = \frac{pr_{\hat{i}-1,r^l}}{pr_{\hat{i}-1,r^h}} .$$

products from the bipartite country-product network, at least in a world as described by our model.

Table C.1.: Rank correlations between measures derived from proposed algorithms and fundamental values[a]

	Model	
	Countries	Products
Hidalgo and Hausmann (2009)	0.7138 / 0.0456 (mean / std)	0.3431 / 0.0344 (mean / std)
Tacchella et al. (2012)	0.9907 / 0.0014 (mean / std)	0.7639 / 0.0104 (mean / std)

[a] *Source*: Own calculations. The data was retrieved from a Monte Carlo simulation with 1000 iterations.

C.6. Details on the empirical analysis

C.6.1. Derivation of Hypothesis 5.1

In our model GDP per capita is proportional to the wage rate:

$$GDP^k_{cap,t} = \frac{\sigma}{\sigma - 1} w_{r^k,t} \ ,$$

which implies:

$$-\frac{1}{\lambda} \log\left[-\log\left(r^k_t\right)\right] = \log\left(GDP^k_{cap,t}\right) - \log\left(\frac{\sigma}{\sigma-1}\right) - \frac{1}{\lambda}\log\left[-\log(\underline{r})\right] \ ,$$

and hence:

$$\log\left(q^k_{i,t}\right) = -\log\left(\frac{\sigma}{\sigma-1}\right) - \frac{1}{\lambda}\left[\log(\lambda) + \log(i) + \log\left(-\log(\underline{r})\right)\right] + \log\left(GDP^k_{cap,t}\right) \ .$$

Now in equilibrium all qualities of product i are sold at the same quality-adjusted price, $\rho_{i,t}$. Hence, if product $i \in [0, N]$ is produced in country k at time t, its price $p^k_{i,t}$ is proportional to its quality, $p^k_{i,t} = q^k_{i,t}\rho_{i,t}$, i.e. the elasticity with respect to a country's GDP per capita is the same for product quality and for product price, and we can use the latter instead. Taking logs and using the equilibrium values of q_i and ρ_i, we obtain:

$$\log\left(p^k_{i,t}\right) = \frac{1}{\lambda} + \log\left(GDP^k_{cap,t}\right) \ , \tag{C.13}$$

an expression we can use to estimate the relationship between a country's GDP per capita and its export quality. In particular, taking into account that, according to our model, we can observe $\log\left(p_{i,t}^k\right)$ only if country k is competitive for product i, i.e. only if $p_{i,t}^k \geq \rho_{i,t}$, and assuming normally distributed errors, we get the following censored regression model:

$$\log\left(p_{i,t}^k\right) = c + \beta \log(GDP_{cap,t}^k) + u_{i,t}^k, \quad u_{i,t}^k \Big| GDP_{cap,t}^k \sim \mathrm{N}(0, \sigma^2) \tag{C.14a}$$

$$\log\left(\tilde{p}_{i,t}^k\right) = \begin{cases} \log\left(p_{i,t}^k\right) & \text{if } p_{i,t}^k \geq \rho_{i,t} \\ \text{NaN} & \text{otherwise} \end{cases}, \tag{C.14b}$$

where $\tilde{p}_{i,t}^k$ denotes the observed price level.

To take this model to the data, we reintroduce product-time dummies capturing (time-varying) product characteristics, $\boldsymbol{d}_{i,t}$. We further allow the effect of $GDP_{cap,t}^k$ on output prices and the variance of the error term to differ across products, i.e. we have β_i and σ_i in equation (C.14a) above. Finally, we cannot observe the quality-adjusted price of a product, $\rho_{i,t}$. However, as shown by Carson and Sun (2007), we can use the minimum price level that we observe for product i in period t, $\min_{k \in \{1,2,\ldots,N_c\}} p_{i,t}^k$, instead. This does not affect consistency and asymptotic efficiency of the maximum-likelihood estimator.

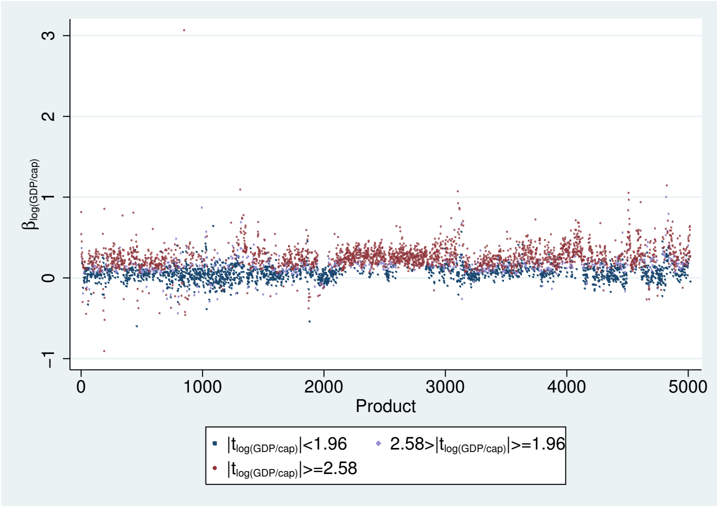
In summary, the previous derivations give rise to the censored regression model outlined in Hypothesis 5.1.

C.6.2. Further estimation results

In this part of the appendix, we present some robustness tests for the empirical observations outlined in section 5.5.3.

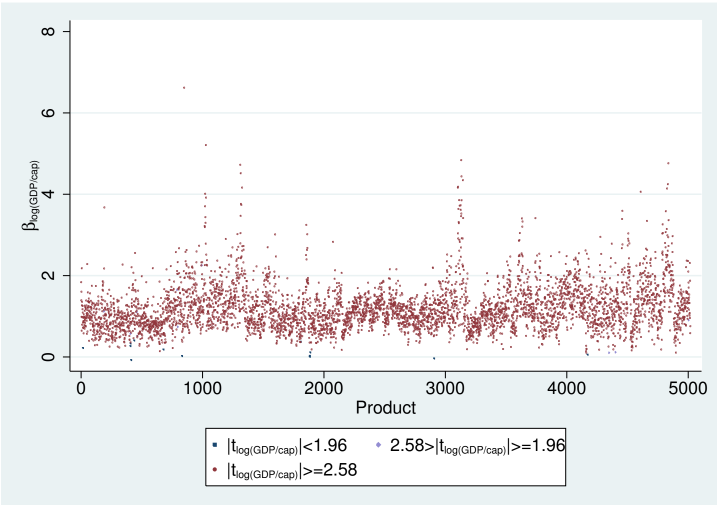
C.6.2.1. Product classification at the hs6 level

Figure C.4.: OLS estimates of $\beta_{\log(GDP_{cap})}$ – hs6 product classification



Notes: This figure plots the OLS estimates of $\beta_{\log(GDP_{cap})}$ in equation (5.19a), using the subsamples with observed unit values. Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is in purchasing power parities and is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

Figure C.5.: ML estimates of $\beta_{\log(GDP_{cap})}$ – hs6 product classification



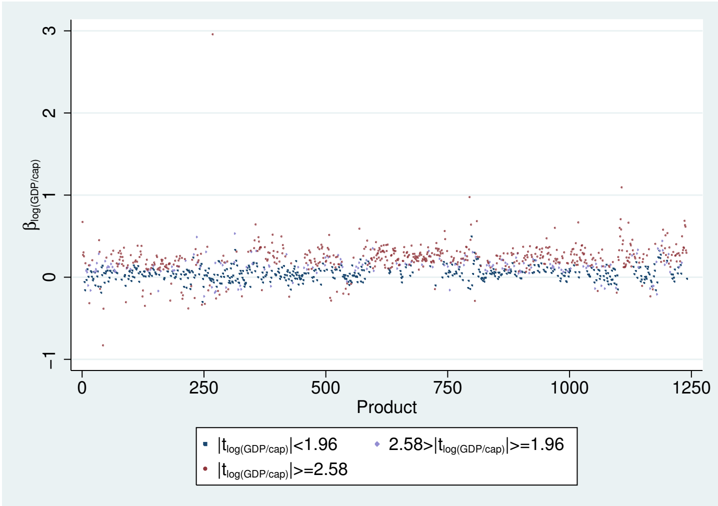
Notes: This figure plots the ML estimates of $\beta_{\log(GDP_{cap})}$ in equation (5.19a). Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is in purchasing power parities and is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

C.6.2.2. Alternative selection criterion for outliers

In this section, we classify observations as outliers whenever:

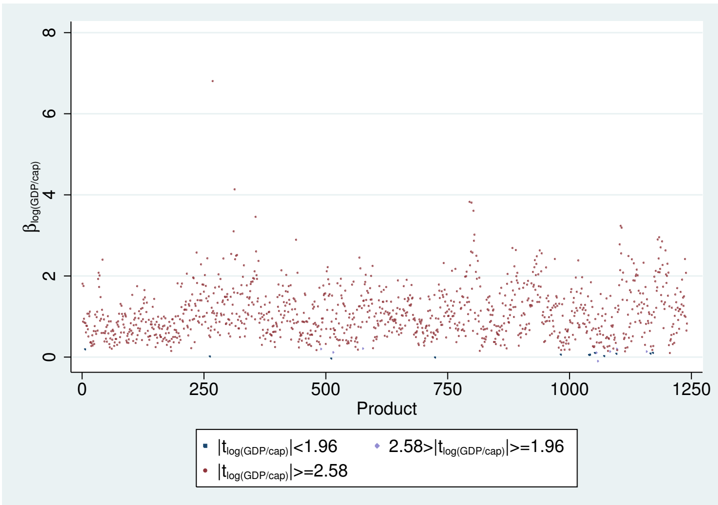
$$uv_{i,t}^{k} \geq 100 \times median_k(uv_{i,t}^{k}) \wedge uv_{i,t}^{k} \geq 50 \times median_t(uv_{i,t}^{k})$$
$$\vee$$
$$uv_{i,t}^{k} \leq \frac{1}{100} \times median_k(uv_{i,t}^{k}) \wedge uv_{i,t}^{k} \leq \frac{1}{50} \times median_t(uv_{i,t}^{k}) \; .$$

Figure C.6.: OLS estimates of $\beta_{\log(GDP_{cap})}$ – alternative selection criterion for outliers



Notes: This figure plots the OLS estimates of $\beta_{\log(GDP_{cap})}$ in equation (5.19a), using the subsamples with observed unit values. Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is in purchasing power parities and is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

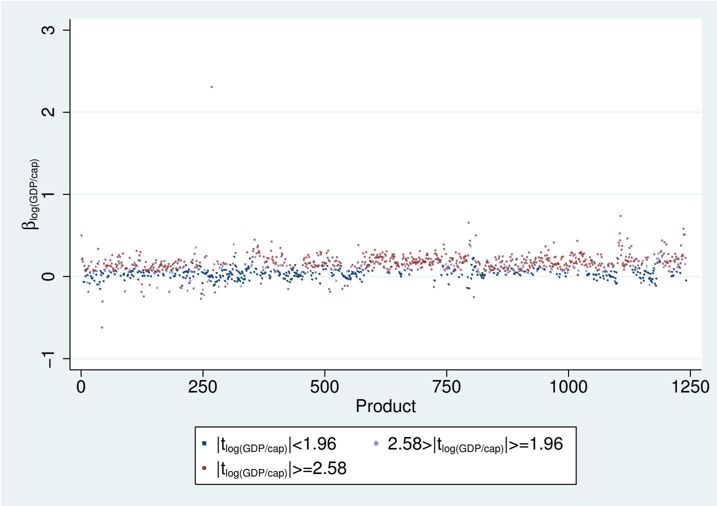
Figure C.7.: ML estimates of $\beta_{\log(GDP_{cap})}$ – alternative selection criterion for outliers



Notes: This figure plots the ML estimates of $\beta_{\log(GDP_{cap})}$ in equation (5.19a). Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is in purchasing power parities and is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

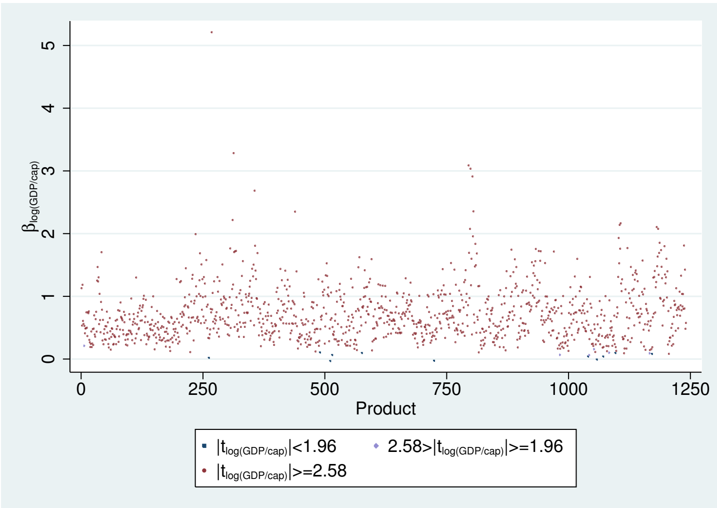
C.6.2.3. GDP at market exchange rates

Figure C.8.: OLS estimates of $\beta_{\log(GDP_{cap})}$ – GDP at market exchange rates



Notes: This figure plots the OLS estimates of $\beta_{\log(GDP_{cap})}$ in equation (5.19a), using the subsamples with observed unit values. Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

Figure C.9.: ML estimates of $\beta_{\log(GDP_{cap})}$ – GDP at market exchange rates



Notes: This figure plots the ML estimates of $\beta_{\log(GDP_{cap})}$ in equation (5.19a). Standard errors are clustered by exporting countries. The trade data is taken from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (2013). The data on GDP per capita is taken from World Bank (2013). The data ranges from 1995 to 2011 and was downloaded in August 2013.

C.7. A variant with product-specific minimum-quality requirements

In the model presented in the main text, we introduce two dimensions of product heterogeneity: product-intrinsic complexity and endogenously chosen product quality. Complexity is defined as the number of tasks involved in production. Production is subject to a minimum-quality constraint, where the minimum quality is the same for each product.

In this part of the appendix, we present a variant of our model, where we assume that every product involves a continuum of measure 1 of tasks, irrespective of its complexity. We newly define the complexity of a product as the product-specific minimum quality. In particular, we assume that product i has minimum quality, $q_{i,\min} = [i]^{\frac{1}{\lambda}}$, $\forall\, i \in [0, N]$. It turns out that this model exhibits the same qualitative characteristics. The main difference is that now, in an equilibrium with sufficient skills, the quality-adjusted price and output level is the same for each product. This follows naturally from the fact that production is equally difficult for any two products of same quality.

With the described changes in assumptions, the production function (5.7) changes to:

$$E\left[x_{i,q}\right] = [r]^{q^{\lambda}}\, L_i(r), \quad q \geq [i]^{\frac{1}{\lambda}} \ .$$

This is, up to the minimum-quality constraint, the same production function as the one faced by firm $i = 1$ in the version of the model presented in the main text. The discussions of section 5.2.2 apply to all firms $i \in [0, N]$ and hence also to firm $i = 1$. It follows that Lemma 5.1 also applies in the present case, with the only difference that:

$$q_i(r) = \max\left\{[i]^{\frac{1}{\lambda}}\, , \left[-\frac{1}{\lambda \log(r)}\right]^{\frac{1}{\lambda}}\right\} \ ,$$

which does not affect the threshold complexity and skill levels, $\tilde{i}(r)$ and $\tilde{r}(i)$.[11] Also, as long as both countries produce at preferred quality, the relative productivity of two countries with different skill levels of labor is still given by equation (5.17). This implies that in an equilibrium with sufficient skills, the equilibrium wage is still given by Proposition 5.1(i). Now, however, this equilibrium is characterized by symmetry across firms in terms of quality-adjusted prices and output levels, as well as in their demand for effective labor. It follows that Assumption 5.1 simplifies to:

[11] Similarly, the discussions of appendix C.2 apply here, i.e. we could allow for an arbitrary distribution of skills across countries and allow the firm to hire workers with different skill levels for every task involved in production. This would not affect aggregate outcomes.

Assumption C.1

$$\frac{\int_{e^{-\frac{1}{\lambda i}}}^{\overline{r}} [-\log(r)]^{-\frac{1}{\lambda}} \; dF_r(r)}{\int_{\underline{r}}^{\overline{r}} [-\log(r)]^{-\frac{1}{\lambda}} \; dF_r(r)} \geq 1 - \frac{i}{N}, \quad \forall\, i \in [0, N] \;,$$

and we can show that the equilibrium satisfies:

Proposition C.1

Let Assumption C.1 be satisfied. Then in any equilibrium it holds:

(i) $w_r^\star = \left[\frac{\log(\underline{r})}{\log(r)}\right]^{\frac{1}{\lambda}} \;\forall\, r \in \mathcal{R}$

(ii) $\mathcal{R}_i^\star \subseteq \{r \in \mathcal{R} :\, r \geq \tilde{r}(i)\} \;\forall\, i \in [0, N]$

(iii) $q_i^\star(r) = \left[-\frac{1}{\lambda \log(r)}\right] \;\forall\, (i, r) \in [0, N] \times \mathcal{R}_i^\star$

(iv) $\rho_i^\star = \frac{\sigma}{\sigma-1} \left[-e\lambda \log(\underline{r})\right]^{\frac{1}{\lambda}} \;\forall\, i \in [0, N]$

(v) $\chi_i^\star = \tilde{L} \left[-e\lambda \log(\underline{r})\right]^{-\frac{1}{\lambda}} N^{-1} \,\forall\, i \in [0, N]$

(vi) $\tilde{L}_i^\star = \tilde{L} N^{-1} \,\forall\, i \in [0, N]$

(vii) $P^\star = \frac{\sigma}{\sigma-1} \left[-e\lambda \log(\underline{r})\right]^{\frac{1}{\lambda}} N^{\frac{1}{1-\sigma}}$

(viii) $C^\star = \tilde{L} \left[-e\lambda \log(\underline{r})\right]^{-\frac{1}{\lambda}} N^{\frac{1}{\sigma-1}}$

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