Growth Differences across Countries:
Inequality, Values, and the Diffusion of Technology

DISSERTATION
of the University of St.Gallen,
School of Management,
Economics, Law, Social Sciences
and International Affairs
to obtain the title of
Doctor of Philosophy in Economics and Finance

submitted by

Adrian Jäggi

from Madiswil (Bern)

Approved on the application of

Prof. Dr. Reto Föllmi

and

Prof. Dr. Manuel Oechslin

Dissertation no. 4929

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The University of St.Gallen, School of Management, Economics, Law, Social Sciences and International Affairs hereby consents to the printing of the present dissertation, without hereby expressing any opinion on the views herein expressed.

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The President:

Prof. Dr. Thomas Bieger

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St.Gallen, July 12, 2019 Adrian Jäggi

Abstract

This dissertation uses theoretical as well as empirical tools to study determinants of cross-country differences in income growth, focussing on the role of consumer inequality, values, and the diffusion process of technologies.

Chapter 1 investigates how household income inequality shapes the diffusion of technologies. A simple demand side model with hierarchical preferences is used to show that after some minimum level of average income relative to the price of the technology is achieved, more consumer inequality hinders the diffusion process for new technologies. Using data on 39 major technologies, the empirical part tests this proposition. It is found that more inequality, as measured by the Gini index, is detrimental to the diffusion of new technology, while a large middle class is conducive to technology diffusion. These effects are stronger for consumer than for producer technologies. Furthermore, there is some evidence that the negative effect of inequality on the diffusion of technologies is more pronounced in rich countries. For the extensive margin, the chapter presents evidence for a positive effect of inequality on technology adoption.

Chapter 2 introduces a model of creative destruction with non-homothetic preferences for quality to study the joint growth effects of inequality and openness. While the growth effects of consumer inequality are non-trivial, the chapter shows that once it is possible for rich consumers to import high quality goods, higher inequality interacted with more openness has a negative impact on quality upgrading in countries that are not operating at the technology frontier. This effect materializes through reduced incentives for domestic firms to innovate. The empirical analysis uses sectoral quality data to investigate these model predictions. It is shown that for developing countries, consumer inequality and openness indeed have a joint negative effect on the rate of quality upgrading.

Chapter 3 establishes a measure of bilateral differences in values using 857 questions from the World Values Survey. The chapter explores the determinants of value distance, linking it to geography as well as the historical relatedness of populations across 90 countries. Furthermore, the explanatory power of value differences for economic development is assessed and a close association between bilateral value distances and differences in GDP per capita is found.

Chapter 4 examines the role of differences in loss aversion in explaining cross-county variations in economic fundamentals. Coming from a macroeconomic perspective, it tests whether preferences stated in Kahneman and Tversky's prospect theory, namely reference point dependence and loss aversion, prevail on the aggregate and whether the average degree of loss aversion differs across countries. The chapter documents evidence of loss aversion for a broad set of OECD countries, while the average loss aversion clearly differs across these countries. Furthermore, in line with what theory predicts, loss aversion is negatively correlated with GDP and consumption per capita and positively correlated with consumption smoothing.

Zusammenfassung

Diese Dissertation verwendet theoretische und empirische Methoden, um Determinanten länderübergreifender Unterschiede im Einkommenswachstum zu untersuchen. Dabei stehen Ungleichheit, Werte und der Diffusionsprozess von Technologien im Vordergrund.

Kapitel 1 untersucht, wie Einkommensungleichheit die Verbreitung von Technologien beeinflusst. Ein einfaches nachfrageseitiges Modell mit hierarchischen Präferenzen zeigt, dass nach Erreichen eines Minimums in Durchschnittseinkommens im Verhältnis zum Preis der Technologie mehr Ungleichheit den Diffusionsprozess für neue Technologien behindert. Anhand von Daten zu 39 wichtigen Technologien testet der empirische Teil diese Aussage. Es wird festgestellt, dass mehr Ungleichheit, gemessen am Gini-Index, die Verbreitung neuer Technologien verlangsamt, während eine grosse Mittelschicht der Technologieverbreitung förderlich ist. Diese Effekte sind stärker für Verbraucher- als für Produzententechnologien. Die negativen Auswirkungen der Ungleichheit auf die Verbreitung von Technologien sind in reichen Ländern stärker ausgeprägt. Für die erstmalige Einführung von Technologien liefert das Kapitel Belege für einen positiven Effekt der Ungleichheit.

Kapitel 2 führt ein Modell der kreativen Zerstörung mit nicht-homothetischen Präferenzen ein, um Wachstumseffekte von Ungleichheit und Offenheit zu untersuchen. Während die Effekte von Ungleichheit nicht trivial sind, zeigt sich, dass sobald hochwertige Güter für reiche Verbraucher importiert werden können, höhere Ungleichheit in Verbindung mit mehr Offenheit negative Auswirkungen auf Qualitätssteigerungen in sich entwickelnden Ländern hat. Dieser Effekt entsteht durch geringere Innovationsanreize für inländische Unternehmer. Die empirische Analyse verwendet sektorale Qualitätsdaten, um diese Vorhersagen zu testen. Es zeigt sich, dass für Entwicklungsländer Ungleichheit der Verbraucher und Offenheit gemeinsam einen negativen Einfluss auf Qualitätssteigerungen haben.

Kapitel 3 entwickelt ein Mass für bilaterale Unterschiede in Wertvorstellungen aus 857 Fragen der World Values Survey. Das Kapitel untersucht die Determinanten der Wertdistanz und verbindet sie mit Geographie sowie historischer Verwandtschaft der Bevölkerung in 90 Ländern. Darüber hinaus wird die Erklärungskraft von Wertunterschieden für die wirtschaftliche

Entwicklung untersucht und ein enger Zusammenhang zwischen bilateralen Wertdistanzen und Unterschieden im BIP pro Kopf festgestellt.

Kapitel 4 untersucht die Rolle von Unterschieden in Verlustaversion bei der Erklärung von Unterschieden in wirtschaftlichen Fundamentaldaten. Aus makroökonomischer Sicht wird geprüft, ob die in Kahneman und Tversky's Prospekttheorie genannten Präferenzen, Referenzpunktabhängigkeit und Verlustaversion, sich auf das Aggregat auswirken und ob der durchschnittliche Grad der Verlustaversion von Land zu Land unterschiedlich ist. Das Kapitel dokumentiert Verlustaversion für eine Reihe von OECD-Ländern, während die durchschnittliche Verlustaversion sich in diesen Ländern deutlich unterscheidet. Darüber hinaus ist die Verlustaversion gemäss den Prognosen der Theorie negativ mit dem BIP und Konsum und positiv mit Konsumglättung korreliert.

Contents

Chapter 1

Income Inequality and Technology Diffusion

1.1 Introduction

This paper studies the effect of income inequality on the diffusion of technologies. Previous literature has shown that technology and its diffusion are important determinants of economic development (e.g. Jones (2016)). At the same time, it is well documented that the distribution of incomes has changed in recent decades in many countries (e.g. Alvaredo et al. (2018); Piketty (2014); Piketty and Zucman (2014); Piketty, Saez and Zucman (2018)). Therefore, investigating how inequalities on the consumer side affect the diffusion of new technologies might help understand better the diffusion process of new technologies, an important determinant of development.

There is a huge literature explaining how new technology is created, how it relates to total factor productivity and how it spreads across countries. However, most contributions look at technology diffusion through the lens of the production side of the economy. This paper explicitly focuses on how inequality on the demand side (i.e. income inequality) might affect the diffusion of new technology. In this sense, this paper tries to combine insights from the literature that examines the effect of inequality on economic growth (e.g. Foellmi and Zweimüller (2006); Foellmi, Wuergler and Zweimüller (2014)) with findings about the diffusion process of technologies (e.g. Comin and Hobijn (2010); Comin, Hobijn and Rovito (2008)).

In a first part, the paper establishes the link between income inequality and technology diffusion by introducing hierarchic preferences and showing that after a technology has passed its initial stage of diffusion, income inequality hinders the diffusion process of the technology. Therefore, the main hypothesis of the paper is that income inequality is detrimental to the intensive margin of technology diffusion. The literature established that diffusion curves of new technology can usually be characterized by two margins (e.g. Comin and Mestieri (2014)): The extensive margin mirroring initial adoption in a country and the intensive margin (also named the penetration rate) describing the diffusion process within a country. Since the intensive margin has been found to be more important in explaining differences in development (Comin and Mestieri, 2018), this paper mainly examines the effect of inequality on the intensive margin.

To test this hypothesis empirically, I collect data on the diffusion of technologies across countries, largely following Comin and Hobijn (2009). I then measure the level of technology diffusion by either its usage per capita or by a measure called "technology adoption lag", which was introduced by Comin, Hobijn and Rovito (2008). This measure basically calculates the backwardness of a country to the United States. Furthermore, to measure inequality, I collect data on the Gini index along with quantile shares of income. Figure 1.1 gives a first glimpse at the relationship that I will look at in the empirical part. It shows that the Gini index (in the year 2000) correlates negatively with a measure of technological development in 2000, taken from Comin, Easterly and Gong (2010), while a strong middle class is positively associated with the technology index.

— Figure 1.1 about here —

Regression analysis will confirm that inequality indeed has a detrimental effect on the diffusion of technologies. A robustness exercise using a measure for redistribution to instrument for the inequality measure as well as dynamic panel methods confirm this finding. While inequality might be conducive to initial adoption of a country (the extensive margin), it is shown to have significantly adverse effects on the diffusion process (the intensive margin). Furthermore, the effects are shown to hold stronger for rich countries, and as could be expected, the effects are largely driven by consumer technologies, while the effect on producer technologies is much smaller. Nevertheless, assuming that further advances in information and communications technology (ICT) are of increasing importance also for a countries' productivity, it can be argued that these findings are relevant from a growth (or productivity) perspective as well.

The remainder of this paper is structured as follows: Section 1.2 presents the relevant literature for this study. Section 1.3 elaborates on the shape of technology diffusion curves and introduces optimal consumer demand for technologies assuming hierarchic preferences. In section 1.4 I will describe the data and provide descriptive statistics. Section 1.5 shows results for the intensive margin from panel regressions. Various robustness checks for these regressions are presented in section 1.6. In section 1.7 I provide some evidence on the extensive margin, while section 1.8 concludes.

1.2 Literature Review

The literature investigating technology as a source for economic growth is vast (see, for example Jones (2016), for an overview). Especially following the work of Solow (1956, 1957), a rich amount of research on productivity growth as a driver of economic growth emerged. The literature on endogenous growth has put forward the argument that advances in technology, which are a key driver of economic growth, result from investment in research and development (Aghion and Howitt, 1992; Romer, 1990). The work building on Schumpeterian ideas of creative destruction describes the growth process in the light of the idea that growth is generated by innovations. The essence in these models is that entrepreneurs invest in R&D to find innovations because they are motivated by the prospect of a monopoly rent (Aghion and Howitt, 1996; Aghion, Akcigit and Howitt, 2014, 2015). Parente and Prescott (2000) claim that the main part of income differences across countries stems from TFP differences.

Most of this classical literature is concerned with productivity growth at the technology frontier. However, since investment in R&D is concentrated in some rich countries, it cannot be the only source of technological progress (Keller, 2010). Furthermore, technologies do not have the same impact on productivity in all countries (Acemoglu, 2008). The literature exploring drivers of technology diffusion is extensive as well. Stoneman and Battisti (2010) provide a good overview of findings. Parente and Prescott (1994) and Basu and Weil (1998) argue that technology flows stop at national borders because there are (institutional) barriers to technology diffusion. Eaton and Kortum (1999) provide a model with of positive spillovers from inventing countries, while Fagerberg, Srholec and Verspagen (2010) stress the importance of so-called technological capabilities of the adopting country. Keller (2010), noting that foreign sources typically account for a large share of domestic productivity growth, investigates the impact of trade and foreign direct investment on the flow of technological knowledge. Other studies where technology diffuses due to trade or idea flows include Alvarez, Buera and Lucas (2013), where ideas flow through cross-country meetings of business people, and Grossman and Helpman (1991), where technological knowledge flows through R&D spillovers. Agha and Molitor (2018) find that information frictions might slow down the diffusion of technology, and that local opinion leaders can play a key role in easing those frictions. Packalen and Bhattacharya (2015) examine the effect of geographical proximity and find that it has a considerably positive impact on the adoption of new ideas.

An often-mentioned important driver of technology diffusion is human capital (Easterly et al., 1994; Nelson and Phelps, 1966). Benhabib and Spiegel (2005) and Comin and Mestieri (2014) find a positive impact of human capital on technology diffusion. Comin and Hobijn (2004) provide further evidence that besides a country's openness, adoption history and type of government, education is a key determinant for the speed of technology adoption. Caselli and Coleman (2001) show that the higher the level of primary schooling, the more computers are imported. Lee (2001) finds that human capital plays a crucial role in the increasing technology gap between developing and advanced countries. As Comin and

Mestieri (2014) note, the effects of different potential drivers on technology adoption might vary significantly across different technologies. A country's adoption history was found to be an important driver of diffusion of new technology (Comin and Hobijn, 2004; Comin and Mestieri, 2014; Comin, Hobijn and Rovito, 2008), suggesting that some inputs in the adoption process are transferable. Comin and Mestieri (2014) note that this kind of persistence in adoption, however, might also be the result of some other persistent factor that affects adoption of technology: Similar as for income, such factors might include genetic diversity (such as in Ashraf and Galor (2013)), genetic distance to the technology frontier (Spolaore and Wacziarg, 2009) or stem from differences in the quality of institutions, as put forward by Acemoglu, Johnson and Robinson (2002). Cervellati, Naghavi and Toubal (2018) document that while trade openness and democratization by themselves do not have any significant impact on the adoption of technology, the interaction between the two factors significantly affects technology diffusion; i.e. trade liberalization and democratization are complementaries in shaping incentives for the adoption of new technologies. Other drivers of technology diffusion that have been identified in recent studies include differences in labor market regulations (Alesina, Battisti and Zeira, 2017), the level of development of the financial system (Cole, Greenwood and Sanchez, 2016), the resolution of the mismatch between a technology's capability and the requirements of potential users (Gross, 2018) or the role of the business cycle (Comin and Gertler, 2006; Comin and Mestieri, 2014).

A more recent strand of literature which is relevant for this paper looks at the effect of technology advancement on inequality (i.e. the reverse of the research question of this study). Acemoglu (2002) finds that skill biased technological change might lead to increases in inequality. Karabarbounis and Neiman (2013) document a significant decline in the labor share since the early 1980's and attribute this phenomenon to the decrease of the relative price of investment goods due to ICT advances, which induced firms to replace labor with capital. Autor (2014), however, argues that in recent research, the extent of machine substitution has been overrated, while the extent of machine complementary has been ignored. Akerman, Gaarder and Mogstad (2015) find that broadband internet improves outcomes for skilled workers, whereas it worsens outcomes for unskilled workers. Bresnahan (2010) claims that so-called general purpose technologies first lead to a slump (since many resources are required to develop the new technology) before the adoption of the new technology is finally reflected in a boom and economic growth. There is an ongoing debate between those who are optimistic (e.g. Brynjolfsson and McAfee (2014); Mokyr, Vickers and Ziebarth (2015)) and pessimistic (e.g. Gordon (2012) who worries about secular stagnation and claims that most productivity-enhancing innovations have already been made) about the overall effects of the recent advances in ICT.

All these contributions mainly look at technology diffusion from the production side of the economy. This paper, however, investigates the effect of income inequality on the diffusion of technology. Here, the existing literature mainly focuses on the effects of inequality on growth. Bénabou (1996) points out the importance of looking beyond the first moment of income in initial conditions when comparing countries' paths of development. For example, while South Korea and the Philippines had similar levels of GDP, population, urbanization and school enrolment rates in the 1960's, the distribution of income and wealth were quite different. Easterly (2007) finds inequality to be a large barrier to prosperity, institutional quality and schooling. Matsuyama (2002) shows that in a model where productivity improvements and increases in the number of consumer goods reinforce each other through price adjustments and a growing size of the consumer market, the effect of inequality on growth is not trivial and potentially non-monotonic.

There is evidence for both, positive as well as negative effects. Foellmi and Zweimüller (2006) show that in an innovation-based growth model with product innovations and hierarchical preferences, inequality fosters economic growth because inequality stimulates R&D. If firms can also undertake process innovation, however, the impact of inequality on economic growth is ambiguous (Foellmi, Wuergler and Zweimüller, 2014). Foellmi and Zweimüller (2016) look at the effect that the productivity gap between innovators and followers has on the relationship between inequality and growth. Kuznets (1955) argues that when individuals in the top bracket of the income distribution have more income, savings in the economy will be higher, since rich individuals save a higher proportion of their income. Hence, inequality might foster growth, because more unequal societies save more. Galor and Moav (2004) also explore the savings channel and argue that during the first stages of industrial revolution, physical capital was the main driver of growth. Therefore, inequality was beneficial to growth, since resources were in the hands of those who saved more. However, as human capital accumulation became the main driver of economic growth, the impact of inequality on growth reversed, since inequality hampers human capital formation (see also Galor and Zeira (1993)). Persson and Tabellini (1994) relate inequality to distributional conflicts, which lead to fiscal inefficiencies and therefore hamper growth. Halter, Oechslin and Zweimüller (2014) explore the time dimension of the impact of inequality on growth. Noting that many of the growth enhancing effects of inequality set in relatively fast, whereas the growth-reducing effects take time to set in, they provide evidence that indeed inequality is growth-enhancing in the short term, but hampers growth in the long run. Voitchovsky (2005) finds that the effect of inequality on economic growth depends on the part of the income distribution looked at: Inequality at the top is found to be positively related to growth, whereas the converse holds for regions further down the income distribution. Barro (2000) concludes similarly, finding that high inequality is detrimental to economic growth in poor countries, but conducive to growth in rich countries. In a more recent paper on the topic, however, Brueckner and Lederman (2018) find that transitional growth is boosted by income inequality in countries with a lower initial income, while the opposite is true for countries with high initial income.

1.3 Inequality and Technology Diffusion

There is only limited evidence on the link between inequality and technology diffusion. Fuchs (2009) estimates a negative relationship between inequality and the diffusion of internet access, while Hyytinen and Toivanen (2011) find a positive effect of inequality on the diffusion of mobile phones in developing countries. Especially for these more recent consumer technologies, availability to individuals seems to be crucial also for a country's productivity. Individual's knowledge in operating modern technologies adds to the human capital stock and increases productivity in production, especially for increasingly service-oriented economies. Furthermore, one could imagine that ICT intensity increases the speed of diffusion for other (production) technologies, even if results about the effects of ICT intensity on productivity are mixed (Acemoglu et al., 2014; Basu, Fernald and Shapiro, 2001; Black and Lynch, 2001; Brynjolfsson and Hitt, 2000). To generate predictions about how inequality affects the diffusion of new technologies, I will first introduce a simple demand-side model with non-homothetic preferences. Then, I will consider past findings of the literature to formulate additional hypotheses.

The demand-side model follows closely Foellmi and Zweimüller (2008), where here the consumption goods considered are the technologies. These technologies are denoted and ranked by an index i, where lower i correspond to older technologies. I assume that consumers have hierarchic preferences. Consumers first consume basic technologies and once they climb the income ladder they start consuming more advanced technologies. There are, potentially, infinitely many technologies consumers can consume. Denoting the contemporaneous utility as $v(c(i))$ one can then define the consumers preferences as

$$U(c(i)) = \int_0^\infty \xi(i)v(c(i))\mathrm{d}i, \tag{1.1}$$

where I assume $v' > 0$ and $v'' < 0$ and $\xi(i)$ denotes the hierarchy function, which is assumed to monotonically decrease in i, $\xi'(i) < 0$, and therefore basic technologies get a higher weight than advanced technologies. This introduces the desired hierarchy of the technologies in the preferences. To make the hierarchic preferences meaningful, it has to be the case that not all consumers will buy all technologies, i.e. the non-negativity constraint on consumption will be binding for some goods. Again following Foellmi and Zweimüller (2008), I assume $\xi(i) = i^{-\gamma}$ with $\gamma \in (0, 1)$. Second, I assume instantaneous utility to be quadratic, i.e. $v(c(i)) = 0.5[s^2 - (s - c(i))^2]$. This allows for a binding non-negativity constraint, as marginal utility at zero consumption is finite. Then,

$$U(c(i)) = \int_0^\infty i^{-\gamma} 0.5[s^2 - (s - c(i))^2]\mathrm{d}i, \tag{1.2}$$

which consumers maximize subject to a budget constraint given by

$$e = \int_0^\infty p(i)c(i)\mathrm{d}i \tag{1.3}$$

and the non-negativity constraints $c(i) \geq 0$. The solution to this maximization problem gives (for goods that are consumed, i.e. $c(i) > 0$)

$$c(i) = s - \lambda i^\gamma, \tag{1.4}$$

where λ is the Lagrange-multiplier. Furthermore, for the last good that is consumed N, $c(N) = s - \lambda N^\gamma$. For reasons of continuity, $c(N) = 0$ and therefore $\lambda = s/N^\gamma$. Using this in (1.4) delivers consumption as a function of i and the total number of goods N,

$$c(i) = s - i^\gamma s N^{-\gamma} = s\left[1 - \left(\frac{i}{N}\right)^\gamma\right], \tag{1.5}$$

where $i \in [0, N]$. Here one can see the hierarchy of the goods: The quantities consumed depend on the relative position of a good in the hierarchy of needs i/N. γ captures the the steepness of this hierarchy.[1] Using the budget constraint, one can then establish $N = ke$, where $k = \frac{1+\gamma}{s\gamma}$. This leads to the individual consumption function:

$$c(i) = s\left[1 - \left(\frac{i}{ke}\right)^\gamma\right]. \tag{1.6}$$

Figure 1.2 shows individual consumption of good c as a function of i as well as as a function of e. Obviously, $c(i)$ is falling in i, showing the hierarchy of the goods. Furthermore, $c(i)$ is increasing and concave in e.

— Figure 1.2 about here —

[1] Note that s is a parameter that will not matter for the results here.

Note that since $i \in [0, N]$, and goods are continuous, the last good N is consumed in zero quantity, i.e. $c(N) = 0$. Good zero is consumed in quantity s. Hence, $c(i) \in [0, s]$. To derive aggregate consumption of good i, i.e. $C(i)$, $c(i)$ needs to be integrated over the distribution of e. Note that the integration boundaries start not at zero but some minimum level $e_{min}(i)$. I assume incomes to be Pareto distributed, i.e.

$$g(e) = \frac{\alpha e_m^\alpha}{e^{\alpha+1}} \tag{1.7}$$

with shape-parameter α and and scale-parameter e_m. A nice feature of this distributional form is that one can express the Gini index of the Pareto distribution in terms of the shape-parameter α, i.e. $G = \frac{1}{2\alpha-1}$, where G is the Gini index (Kleiber and Klotz, 2003). Note that here e_m is the minimum level of income among individuals, while $e_{min}(i)$ denotes the minimum level of income required to consume good i. Integrating equation (1.6) over the distribution (1.7) and using the fact that $e_{min}(i)$ sets equation (1.6) equal to zero, i.e. $e_{min}(i) = \frac{i}{k}$, leads to

$$C(i) = \frac{\gamma}{\alpha+\gamma}\left(\frac{e_m}{e_{min}(i)}\right)^\alpha. \tag{1.8}$$

Then, since I want to study the effect of a change in inequality on the demand of good i, I need to take the derivative of equation (1.8) with respect to α. However, changing α also changes the mean of income in the Pareto distribution.[2] Since I want to study a mean-preserving inequality change, I have to replace e_m with the mean income, $\bar{e}$. For the Pareto distribution,

$$e_m = \frac{\alpha-1}{\alpha}\bar{e}. \tag{1.9}$$

Using this in equation (1.8) leads to

$$\frac{\partial C(i)}{\partial \alpha} = \left(\frac{\alpha-1}{\alpha}\right)^\alpha B^\alpha \frac{\gamma}{\alpha+\gamma}\left[\ln B + \ln\left(\frac{\alpha-1}{\alpha}\right) + \frac{\gamma+1}{(\alpha+\gamma)(\alpha-1)}\right], \tag{1.10}$$

[2] The mean of the Pareto distribution is $\frac{\alpha e_m}{\alpha-1}$ (Kleiber and Klotz, 2003). Therefore, increasing α (i.e. decreasing inequality) lowers the mean of the Pareto distribution, because $\frac{\partial \frac{\alpha e_m}{\alpha-1}}{\partial \alpha} = -\frac{e_m}{(\alpha-1)^2} < 0, \forall \alpha > 1$. Therefore, by increasing α, one would not only decrease inequality in the economy, but also make the economy poorer as a whole.

where $B \equiv \frac{\bar{e}}{e_{min}(i)}$. The term outside the square brackets is positive since $\alpha \geq 1$, while the sign of the term in the square brackets depends on B, γ and α. Hence, I will determine how large B must be in order to make the expression positive[3], for different values of γ and α. Table 1.1 reports these values.

— Table 1.1 about here —

Therefore, for reasonable values of the Gini index and for technologies that are not introduced too recently to the market (i.e. $\bar{e}$ is significantly larger than e_{min}), a higher level of inequality reduces consumption of the technology. This is summarized in proposition 1.

Proposition 1. *Higher inequality reduces consumption of a certain technology if the minimum income required to buy a certain technology is not too high compared to the mean of the incomes.*

This proposition is illustrated in figure 1.3, where total consumption is plotted as a function of both the inequality parameter α as well as the mean income of the economy $\bar{e}$. As stated in proposition 1, if $\bar{e}$ is low higher inequality, indicated by a lower value of α, leads to higher consumption levels. However, as the level of $\bar{e}$ goes up, more inequality becomes worse for total consumption, such that for higher values of $\bar{e}$, relative to $e_{min}(i)$, inequality reduces total consumption.

— Figure 1.3 about here —

This proposition can be combined with previous findings that technology diffusion curves can be characterized by two parameters: A horizontal and vertical shift, reflecting the intensive and the extensive margin, respectively (Comin and Hobijn, 2010; Comin and Mestieri, 2014). The importance to distinguish the two margins was already pointed out by Griliches (1957), and recent contributions distinguish between the two margins as well (Agha and Molitor, 2018; Gross, 2018). Proposition 1 suggests that if a technology is very recent (and therefore expensive), higher inequality increases its consumption. Hence, higher inequality

[3]Remember, a higher value of α represents a more equal distribution. Hence, whenever equation (1.10) is positive, inequality is bad for consumption / diffusion of the technology

is beneficial to the extensive margin of technology diffusion (the adoption lag). If the technology has been on the market for a longer period of time, its price decreases. Then, the technology is purchased by more households if inequality is low. Hence, lower inequality is beneficial to the intensive margin of technology diffusion. Note here that this results does not hinge on the assumption that income is distributed with a Pareto distribution. In appendix D I show that this result also holds for a log-normal distribution of incomes. Comin and Hobijn (2010) and Comin and Mestieri (2018) conclude that a large fraction of variation in income per capita across countries can be explained by technology adoption, whereas the intensive margin is more decisive than the extensive margin. Recently, adoption lags have converged. But the ongoing divergence in the intensive margin prevents poorer countries to catch up with the western countries (Comin and Mestieri, 2014, 2018). Therefore, in the empirical part of the paper, I will mainly focus on the intensive margin: I will compare intensity levels of technology diffusion across countries and time, disregarding the point in time when the technology was introduced in a specific country.[4] The model predictions can also be aligned well with findings in Foellmi and Zweimüller (2006) and Foellmi, Wuergler and Zweimüller (2014). For the initial phase of the technology, the price effect will dominate the market size effect, and a rich class of consumers is required in order to afford the new technology. However, as the technology becomes more mature, process innovation becomes more important and hence the market size effect dominates. A larger income gap between the rich and the poor will hinder diffusion of technology (Foellmi, Wuergler and Zweimüller, 2014). Based on these considerations, the following hypotheses can be derived:

Hypothesis 1. *Higher inequality decreases the adoption lag. In order to introduce a new technology in a country, a wealthy rich class is needed as potential buyers. Therefore, inequality is beneficial to the extensive margin of technology adoption.*

Hypothesis 2. *Higher inequality lowers the penetration rate. In order for a technology to have high penetration rate, a large share of the population needs to be able to afford the technology when its price has been lowered after the first*

[4] I will provide some evidence on the extensive margin in section 1.7.

stages of introduction. This is the case if incomes are distributed more evenly.

In addition, the size of the middle class might matter as well (Bénabou, 1996). If there is a large middle class that can afford the technology, its diffusion will be faster. Therefore, in general, I conjecture that having a large middle class is beneficial to technology diffusion. Furthermore, inequality might be beneficial in the short run, while in the long term, the effect tends to be negative. This is due to the fact that the beneficial effects from inequality are purely economic and hence set in relatively fast, while the growth hindering effects are tied to the political process and take time to be effective (Halter, Oechslin and Zweimüller, 2014). Intuitively, income inequality should have a stronger impact on the diffusion of consumer technologies, since the effect is direct. Lastly, the findings in Barro (2000), Voitchovsky (2005) and Brueckner and Lederman (2018) suggest that the level of income in the country also affects the effect of inequality on growth and hence the same might be true for technology diffusion. For technology diffusion, building on Foellmi and Zweimüller (2006), I expect the effects to be in line with Brueckner and Lederman (2018), i.e. that inequality becomes worse the richer a country becomes. Imagine a rich country, in which the mean consumer can afford a certain technology at time t. If now income is redistributed from the poor to the rich, some consumers that are poorer than the mean but could afford the technology before redistribution can not afford it any longer. At the same time, nothing changes for the consumers that are richer than the average. Hence, redistributing from the poor to the rich is bad for technology diffusion in a rich country. However, in a poor country, where the mean consumer can not afford the technology at time t, redistributing income from the poor to the rich means that now some consumers that are richer than the mean and could not afford the technology before redistribution can now afford it. Hence, redistributing from the poor to the rich is good for technology diffusion in a poor country. These considerations lead to the following additional hypotheses, relating to the intensive margin of technology diffusion:[5]

[5] Note that in this paper the term technology diffusion is generally referring to the penetration rate, i.e. the intensive margin of technology diffusion. The extensive margin of technology diffusion is explicitly referred to as the extensive margin or the adoption lag.

Hypothesis 3. *The size and the relative wealth of the middle class can have important effects on the penetration rate. Whereas the redistributional effects towards a large and solid middle class can be ambiguous (i.e. dependent on whether redistribution is from the rich or the poor), in general a large middle class is desirable if the median income level is not too low.*

Hypothesis 4. *Higher inequality increases technology diffusion in the short run, but decreases diffusion in the long run. The total effect of inequality on technology diffusion is negative.*

Hypothesis 5. *Income inequality has a larger impact on the diffusion of consumer technologies than on the diffusion of production technologies, because the effect is direct.*

Hypothesis 6. *The negative effect of inequality on technology diffusion is more pronounced in rich countries. For poor countries, the effect might even be positive.*

1.4 Data

The main sources for the data on technology usage are the World Development Indicators (WDI) provided by The World Bank (2015) and the International Historical Statistics (IHS) by Mitchell (2013). Generally, data in the WDI dataset start in 1960. Hence, the IHS database is used to generate longer time series for the technology data. Additionally, I use data on some more recent health technologies from the OECD (2016). For steel production, I use the data provided by The World Steel Association (2015) and complement them with data from Comin and Hobijn (2009). For data on financial technologies, I use data provided by The Bank for International Settlements (2015) along with Comin and Hobijn (2009). Combining these data sources gives me cross-country data on the diffusion of 39 technologies. These technologies and their origin are documented in table A.1 in the appendix. For all technologies that are not already expressed as a share of population, I divide the usage level by the size of the population.

Data on inequality (i.e. Gini indices and quantile shares) I collect from four different sources: Deininger and Squire (1996), Solt (2016), the WDI (The World

Bank, 2015) and the World Income Inequality Database (WIID, UNU-WIDER (2015)). Solt (2016) is a very comprehensive database for data on Gini indices that combines data from various other data sources. Therefore, for the Gini indices, I will use this source. Regarding quantile shares, I combine data from Deininger and Squire (1996), the WDI and the WIID, while using data from Deininger and Squire (1996) only if the reported quality in medium or high. Also, data coming from the WDI and the WIID are prioritized.

To control for additional influences in the regression analysis later, I collect data on political institutions from Freedom House (2016), who provide an index that measures political rights on a scale from one to seven. To measure income per capita, I use real GDP and population data from the Penn World Table (PWT), version 9.0 (Feenstra, Inklaar and Timmer, 2015). From the same source I use the export share, to which I add the import share, to proxy for openness. Finally, I use an index of human capital, again provided by the PWT, which is based on years of schooling (Barro and Lee, 2013) and returns to education (Psacharopoulos, 1994).

1.4.1 Usage lags

One way to measure and compare technology diffusion across countries is by looking at per capita levels in a given country. This gives, for example, the share of people having access to the internet. However, since not all technology variables are measured as a percentage of the population, per capita usage levels are difficult to compare across technologies. Therefore, I will borrow a measurement from Comin, Hobijn and Rovito (2008) called technology usage lag. The technology usage lag is the answer to the following question: "How many years before year t did the United States last have a usage intensity of technology x that country c has in year t?" Hence, for all our technology variables, I compute

$$\tau_{c,x,t} = \frac{pc_{c,x,t} - pc_{US,x,\underline{s}}}{pc_{US,x,\bar{s}} - pc_{US,x,\underline{s}}}(\bar{s} - \underline{s}) + \underline{s}, \tag{1.11}$$

where $\bar{s}$ is the last time the United States passed level $pc_{c,x,t}$ and $\underline{s}$ is the last time the United States has a usage level lower or equal to $pc_{c,x,t}$. Then, the usage lag for technology x in country c at time t is simply

$$lag_{c,x,t} = t - \tau_{c,x,t}. \tag{1.12}$$

This measure is simple to interpret and has the advantage that it is comparable across technologies. Naturally, the technology usage lag might be negative, indicating that the United States is not the technology frontier for that technology. A potential drawback of the usage lag measure is that there are cases where it is censored. This is the case when either the United States never achieved the usage level of country c or when the United States never had such a low level as country c has in a particular year t.

In order to compare the usage lag across technologies, following Comin, Easterly and Gong (2010), I create a second (standardized) technology variable, where I divide the usage lag by the year minus the invention year of the technology:

$$\widetilde{lag_{c,x,t}} = 100 \times \left(\frac{lag_{c,x,t}}{t - Inventionyear_x} \right). \tag{1.13}$$

Hence, I correct for the fact that older technologies that have potentially larger usage lags by dividing by a larger number (t minus the invention year of the technology). With this measure, I can then compute the average standardized usage lag of a country c in year t:

$$lag_{c,t} = \frac{1}{n} \sum_{x=1}^{n} \widetilde{lag_{c,x,t}}, \tag{1.14}$$

where n is the number of technologies. This measure is a summary statistic of as country's technological backwardness and will serve as the main outcome variable in the empirical analysis.

1.4.2 Descriptive statistics

Merging the data on inequality, the technologies and the control variables gives an unbalanced panel covering over 200 countries, 39 different technologies, various measures of inequality (Gini indices and quantile shares) and a set of potential covariates. Since inequality data are hardly available prior to 1960, I restrict the sample to observations for years after 1960. Furthermore, I remove observations for geographic entities that are not countries (any more), such as the OECD total or the Ussr.

For the technology data, i.e. all usage levels and usage lags, zeros are recoded as missing values. From the original data sources, it is not clear what the difference between a zero and a missing value is. I.e. if the technology is not used in any given country, sometimes this is coded as a missing, while for other technologies it is coded as a zero. Also, I recode all technology usage lags for the United States as missing: By definition, the usage lags are computed relative to the United States, and therefore having the United States in the sample makes no sense.

All technologies are classified as either consumer- or producer technologies (see table A.1 in the appendix), and the average standardized usage lag formulated in equation (1.14) is computed for consumer- and producer-technologies separately – along with the measure for all technologies together.

For most parts of this section I will restrict myself to describing two technologies (along with the average standardized usage lag calculated over all technologies), namely electricity production and internet access. Electricity is without doubt one of the most important technologies developed in the past 200 years. Furthermore, it is an interesting case because it is a rather old technology and might reflect an example of an inferior technology for the sample years considered. Internet access, however, is a very recent technology that certainly has not reached its peak in many countries. Additionally, internet access can be viewed an example for a consumer technology, whereas electricity production is likely to be rather a producer technology. Furthermore, I also provide descriptive statistics for the main explanatory variables, i.e. the Gini indices and the quantile shares.

Technology data — Tables A.3 and A.4 in appendix A present the basic descriptive statistics for the 39 technology variables. Table A.3 presents descriptive statistics for the technology variables in per capita levels. Obviously there is huge variation in per capita technology variables, deriving from the fact that different years as well as different countries are in the sample. Also, for some technologies the number of observations is rather small, mostly due to the fact that the technologies are rather recent innovations. In table A.4, descriptive statistics for the usage lags suggest that for some technologies, the number of observations is very low (due to censoring, see section 1.4.1). Also, for most of the technologies, the minimum is below zero, meaning that at least for one country-year combination, the United States was not the technology leader. However, in total this is true for only around 3.5% of the observations.

Next I present graphical representation of some of the technology data (per capita electricity production and internet access). To preserve readability, most of the figures are delegated to appendix B. The left panel of figure B.1 plots per capita electricity production for a set of six countries and reveals that usually diffusion curves are concave (see, for example, Comin and Mestieri (2014)). China, which only recently started to develop, is an exception here. Also, for the developed countries, we can see that the technology is phasing out, i.e. the technology might have reached its peak already. For internet access (right panel of figure B.1), a different picture emerges. The technology seems to have diffused very fast (at least in developed countries), suggesting that newer technologies spread faster.

Figure B.2 shows the histogram of the usage lags for electricity production as well as for internet access. For both technologies there are very little observations with a negative usage lag, suggesting that for electricity production and internet access, one can indeed assume that the United States is the technology frontier country. Furthermore, the usage lags are obviously larger for electricity production, because the technology is much older than internet. Therefore, when comparing two technologies with each other, I need to standardize the usage lag, as suggested in section 1.4.1

The main outcome variable I will use in the empirical analysis is the average standardized usage lag, as defined in section 1.4.1. This measure is a summary statistic of technological backwardness against the United States. Figure 1.4 shows the distribution of these usage lags, calculated using all 39 technologies I collected data for.

— Figure 1.4 about here —

In addition to the average standardized usage lags for all technologies, I will also use a standardized usage lags for consumer and producer technologies separately. However, the distributions of these two measures look very similar to the distribution in figure 1.4. Part III of table A.2 in the appendix provides the descriptive statistics for all three measures. Figure B.3 in the appendix shows the average standardized usage lag in the year 2010 for all countries. Not surprisingly the figure shows that Europe, North America and parts of East Asia lag only little behind the United States, while Africa, Latin America and parts of South Asia are further behind.

Inequality data — Next, I will describe the inequality data. As part I of table A.2 shows, also in the inequality measure, there is quite some variation across countries and time, with the Gini index ranging from 18 to 64 and the share of income going to the top 20% anywhere between 27% and over 70%.

Figure 1.5 reveals a well-known fact: A major share of income goes to the top 20% of earners. The left panel of the figure shows the distribution of the quantile shares across countries and years (i.e., the figure has no country and time dimension, such that the data are pooled across years and countries). The panel on the right shows the distribution of the Gini index, again pooled across time and countries.

— Figure 1.5 about here —

Examining the data it becomes clear that compared to other factors, the within-country variation in the Gini index measure over time is, for many countries, rather small. This will pose some limitations for the empirical exercise, since after controlling for country fixed effects, the within-country variation of the Gini index measure will be very small. Hence, including country fixed effects will only be possible when collapsing the panel to lower frequencies.

Covariates — Descriptive statistics for the covariates used in the regression analysis later are provided in part II of table A.2 in the appendix. Real per capita GDP (Income) ranges from 162 US Dollar in Liberia in the year 1995 to almost

239’000 US Dollars in the United Arab Emirates in 1970. Political rights (Institutions) are scored on a scale from one to seven, one being the best score in the sense of maximum political rights. Many countries achieve the best score of one in many years, while North Korea, Syria, Cuba but also China are examples of countries scoring the worst score of seven in recent years. Openness is measured by the share of merchandise exports in GDP plus the share of merchandise imports in GDP. Human Capital is measured as an index based of years of schooling and returns to education. Here, the highest value of 3.73 is achieved by the United Kingdom in the year 2014, while the lowest value of 1.01 was registered for Burkina Faso in 1960.

Correlation between inequality and technology diffusion — Figure 1.6 provides a first idea how the overall technological development in the sample relates to inequality.

— Figure 1.6 about here —

Note that the figure pools observations across countries and years. From visual inspection, inequality as measured by the Gini index seems to increase the usage lag, while a strong middle class seems beneficial to technology diffusion.

An illustrative example — To illustrate the claim that inequality affects technology diffusion in a negative way, this section briefly compares the development of the main indicators described above for South Korea and the Philippines (two countries that are often taken as an example in studies about the effects of inequality, see, for example, Bénabou (1996)). As is evident from panel (a) in figure B.4, at the beginning of the 1960’s both countries had a similar level of development (measured by per capita GDP) and also had similar levels of electricity production. So in these dimensions, both countries are comparable in 1960, except for the fact that the Philippines were much more unequal, as indicated by the grey line in the figure. Over time, the Philippines remain much more unequal, and South Korea experiences rapid growth in its GDP as well as dramatically decreases its lag against the United States in electricity production. For the Philippines, however, GDP remains almost flat, and the country falls further behind the technology frontier in electricity production.

Panel (b) of figure B.4 verifies the findings for the second technology of internet access. One can see that while Korea is converging to the United States, the lags in the Philippines seem to increase over time. In figure B.5 it becomes evident that these observations are also reflected in the main outcome measure used in this paper, the average standardized usage lag. While this measure remains relatively flat over time in the Philippines, one can observe a sharp decrease in the measure for South Korea. Of course, many other factors might have played a role here. The next section will therefore present results from regression analysis.

1.5 Regression Analysis

In this section I present results from panel regressions. I use the Gini index and the share of income going to the middle class (i.e. the share of income going to the second, third and fourth quantile) as inequality measures and investigate their respective effect on the diffusion of the single technologies (measured as the usage level as well as the usage lag). Furthermore, as a main outcome variable, I also use the average over the standardized usage lags, derived in equation (1.14), as a measure of the overall technology level in a given country and year (the average standardized usage lag).

I rely on panel regressions with fixed effects. Since inequality within countries varies very little compared to technology levels over time, country fixed effects cannot be used in this particular setting. Therefore, I use fixed effects for continents along with year fixed effects. To take out the effect that more developed countries tend to be more equal and at the same time more technologically advanced, I control for the countries' income level, measured as the log real GDP per capita (GDP) in most of the specifications. Furthermore, following the literature, (see e.g. Comin and Mestieri (2014)), I also control for differences in human capital (Human capital), which is an index that combines years of schooling and returns to education, and openness (Openness), where I use the export share of GDP minus the import share of GDP as a proxy. All three series are taken from the Penn

World Table (Feenstra, Inklaar and Timmer, 2015). Additionally, a measure of political rights is included (Institutions), again to try to control for some of the unobserved effects. This measure is taken from Freedom House (2016).

The model I estimate, therefore, is of the form

$$y_{c,t} = Ineq_{c,t}\beta + \boldsymbol{X_{c,t}}\gamma + \alpha_c + \alpha_t + u_{c,t}, \tag{1.15}$$

where $y_{c,t}$ is the outcome (technology) vector, $Ineq_{c,t}$ the vector of the regressor for the inequality measure and β the coefficient of interest. $\boldsymbol{X_{c,t}}$ is a matrix of control variables (including a constant), α_c and α_t are region (continent) and time fixed effects. Furthermore, as is standard in the literature, all standard errors are clustered at the country level throughout. Zeros in the technology variables are replaced with N/A values, as was explained in section 1.4.2.

Table 1.2 shows the results regressing the Gini index on the average standardized usage lag, which reflects a country's average technological backwardness against the United States.

— Table 1.2 about here —

Table 1.3 repeats the exercise using the share of income going to the middle class as outcome variable.

— Table 1.3 about here —

Columns 1 to 4 test hypotheses 2 and 3, the main hypotheses of this paper. Columns 5 and 6 test hypothesis 6, while columns 7 and 8 shed light on hypothesis 4. As expected, a higher level of human capital reduces the lag in technology diffusion, as does openness to trade. With both specifications and in most of the models, the estimated effect is negative and significant. Furthermore, the availability of technology significantly increases with income. Finally, the proxy for institutions is estimated to be positive, as was expected, as a higher score in the institutions index reflects less political rights. While in the regressions with the Gini index institutions seem to be statistically significant, using the share of income going to the middle class as outcome variable its significance is lower.

Perhaps some of its effects, however, might be taken up by human capital and income already. Overall, the control variable show the expected signs and are statistically significant in general.

Looking at the coefficients of interest, these first results also seem to confirm the main hypotheses: A higher Gini index significantly increases the average standardized usage lag to the United States, whereas having a strong middle class reduces the usage lag. Note that due to how the average standardized usage lag is defined, one cannot make any sensible statement about the economic size of the effect. However, looking at various individual technologies (appendix E), allows to quantify the effects. The share of people having access to the internet, for example, increases by 3.8 to 4.6 percentage points when the Gini index decreases by 10 points, and the standardized coefficient is between -0.13 and -0.15 (table E.1). Or, an average country catches up 0.7 to 1 years to the United States if its Gini index falls by 10 points, amounting to a standardized coefficient of 0.10 to 0.16 (table E.2). The results for the according regressions using the share of income going to the middle class are reported in tables E.3 and E.4. When interpreting the size of the coefficients, it is useful to keep in mind that the inequality measures used here are likely to underestimate within country inequality (see, for example, Atkinson, Piketty and Saez (2011) or Ravallion (2018)). Therefore, the estimated size of the coefficients can be read as lower bounds of the effects. Tables E.5 to E.20, which show the results for some other selected technologies, show similar patterns. Interestingly, for mobile phones, inequality seems to matter less than for other modern ICT. This might indicate that mobile phones are actually an important production good of the poor (Hyytinen and Toivanen, 2011). For the other modern ICT, the results are very robust. This is an important finding, since the spread of modern technology seems to become of ever greater importance, not just for the consumers' side but also for the production side in service-based economies.

More generally, the results found seem to hold stronger for consumer than for producer technologies. I divided all the technologies considered here into technologies that are rather consumer and those that are rather producer technologies (see table A.1 in the appendix). Then, I recalculate the average standardized usage lag using only consumer (producer) technologies and again estimate the effect of inequality on technology diffusion. Tables B.1 to B.4 reveal that basically the whole effect is driven by consumer technologies. The effects of inequality are both statistically and economically stronger when including consumer technologies only to calculate the average standardized usage lag. The standardized coefficients are more than twice the size for the specifications using consumer technologies only. Furthermore, in many specifications with producer technologies, the inequality measure is not significant. Overall, this is very strong support for hypothesis 5. Furthermore, comparing rail passengers (measured by person-kilometres travelled) to rail freight (measured by ton-kilometres), one finds that while rail passenger transport is significantly and consistently influenced by income inequality, this is not at all the case with rail freight. Hence, for a technology that is applied as a consumer and as a producer technology, inequality only affects the diffusion for the consumer technology purpose. For aviation, this finding holds to a lesser extent, probably highlighting that air travel is only affordable in better-off countries or the rich in developing countries. Nevertheless, these two examples showcase the finding that inequality influences consumer technologies to a greater extent than producer technologies do.

Does inequality really hinder the diffusion of *new* technology? Many of the technologies in the sample here are not very recent inventions, and also they were not in 1960, the year the panel starts. The only possibilities to shed some more light on this question is by looking into a technology whose production methods have changed over time. This panel includes data on different production methods of steel, and because some are more modern than others (see Comin and Hobijn (2004)), I can investigate how inequality impacts the diffusion of the different methods. As expected, I find that for the more modern production methods, diffusion is significantly influenced by inequality, whereas this is not the case for the older, outdated technologies. For the oldest steel production method (open hearth furnaces), the inequality measure is rarely significant, and in some specifications the estimated coefficients even point to a positive link between inequality and technology diffusion. The second newest production method, electric arc furnaces, establishes the negative link between inequality and technology diffusion, but in many specifications, the estimated coefficients are not significant. Only for the most recent production technology (blast oxygen furnaces) is diffusion systematically and negatively related to inequality. This gives some backing to the premise that indeed the effect on the diffusion of new technologies is measured.

Columns 5 and 6 include the interaction between the inequality variable and GDP. According to hypothesis 6, the expected effect is that the detrimental effect of inequality is more pronounced in rich countries. Tables 1.2 and 1.3 show mixed results. The interaction of the Gini index with per capita GDP points to the anticipated direction, suggesting that indeed inequality might become more detrimental in rich countries. However, the estimates are not statistically significant, and the point estimates for the Gini index alone are also positive. Therefore, I cannot conclude that for poor countries, inequality speeds up technology diffusion; only that inequality might be more detrimental in developed economies. For the share of income going to the middle class, the results are much less clear; the estimates for the interaction between the share going to the middle class and per capita GDP do not seem to be significantly influencing the average standardized usage lag.

When only considering the consumer technologies, however, the results become much more clear. The interaction between the Gini index and income is positive and statistically significant, while the Gini index alone is not estimated precisely. The same holds for the share of income going to the middle class, where the interaction term is negative and statistically significant and the coefficient for the middle class share alone remains insignificant (see tables B.1 and B.2). Therefore, for consumer technologies, the detrimental effect of inequality is more severe in rich countries, while I do not find evidence for positive effects of inequality in poor countries. For producer technologies, no such effects are apparent. Furthermore, for the most recent ICT, the hypothesis can be confirmed, for both the Gini index as well as the share of income going to the middle class. Here, I even find some evidence for the hypothesis that inequality can be good for technology diffusion in poor countries, while with rising GDP inequality becomes detrimental (see tables E.1 to E.8 and note that the result holds for the diffusion of broadband internet as well). The exception again are mobile phones, consistent with the arguments above. This hints to the fact that in poor countries, inequality is conducive to technology diffusion, since a rich upper class is required to be able to afford the new technology: The extensive margin is more important for technology diffusion. This is in line with the arguments made in hypothesis 1. The extensive margin of technology diffusion will further be discussed in section 1.7.

Finally, columns 7 and 8 do not seem to confirm hypothesis 4. Adding an inequality measure that is lagged by five years, I do not find any evidence for different effects in the short and in the long run. In some specifications, only the lagged inequality measure is significant, while in others, only the contemporary measure (or both) are significant. However, the effects of the contemporary and the lagged inequality measure both imply a negative effect of inequality on technology diffusion. Hence, in this setting I cannot distinguish between short and long run effects. However, other methods might be required for that purpose (see section 1.6.2).

Overall, the results suggest that indeed high inequality, measured by the Gini index, has a detrimental effect on the diffusion of new technologies, while a strong middle class has positive effects on technology diffusion. The effect is especially apparent for modern ICT, and is much stronger for consumer than for producer technologies. Furthermore, there is evidence that inequality impedes technology diffusion more in richer countries. For modern ICT, the results further suggest that the effect of inequality might be even positive in poor countries. Finally, in the current setting, I do not find any evidence for different short and long run effects of inequality on the diffusion of technology.

To illustrate and give an overview of the estimates for the different individual technologies, figure 1.7 show the distribution of the estimates for the Gini index when regressing on the individual technologies' usage lag, using the preferred specification model 4. The figure shows a box plot of the estimated coefficients, surrounded by a kernel density estimate. Also, the figure shows the distribution of the estimated coefficients for all technologies, for consumer technologies only and for producer technologies only. The figure suggests that the estimates on the Gini indices are mostly positive, as could be expected from the hypotheses.

— Figure 1.7 about here —

Figure B.6 in the appendix shows some more information on the estimated coefficients for the individual technologies. This figure reports the estimated coefficient for each technology, along with the 95% confidence interval. Again, it can be confirmed that at least for consumer technologies, the estimated effect of the Gini index on the technology lag is positive, and statistically significant for several technologies.

1.6 Robustness Checks

In this section I provide some robustness checks for the results derived in section 1.5. An instrumental variable approach will be introduced as a first check. Then, I aggregate the panel to a 5-year frequency and estimate a dynamic panel to allow for the auto-regressive nature of the technology variable as well as country fixed effects.

1.6.1 Instrumental variable approach

Since Solt (2016) provides data for both net Gini indices as well as market Gini indices (i.e. inequality measures before and after redistribution), it is possible to create a measure that proxies the extent of income redistribution in any given country and year. I.e. one can construct a year and country specific measure for redistribution policy. Following Solt (2016), I thus construct a measure for (relative) redistribution as:

$$Redistribution_{c,t} = \frac{Gini_{c,t}^{MARKET} - Gini_{c,t}^{NET}}{Gini_{c,t}^{MARKET}}. \tag{1.16}$$

To strengthen the argument that inequality shapes the diffusion of technologies, I then use this redistribution measure to instrument for the Gini index. The presence of omitted variables, which poses a potential problem to the main specifications because it does not allow to control for country fixed effects, might therefore be alleviated if the exclusion restriction is credible. Also, it is a possible strategy to tackle the problem of reversed causality (i.e. that the diffusion of technology might influence inequality).

The exclusion restriction requires that the only effect of the redistribution measure on the diffusion of technology is through inequality, conditional on the set of control variables. Because it seems likely that more developed countries have stronger preferences for redistributive policies, GDP needs to be controlled for in order to make the exclusion restriction credible. Therefore, I choose to include GDP as a control variable in most specifications, despite the fact that GDP might be endogenous as well, because the diffusion of technology might also influence GDP. I will address this issue further below.

Table 1.4 summarizes the results for the instrumental variables regressions. The six specifications are the same that were used in section 1.5.[6] As a dependent variable, I again use the average standardized usage lag. The results for the first stage indicate that the instrument is strong; a problem with weak instruments does not seem to apply. The lower part of table 1.4 shows the results for the second stage. The first 4 columns strengthen the main result found in the last section: More inequality indeed leads to higher usage lags, i.e. it hinders the diffusion of technology. As in the main results, the interaction between the Gini index and the level of GDP do not seem to play any significant role when including all technologies to calculate the average standardized usage lag (columns 5 and 6).

— Table 1.4 about here —

A further potential endogenity issue is posed by using per capita GDP as an explanatory variable. It is reasonable to assume that the diffusion of technology influences per capita GDP, and hence another reverse causality problem might be present. Hence, especially the results for columns 5 and 6 above should be interpreted with care. This reverse causality problem is much more likely to arise for producer than for consumer technologies: If technology diffusion increases GDP via advances in productivity, this seems to be rather driven by productive production technologies than by consumer technologies. Therefore, I re-estimate the IV specification again, but this time using the average standardizes usage lag calculated over the consumer technologies only, similar to the approach I followed

[6] I do not report results for the specification with the lagged Gini index here. However, as in the main specification, no significant effects result from adding the lagged Gini index as an additional regressor if the contemporaneuos Gini index is included already.

in section 1.5, where I divided the technologies into consumer and producer technologies. Table B.5 in the appendix presents the results. The result for the main hypothesis (columns 1–4) remains the same and the effects are even stronger, but now for consumer technologies there is also weak evidence for hypothesis 6: The point estimate for the Gini index is negative, while the interaction term is positive, as expected. Furthermore, the coefficient for the interaction term is significant at the 10% level in one specification. Hence, when only looking at consumer technologies, the results from the baseline analysis can be replicated: There is evidence that higher inequality hinders the diffusion of technology, while this effect seems to be more pronounced in rich countries. There is no evidence again, however, that inequality is conducive for technology diffusion in poor countries.

1.6.2 Dynamic panel estimation for usage lags

The reason why country fixed effects cannot be introduced in the main specification in section 1.5 is that there is not enough variation in the Gini index over time within a country. One way to tackle this issue is by aggregating the panel to a lower frequency. Hence, I aggregate the data to have a 5-year frequency, using the latest available data point for each 5-year period. Furthermore, the results in Comin, Hobijn and Rovito (2008) indicate that technology usage lags can to a large part be explained by their past values. Therefore, it makes sense to include a lagged dependent variable as additional regressor. Therefore, the estimation equation becomes

$$y_{c,t} = y_{c,t-1}\delta + Ineq_{c,t}\beta + \boldsymbol{X_{c,t}}\gamma + \alpha_c + \alpha_t + u_{c,t}, \tag{1.17}$$

with $y_{c,t-1}$ denoting the lag of the dependent variable. In this case, however, random and fixed effect models lead to inconsistent estimates (Cameron and Trivedi, 2005; Nickell, 1981), since the regressors and the error term are correlated by construction. Potential solutions to this problem include estimating the equation by applying the System GMM estimators put forward by Arellano and Bover (1995) and Blundell and Bond (1998). Alternatively, the fixed effects model estimates can be bias-corrected (Bruno, 2005), as, for example, in Kotschy and Sunde

(2017). I will apply the bias-corrected fixed effects specification and follow closely Kotschy and Sunde (2017).

I again use the Gini index as the variable for inequality and the average standardized usage lag as the outcome variable. First, tables B.6 and B.7 show the results for a static model, i.e. where δ is restricted to zero in equation (1.17), applying random and fixed effects, respectively. The results for both the random and fixed effects models seem to confirm the main hypothesis (columns 1–3). For the preferred specification with dynamic fixed effects and bias correction the results are even more consistent, as table 1.5 shows. In all the five specifications, the estimate for the Gini index is significant, and in four of them even highly significant. This gives further evidence in favour of the main hypothesis, i.e. that inequality hinders the diffusion of technology. Therefore, using dynamic panel data methods, the main results found in section 1.5 can be replicated when reducing the frequency of the data to five years. The hypothesis of a heterogeneous effect by different levels of per capita GDP cannot be confirmed here.

— Table 1.5 about here —

1.7 Some Evidence on the Extensive Margin

In the main part of the paper, I mainly looked at the diffusion process of new technologies once they were introduced in a given country. I found that, in line with theory, inequality reduces the diffusion process of these new technologies. This short section provides evidence on hypothesis 1, namely that inequality should decrease the adoption lag, i.e. the initial adoption of a technology in a given country. The paper so far has focussed on the on the intensive margin of adoption, because it is the divergence in the intensive margin across countries that prevents poorer countries to catch up with the frontier (see section 1.3). Nevertheless, as also documented in recent studies on technology diffusion (see, for example, Agha and Molitor (2018) and Gross (2018)), it is important to distinguish the two margins of diffusion.

In order to investigate this question, first a measure for the extensive margin of technology diffusion has to be defined. This measure should capture whether a technology, at a certain point in time, has been introduced in a country. Since in the data, the difference between a zero and a missing value is not clear, i.e. for missing values I do not know whether the data point is truly missing or the usage level is zero, I first exclude all observations with missing or zero values, as I did in section 1.5. Then, I consider a technology as adopted in a given country in a given year if its usage level exceeds some threshold level. Since the technologies, and hence their usage levels, vary substantially between each other, it is not trivial to define such a threshold level. To have a measure that is at the same time intuitive and comparable across technologies, I therefore define as the threshold level for each technology the value of its first percentile, pooling over all countries and years.[7]

I then estimate how the probability that the technology has been adopted (is available) at a given country in a given year changes with inequality. Hence, I fit a probability model of the form:

$$\begin{aligned} & P(y_{c,t,i} = 1 | Ineq_{c,t,i}, \boldsymbol{X_{c,t,i}}, \alpha_c, \alpha_t, \alpha_i) \\ = \; & G(Ineq_{c,t,i}\beta + \boldsymbol{X_{c,t,i}}\gamma + \alpha_c + \alpha_t + \alpha_i), \end{aligned} \tag{1.18}$$

where $y_{c,t,i}$ is binary outcome vector measuring the extensive margin of technology diffusion, $Ineq_{c,t,i}$ the vector of the regressor for the inequality measure and β the coefficient of interest. $\boldsymbol{X_{c,t,i}}$ is a matrix of control variables (including a constant), α_c, α_t, and α_i are region (continent), time and technology fixed effects. I assume the function $G(\cdot)$ to be $G(z) = \int_{-\infty}^{z} \phi(v)\mathrm{d}v$, where $\phi(z)$ is the standard normal density, to have a Probit model or to be $G(z) = \Lambda(z) = \exp(z)/[1 + \exp(z)]$ to have a Logit model (see, for example, Cameron and Trivedi (2005)). This function can then be estimated by maximum likelihood. Tables 1.6 (for the Logit model) and 1.7 (for the Probit model) show the results.

— Table 1.6 about here —

— Table 1.7 about here —

[7]Hence, for 99% of the country-year observations a given technology is considered to have been adopted.

Reassuringly, all control variables show the expected signs. While openness and per capita GDP seem to be important predictors for the extensive margin of technology diffusion, the estimates for human capital and institutions are statistically insignificant. As predicted, I find some evidence that inequality is positively affecting initial adoption of new technologies. The effect is statistically significant throughout all specifications, such that there is strong evidence that high inequality fosters initial adoption of new technologies. Also note that this effect seems to be stronger for poorer countries, since the main effect is moderated through the interaction variable. The main effect also holds if I change the threshold level to the 5th or the 10th percentile, as figure 1.8 shows. Note that the result for the moderating effect of income remains robust for the different threshold levels as well. Hence, I conclude that there is evidence that higher inequality fosters the initial adoption of technologies, while the effect is more pronounced in poor countries.

— Figure 1.8 about here —

1.8 Conclusion

This paper investigates how inequality (measured by the Gini index as well as quantile shares) influences the diffusion of new technologies. Most of the literature on technology looks at the production side of technology creation. This paper takes another perspective by looking at the demand side of the economy. Using a simple demand-side model with non-homethetic preferences, it is shown that after some minimum level of average income, compared to the minimum level of income required to afford a new technology, is achieved, more income inequality hinders the diffusion process of technologies. In line with earlier predictions, this suggests that for the extensive margin of adoption of a technology, a higher degree of inequality might be beneficial. However, for the intensive margin (the diffusion of the technology in a given country after its initial adoption has taken place), a lower level of inequality speeds up diffusion.

Using data on the diffusion of 39 major technologies, the paper shows that the hypotheses drawn from this simple demand-side model can not be rejected.

By using an aggregate measure of technological backwardness against the technological frontier, the United States, it is shown that inequality of the households hampers the diffusion of technologies. This result is confirmed when looking at various individual technologies. The results hold for both measures of technology diffusion considered here: The actual usage level (technology usage per capita) as well as a measure that measures the backwardness to the United States. Furthermore, it is found that the effect is much stronger for consumer technologies than for producer technologies. In fact, according to one measure, almost the whole effect is driven by consumer technologies. This again is in line what was to be expected, since the influence of inequality on the diffusion of consumer technologies is direct, while the (potential) effect on producer technologies is only indirect.

In addition to this main finding, the study also finds limited evidence for the existence of an asymmetric effect regarding the development level of countries. Including an interaction between inequality and real GDP, the results show that inequality is detrimental for the diffusion of new technologies mainly in richer countries. This might be due to the consideration that in rich countries, where the mean consumer can afford the new technology, a mean-preserving redistribution from the rich to the poor makes the marginal consumer of the technology unable to afford the technology, therefore reducing the diffusion level. For the extensive margin, the paper presents evidence for a positive effect of inequality on technology adoption. This effect is more pronounced in poor countries.

This paper adds to the literature in the following way. It is the first paper collecting information about technology diffusion and investigating the influence of household inequality on the diffusion process. In that sense, the paper combines earlier contributions that investigate technology diffusion from a supply-side perspective with the rich literature on the effects of income inequality on economic growth. Mainly consumer technologies are considered and found to be affected by inequality in this study. However, especially for modern information and communication technologies (ICT), the speed with which these new technologies are spread across a country might (indirectly) influence countries' potential growth trajectories. With an increasing importance of the services sector, along with the rising importance of skills in the field of the digital economy, the topic and questions asked in this paper might be of growing importance. The fact that the effects of inequality on technology diffusion found are very robust especially for these new ICT suggests that the importance of inequality remains important also for new technologies in this field. Furthermore, if it is to be believed that skills in ICT are of ever-growing importance in the labour market, a particular policy implication would be to try to make accessible modern technologies to broad masses of the population. This could be important, as mentioned above, for productivity advances of the economy as a whole. Additionally, this might also be important in order to provide some degree of equality of chances, which can only be guaranteed if all social classes have to ability become familiar with the latest advances in technology.

Investigating the link between the speed of diffusion of modern technologies and increases in productivity (or the stock of human capital) might be an interesting topic building on this paper. Establishing a link between income inequality, the technology diffusion process and economic growth should be a very interesting task to look into. Furthermore, it could be interesting to see whether the availability of new ICT (especially the internet) leads to faster diffusion of other technologies, reinforcing the link between inequality and the diffusion of technology.

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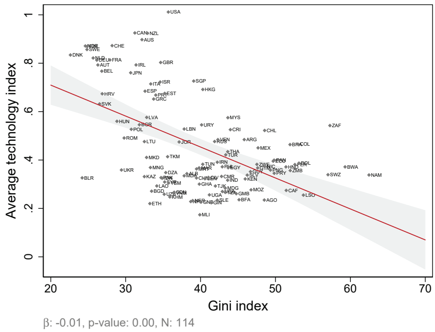
Figures and Tables

Figure 1.1: Inequality and average technology in 2000

(a) Gini index



(b) Income share middle class

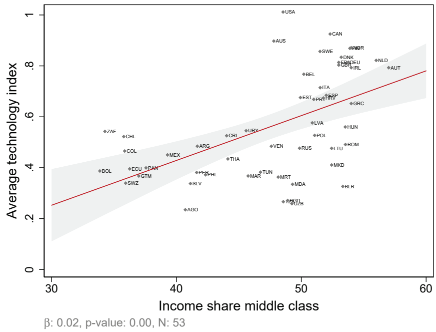
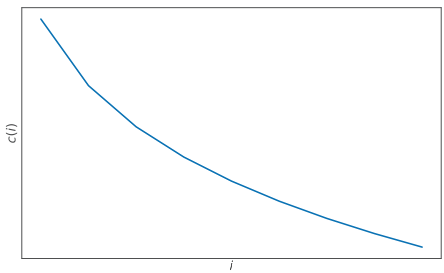
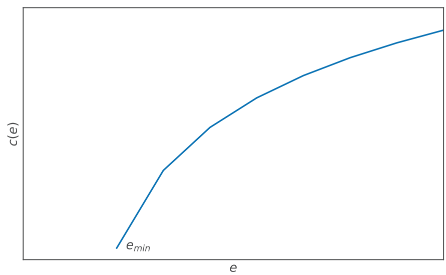


Figure 1.2: Individual consumption as a function of

(a) technology rank in hierarchy, i.

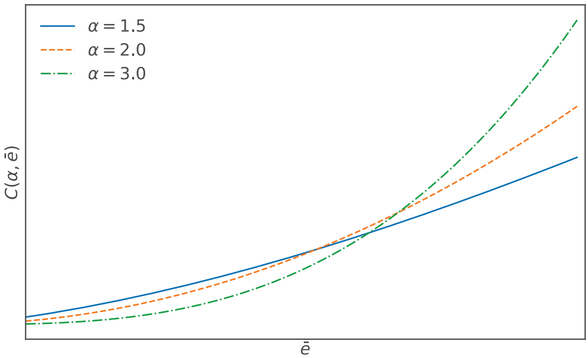


(b) individual income, e.



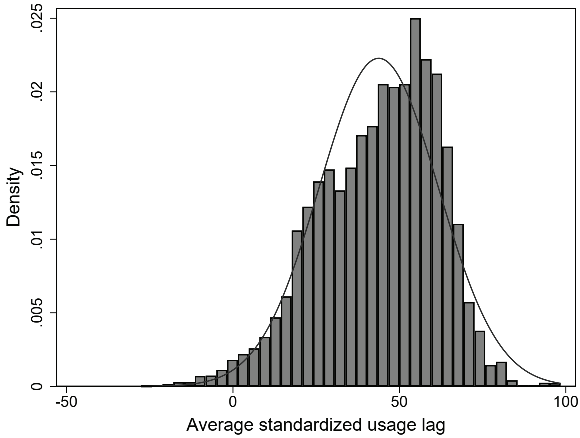
Note: The left panel of the figure plots equation (1.6) for given values for $\gamma = 0.1$, $s = 5.0$ and $e = 1.0$. Note that k is given by $\frac{1+\gamma}{s\gamma}$. For i, values from one to ten are used. The right panel of the figure plots equation (1.6) using the same values for γ and s, but fixes $i = 10.0$ and uses values from one to ten for ke.

Figure 1.3: Total consumption as a function of α and $\bar{e}$



Note: The figure plots total consumption C as a function of $\bar{e}$ and for different values of α, for a given hierarchy-position of the good, $i = 10.0$, steepness parameter $\gamma = 0.1$, and $s = 5.0$ (and hence, $e_{min}(i)$ is fixed). The figure illustrates that for lower values of $\bar{e}$, total consumption is higher for lower values of α, i.e. inequality is good for total consumption. The opposite is true for higher values of $\bar{e}$.

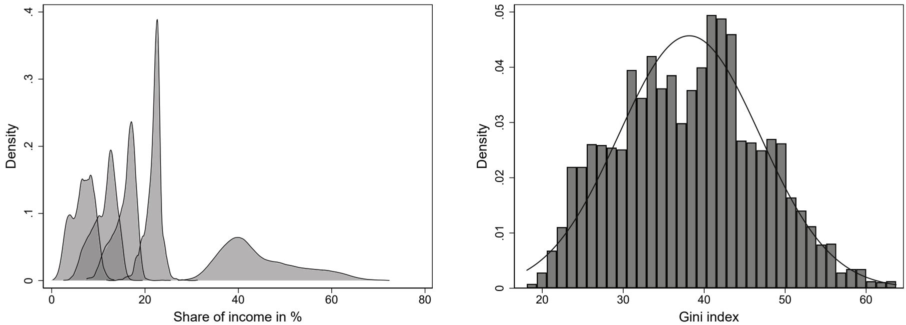
Figure 1.4: Histogram average standardized usage lag



Note: The histogram shows the distribution of the average standardized usage lag, over all 39 technologies, and over all sample years. The variable is calculated according to equation (1.14). A normal density is added for illustrative purpose.

Figure 1.5: Distribution of inequality measures

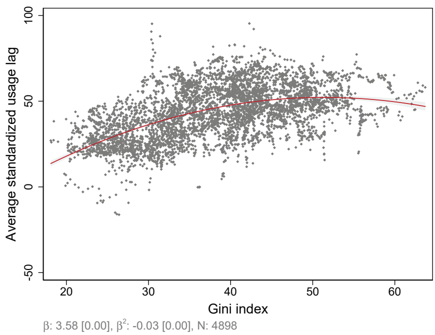
(a) Income quantiles **(b) Gini index**



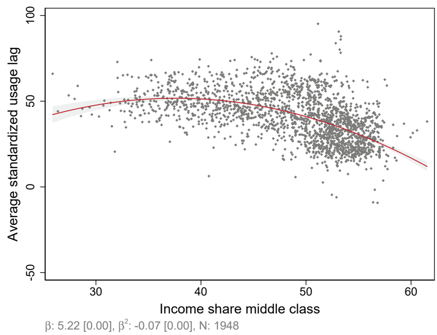
Note: The left panel of the figure shows densities for all five quantile variables, pooled over time. For example, the density on the very right shows how the share of income going to the top 20% of earners is distributed. In some country / year combination, this share is above 70%. The right panel shows the distribution of the Gini index, pooled across countries and years. A normal density is added for illustrative purpose.

Figure 1.6: Average standardized usage lag and inequality

(a) Gini index



(b) Income share middle class

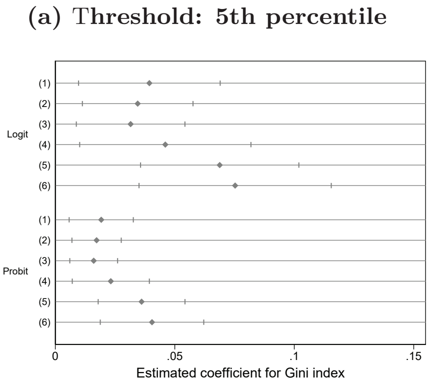


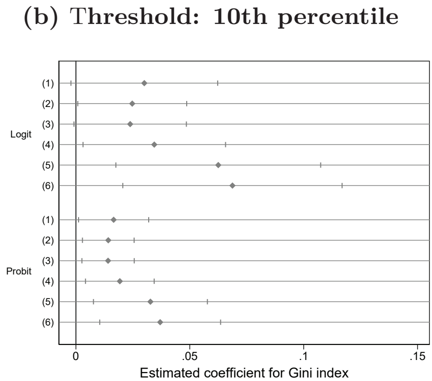
Note: The left panel shows how the Gini index is related to the average standardized usage lag. The regression statistics confirm a hump-shaped relationship, whereas there seems to be a positive relationship in general. The right panel shows the share of income going to the middle class plotted against the average standardized usage lag. Again, the relationship is revealed to be hump-shaped, but here the general relationship seems to be a negative one.

Figure 1.7: Estimated OLS coefficients for the Gini index and the individual technologies' usage lag

Note: This figure shows the distribution of the estimated coefficients for the Gini index in the regressions (equivalent to model 4 in table 1.2) with the individual technologies' usage lag as the dependent variables. The white dot is the median of the estimated coefficients, the box represents the interquartile range, and the spikes are the upper- and lower-adjacent values. This box plots are overlaid by a kernel density estimate using the Epanechnikov kernel. The plot shows three plots, including all technologies, only consumer and only producer technologies.

Figure 1.8: Estimated Logit/Probit coefficients for the Gini index and the extensive margin of technology diffusion





Note: The figure shows robustness checks for the results shown in tables 1.6 and 1.7. The left panel uses the 5th percentile as the threshold value for adoption, i.e. if the usage level of a technology in a given country and year exceeds the value for the 5th percentile for this technology, the technology is considered adopted. The right panel uses the 10th percentile.

Table 1.1: Minimum values for B such that inequality reduces consumption

α	Gini	γ 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1.00	1.00	nan	nan	nan	nan	nan	nan	nan	nan	nan
1.25	0.67	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.15
1.50	0.50	0.76	0.73	0.71	0.69	0.67	0.65	0.64	0.63	0.62
1.75	0.40	1.06	1.03	1.00	0.98	0.96	0.94	0.93	0.91	0.90
2.00	0.33	1.18	1.16	1.14	1.12	1.10	1.08	1.07	1.05	1.04
2.25	0.29	1.24	1.22	1.20	1.18	1.16	1.15	1.14	1.12	1.11
2.50	0.25	1.26	1.24	1.22	1.21	1.19	1.18	1.17	1.16	1.15
2.75	0.22	1.26	1.25	1.23	1.22	1.21	1.20	1.19	1.18	1.17
3.00	0.20	1.26	1.24	1.23	1.22	1.21	1.20	1.19	1.18	1.18

Note: Gini is the Gini index implied by α

Table 1.2: OLS regression results for the Gini index and the average standardized usage lag

Dependent variable:	Average standardized usage lag							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	0.29*** (0.08)	0.26*** (0.06)	0.27*** (0.07)	0.29*** (0.09)	0.09 (0.14)	0.11 (0.16)	0.41 (0.25)	0.41* (0.25)
Human capital	-13.88*** (0.98)	-5.55*** (1.10)	-4.69*** (1.06)	-4.42*** (1.11)	-4.47*** (1.11)	-4.11*** (1.21)	-4.80*** (1.05)	-4.44*** (1.08)
Openness	-6.59*** (0.83)	-2.79*** (0.63)	-3.07*** (0.78)	-3.26*** (0.76)	-2.79*** (0.94)	-3.01*** (0.88)	-2.99*** (0.71)	-3.24*** (0.68)
Income		-7.08*** (0.63)	-6.75*** (0.66)	-6.82*** (0.71)	-9.83*** (2.75)	-10.08*** (3.23)	-6.69*** (0.58)	-6.71*** (0.64)
Institutions			0.56*** (0.20)	0.54** (0.24)	0.50** (0.21)	0.48** (0.24)	0.55*** (0.19)	0.53** (0.23)
Gini index × Income					0.08 (0.06)	0.08 (0.08)		
L5.Gini index							-0.16 (0.25)	-0.14 (0.25)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4307	4307	3983	3983	3983	3983	3514	3514
Standardized beta	0.17	0.15	0.15	0.16	0.05	0.06	0.24	0.24

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table 1.3: OLS regression results for the income share of the middle class and the average standardized usage lag

Dependent variable:	Average standardized usage lag							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	-0.23** (0.11)	-0.26*** (0.08)	-0.28*** (0.08)	-0.22 (0.15)	-0.05 (0.19)	-0.11 (0.20)	-0.00 (0.13)	-0.01 (0.15)
Human capital	-14.67*** (1.07)	-5.52*** (1.20)	-5.17*** (1.20)	-4.27*** (1.32)	-5.09*** (1.23)	-4.20*** (1.31)	-6.09*** (1.82)	-4.86*** (1.53)
Openness	-7.23*** (1.23)	-2.44*** (0.88)	-2.51** (0.98)	-2.69*** (0.99)	-2.17** (1.04)	-2.56** (1.06)	-2.52* (1.33)	-2.59* (1.38)
Income		-8.02*** (0.74)	-7.62*** (0.77)	-7.53*** (0.89)	-2.56 (3.88)	-5.17 (4.71)	-7.53*** (1.27)	-7.43*** (1.35)
Institutions			0.36 (0.22)	0.17 (0.28)	0.30 (0.23)	0.14 (0.27)	0.26 (0.31)	-0.06 (0.39)
Income share middle class × Income					-0.11 (0.09)	-0.05 (0.11)		
L5.Income share middle class							-0.17* (0.10)	-0.08 (0.13)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1795	1795	1685	1685	1685	1685	943	943
Standardized beta	-0.10	-0.11	-0.12	-0.09	-0.02	-0.05	-0.00	-0.00

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Table 1.4: IV regression results for the Gini index and the average standardized usage lag

Dependent variable:	Average standardized usage lag					
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: First stage regressions					
Redistribution	-41.35***	-41.54***	-43.66***	-33.78***	-23.79**	-12.31
	(3.91)	(3.91)	(4.05)	(6.05)	(10.03)	(10.38)
Human capital	-1.60*	-1.89	-2.18*	-0.53	-2.19*	-0.51
	(0.90)	(1.20)	(1.18)	(1.16)	(1.14)	(1.16)
Openness	-0.22	-0.35	-0.22	0.14	-0.05	0.33
	(0.55)	(0.67)	(0.70)	(0.58)	(0.77)	(0.57)
Income		0.26	-0.16	0.11	0.71	1.11
		(0.69)	(0.67)	(0.72)	(0.80)	(0.92)
Institutions			-0.64***	-0.22	-0.70***	-0.29
			(0.21)	(0.24)	(0.21)	(0.25)
Income × Redistribution					-7.02**	-7.83**
					(3.46)	(3.31)
	Panel B: Second stage regressions					
Gini index	0.48***	0.35***	0.32***	0.42**	0.20	0.43
	(0.14)	(0.10)	(0.10)	(0.20)	(0.35)	(0.42)
Human capital	-12.60***	-4.99***	-4.39***	-4.17***	-4.41***	-4.18***
	(1.26)	(1.14)	(1.11)	(1.10)	(1.10)	(1.17)
Openness	-6.36***	-2.70***	-2.99***	-3.25***	-2.87***	-3.25***
	(0.80)	(0.65)	(0.83)	(0.81)	(0.95)	(0.88)
Income		-7.02***	-6.71***	-6.76***	-8.42*	-6.66
		(0.64)	(0.67)	(0.75)	(5.00)	(5.05)
Institutions			0.56***	0.52**	0.53**	0.52**
			(0.20)	(0.24)	(0.22)	(0.25)
Income × Gini index					0.04	-0.00
					(0.12)	(0.13)
Region FE	No	No	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4307	4307	3983	3983	3983	3983
Fstat	111.782	112.646	116.069	31.196	9.664	5.840
Standardized beta	0.27	0.20	0.18	0.24	0.11	0.24

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Fstat denotes the F statistic for weak identification. Standardized beta shows the standardized coefficient for the Gini.

Table 1.5: Dynamic, biased-corrected FE regression results for the Gini index and the average standardized usage lag

Dependent variable:	Average standardized usage lag				
	(1)	(2)	(3)	(4)	(5)
L.Average standardized usage lag	0.64***	0.57***	0.56***	0.56***	0.55***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Gini index	0.22*	0.37***	0.36***	0.73***	0.65***
	(0.13)	(0.12)	(0.13)	(0.21)	(0.21)
Human capital	0.93	4.95*	5.10**	5.14**	5.49*
	(2.43)	(2.60)	(2.44)	(2.43)	(2.99)
Openness	-0.87	-0.05	0.21	0.11	-0.61
	(1.07)	(1.08)	(1.27)	(1.27)	(1.29)
Income		-5.11***	-5.55***	1.54	-5.78***
		(1.25)	(1.44)	(3.57)	(1.35)
Institutions			0.08	0.06	0.19
			(0.23)	(0.23)	(0.28)
Gini index × Income				-0.20**	
				(0.09)	
L.Gini index					-0.31
					(0.20)
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	931	931	881	881	791
Standardized beta	0.13	0.21	0.21	0.42	0.38

Note: Dynamic fixed effects model with bias-correction; the according standard errors are shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table 1.6: Logit regression results for the Gini index and the extensive margin of technology diffusion

Dependent variable:	Extensive margin of technology diffusion					
	(1)	(2)	(3)	(4)	(5)	(6)
Gini index	0.06*** (0.02)	0.05*** (0.02)	0.04** (0.02)	0.05** (0.03)	0.11*** (0.02)	0.11*** (0.03)
Human capital	1.75*** (0.28)	0.62 (0.38)	0.54 (0.38)	0.49 (0.38)	0.33 (0.39)	0.30 (0.40)
Openness	2.90*** (0.68)	1.69*** (0.61)	1.62*** (0.57)	1.26** (0.54)	0.93* (0.49)	0.88* (0.48)
Income		0.89*** (0.21)	0.81*** (0.20)	0.87*** (0.20)	2.88*** (0.54)	2.68*** (0.57)
Institutions			-0.08 (0.06)	-0.09 (0.06)	-0.08 (0.06)	-0.07 (0.06)
Gini index × Income					-0.05*** (0.01)	-0.05*** (0.01)
Region FE	No	No	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Technology FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	69702	69702	65581	63675	65581	63675
Standardized beta	5.87	5.20	4.34	5.27	10.94	10.56

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table 1.7: Probit regression results for the Gini index and the extensive margin of technology diffusion

Dependent variable:	Extensive margin of technology diffusion					
	(1)	(2)	(3)	(4)	(5)	(6)
Gini index	0.02***	0.02***	0.02**	0.02**	0.05***	0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Human capital	0.68***	0.23*	0.20	0.19	0.11	0.10
	(0.10)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Openness	1.02***	0.57***	0.54***	0.42**	0.28*	0.27*
	(0.23)	(0.20)	(0.19)	(0.18)	(0.16)	(0.16)
Income		0.37***	0.34***	0.38***	1.21***	1.14***
		(0.07)	(0.07)	(0.07)	(0.22)	(0.22)
Institutions			-0.03	-0.03	-0.02	-0.03
			(0.02)	(0.02)	(0.02)	(0.02)
Gini index × Income					-0.02***	-0.02***
					(0.01)	(0.01)
Region FE	No	No	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Technology FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	69702	69702	65581	63675	65581	63675
Standardized beta	2.15	1.94	1.62	2.10	4.77	4.72

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Appendix A: Data Appendix

Table A.1: Technology variables and their sources

Label	Main source	Add. source
Consumer technologies		
Automated teller machines	WDI	CHAT
Aviation, million passenger km	Mitchell	
Aviation, 1000 passengers carried	WDI	
Broadband internet subscriptions	WDI	
Cable television subscriptions	CHAT	
Cars in use	Mitchell	
Credit / debit card payments in millions	CHAT	BIS
Electronic funds transfers, transactions in 1000	CHAT	
Internet users	WDI	
Mail delivered	CHAT	
Mobile phone subscriptions	WDI	
Newspaper circulation	CHAT	
Personal computers	WDI	
Radio sets in use	Mitchell	
Railways, million passenger km	WDI	Mitchell
Railways, million passengers	Mitchell	
Servers	WDI	
Telephones in use	Mitchell	
Telephones, subscriptions	WDI	
TV sets in use	Mitchell	
Water, access	WDI	
Producer technologies		
Aviation, freight in million ton km	WDI	Mitchell
Buses / commercial vehicles in use	Mitchell	
Container port traffic, in 20 foot equivalents	WDI	
Computed tomography scanners	OECD	
Electricity production in gWh	WDI	Mitchell
Magnetic resonance imaging units	OECD	
Patent applications	WDI	
Point of sale terminals	CHAT	BIS
Rail freight in million ton km	WDI	Mitchell
Rail freight in million metric tons	Mitchell	
Ships, freight in 1000 tons	CHAT	Mitchell
Ships, number	CHAT	Mitchell
Steel production, BOF in metric tons	WS	CHAT
Steel production, EAF in metric tons	WS	CHAT
Steel production, OHF in metric tons	WS	CHAT
Steel production, total in metric tons	WS	
Tractors, agriculture machineries	WDI	
X-ray scanners in use	OECD	

Note: WDI refers to The World Bank (2015), CHAT to Comin and Hobijn (2009), Mitchell to Mitchell (2013), BIS to The Bank for International Settlements (2015), WS to The World Steel Association (2015) and OECD to OECD (2016).

Table A.2: Descriptive statistics main variables

Variable	Mean	Std. dev.	Min.	Max.	N
Part I: Inequality variables:					
Gini index	38.16	8.73	18.10	63.71	5133
Income share held by lowest quantile	6.64	2.35	0.26	13.37	2017
Income share held by second quantile	11.28	2.58	2.55	19.45	2017
Income share held by third quantile	15.64	2.37	7.51	25.46	2017
Income share held by fourth quantile	21.86	1.68	11.75	31.25	2017
Income share held by highest quantile	44.59	8.24	27.11	72.34	2017
Income share middle class	48.77	6.21	25.88	61.53	2017
Part II: Economic variables:					
Human capital	2.06	0.72	1.01	3.73	7224
Openness	0.55	0.92	0.00	44.11	8764
Income	1.87	1.24	-1.82	5.47	8764
Institutions	3.74	2.23	1.00	7.00	7601
Part III: Main technology variables:					
Average standardized usage lag	43.80	17.91	-27.61	98.41	9557
Average standardized usage lag: Consumer	45.44	19.49	-48.72	98.41	9115
Average standardized usage lag: Producer	47.51	16.79	-27.58	95.18	8307

Note: Gini measures the net (i.e. after redistribution) Gini index. The income shares by quantile measure the share of income going to one specific group, e.g. the income share held by lowest quantile measures the share of income going to the bottom 20% of the population. The middle class is defined as the three middle quantiles (i.e. the second, third, and fourth quantile). Human capital is an index of human capital based on years of schooling as well as returns to education. Openness measures merchandise exports plus merchandise imports as a share of GDP. Income is the (log of) real GDP per capita in 1’000 (2011) US Dollars. Institutions is an index on political rights. The average standardized usage lag is the main outcome variable for this paper; its construction is described in section 1.4.1.

Table A.3: Descriptive statistics per capita technology variables

Variable	Mean	Std. dev.	Min.	Max.	N
Automated teller machines	0.40	0.41	0.00	2.91	2108
Aviation, freight in million ton km	0.06	0.52	0.00	16.81	6907
Aviation, million passenger km	0.69	1.89	0.00	26.63	4896
Aviation, 1000 passengers carried	0.57	1.45	0.00	21.89	6531
Broadband internet subscriptions	78.47	108.71	0.00	616.91	2423
Buses / commercial vehicles in use	24.78	32.41	0.10	319.62	5778
Cable television subscriptions	86.44	111.01	0.00	1545.31	814
Cars in use	100.15	147.59	0.12	778.72	5860
Container port traffic, in 20 foot equivalents	362.19	886.96	0.48	6726.92	1284
Credit / debit card payments in millions	0.04	0.05	0.00	0.23	520
Computed tomography scanners	0.02	0.01	0.00	0.10	525
Electronic funds transfers, transactions in 1000	51.62	439.21	0.00	6113.01	324
Electricity production in gWh	2.53	4.09	0.00	54.72	7719
Internet users	204.39	256.24	0.00	981.60	4069
Mail delivered	0.10	0.11	0.00	0.67	1912
Mobile phone subscriptions	436.67	491.50	0.00	3212.33	4559
Magnetic resonance imaging units	0.01	0.01	0.00	0.05	476
Newspaper circulation	99.03	130.70	0.03	613.06	4686
Patent applications	0.13	0.31	0.00	3.19	4031
Personal computers	100.96	158.96	0.00	962.38	2354
Point of sale terminals	7.91	7.28	0.00	33.23	488
Radio sets in use	237.45	209.90	0.68	1377.04	2395
Rail freight in million ton km	0.96	3.62	0.00	163.55	4651
Rail freight in million metric tons	0.00	0.00	0.00	0.14	3566
Railways, million passenger km	0.35	0.54	0.00	16.08	4615
Railways, million passengers	0.02	0.10	0.00	1.17	3637
Servers	0.23	0.61	0.00	9.76	2407
Ships, freight in 1000 tons	1.88	10.99	0.00	162.24	2818
Ships, number	0.12	0.33	0.00	2.59	1980
Steel production, BOF in metric tons	0.20	0.21	0.00	1.32	1714
Steel production, EAF in metric tons	0.08	0.12	0.00	1.74	2762
Steel production, OHF in metric tons	0.09	0.12	0.00	0.63	909
Steel production, total in metric tons	0.21	0.28	0.00	1.95	2581
Telephones in use	136.63	185.14	0.18	972.76	5761
Telephones, subscriptions	157.87	187.05	0.01	1345.19	8134
Tractors, agriculture machineries	5.76	9.95	0.00	59.08	6094
TV sets in use	150.10	141.37	0.00	879.71	2568
Water, access	842.14	183.38	132.00	1000.00	4851
X-ray scanners in use	0.01	0.00	0.00	0.03	389

Note: All variables are measured per 1'000 of population. The statistics include the observations of all countries in all years available in the sample, which leads to huge variation in the outcome of the variables. As an example, over the whole sample period and all countries, an average of 20.4% had access to the internet, while the maximum penetration rate of internet access in any given year and country is 98.2%. Also, as stated in the main text, the zeros in the data are replaced by a missing value, since it is unclear from the data whether a zero means the technology has not arrived yet or it has arrived but its usage level is close to zero. The zeros appearing in this table are rounded to zeros and are in fact very small positive numbers.

Table A.4: Descriptive statistics usage lag

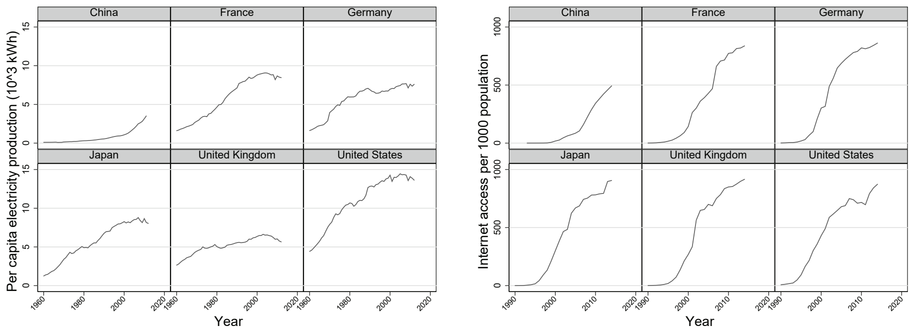
Variable	Mean	Std. dev.	Min.	Max.	N
Automated teller machines	11.55	5.93	-3.97	25.45	997
Aviation, freight in million ton km	32.61	20.02	-30.80	79.64	6297
Aviation, million passenger km	30.36	15.74	-26.47	76.92	4679
Aviation, 1000 passengers carried	16.78	13.50	-33.13	43.74	776
Broadband internet subscriptions	6.27	4.48	-6.84	15.99	1552
Buses / commercial vehicles in use	55.58	17.92	-5.15	94.72	5735
Cable television subscriptions	13.17	7.76	-17.95	26.85	317
Cars in use	61.09	20.87	5.10	102.97	5817
Container port traffic, in 20 foot equivalents	2.57	4.21	-6.60	12.29	134
Credit / debit card payments in millions	6.22	5.54	-6.82	21.85	162
Computed tomography scanners	3.60	3.68	-7.78	14.23	96
Electronic funds transfers, transactions in 1000	0.73	5.13	-9.90	11.00	105
Electricity production in gWh	49.56	22.68	-32.33	108.96	6109
Internet users	8.67	5.61	-9.91	23.46	3003
Mail delivered	54.17	21.47	3.98	103.56	807
Mobile phone subscriptions	6.35	5.71	-10.87	23.00	3730
Magnetic resonance imaging units	8.86	4.90	-10.87	18.45	91
Newspaper circulation	20.33	12.19	0.03	48.41	294
Patent applications	2.24	18.37	-49.89	40.45	421
Personal computers	13.80	6.53	-3.78	26.89	1643
Point of sale terminals	2.21	5.41	-6.81	18.47	362
Radio sets in use	39.79	19.81	-27.98	72.46	1934
Rail freight in million ton km	103.67	24.84	-43.27	148.55	2830
Rail freight in million metric tons	81.42	32.16	0.60	139.83	1008
Railways, million passenger km	58.84	31.44	0.08	130.17	2105
Railways, million passengers	61.10	32.88	0.08	123.28	958
Servers	4.59	3.76	-4.70	12.80	345
Ships, freight in 1000 tons	98.94	64.23	0.79	217.10	897
Ships, number	15.56	24.02	0.01	117.08	880
Steel production, BOF in metric tons	19.42	12.62	-8.36	48.76	1035
Steel production, EAF in metric tons	14.26	15.27	-27.49	49.17	1129
Steel production, OHF in metric tons	11.21	10.04	0.03	47.83	271
Steel production, total in metric tons	8.26	7.16	-0.77	27.61	263
Telephones in use	68.89	27.18	0.31	126.32	5703
Telephones, subscriptions	19.11	13.42	-13.79	53.74	1739
Tractors, agriculture machineries	16.48	11.54	-2.02	42.99	286
TV sets in use	26.90	13.06	-15.45	50.71	2337
Water, access	-6.70	6.32	-23.00	4.80	74
X-ray scanners in use	1.60	1.42	-0.17	3.12	4

Note: The usage lag measures the lag in years to the US.

Appendix B: Additional Tables and Figures

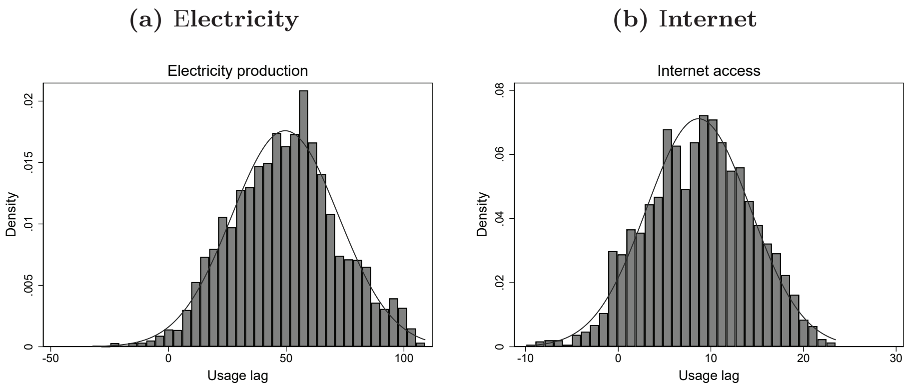
Figure B.1: Electricity production and internet access over time

(a) Electricity **(b)** Internet



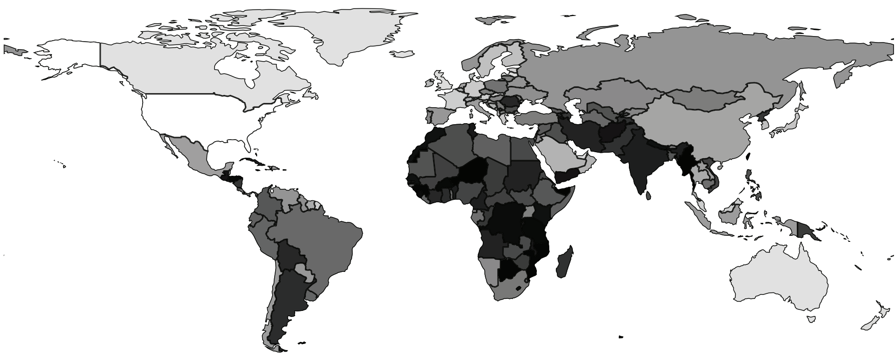
Note: Panel (a) shows per capita electricity production since 1960 in six different countries. While for China there seems to be an upward trend, for the other 5 economies it seems that production has plateaued. Panel (b) shows the share of people having access to the internet since 1990 for six countries. Internet access seems to be a technology for which the diffusion process happened very quickly.

Figure B.2: Histograms of the usage lag of



Note: The left (right) panel shows the technology usage lags in years to the United States for electricity production (internet access), along with an added normal density. Obviously, usage lags for electricity production are much larger than for internet access.

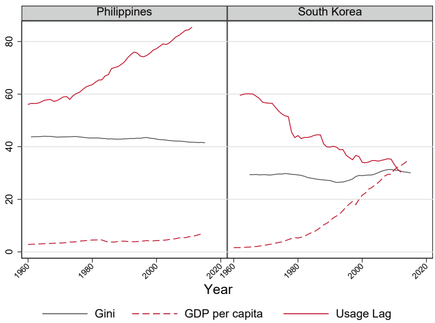
Figure B.3: Average standardized usage lag in 2010 around the world



Note: The figure shows the average standardized usage lag for all countries in the year 2010. Darker shaded areas indicate a higher value for the usage lag, i.e. more technological backwardness towards the United States. The United States, as the baseline country, are coloured in white.

Figure B.4: Electricity production and internet in South Korea and the Philippines

(a) Electricity



(b) Internet

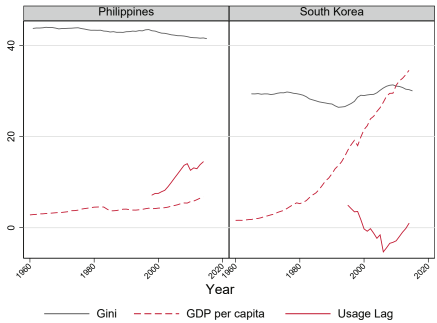


Figure B.5: Average standardized usage lag in South Korea and the Philippines

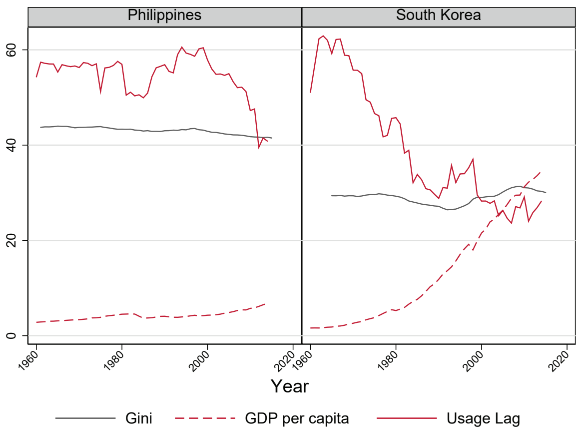
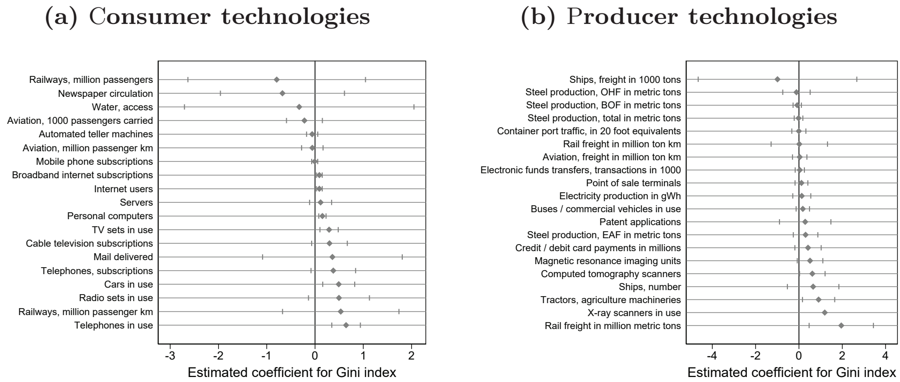


Figure B.6: Estimated OLS coefficients for the Gini index and the individual technologies' usage lag II



Note: This figure shows the estimated coefficient for the Gini measure when regressed on the individual technologies' usage lag, surrounded by the 95% confidence interval. The estimates are taken from specification / model 4 (see table 1.2 for the specification). The left panel shows all consumer technologies, while the right panel shows the producer technologies.

Table B.1: OLS regression results for the Gini index and the average standardized usage lag (consumer technologies)

Dependent variable:	Average standardized usage lag: Consumer technologies only							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	0.44*** (0.08)	0.40*** (0.06)	0.43*** (0.06)	0.45*** (0.09)	-0.07 (0.14)	-0.07 (0.15)	0.37 (0.26)	0.39 (0.26)
Human capital	-15.10*** (1.08)	-6.33*** (1.14)	-4.95*** (1.11)	-5.03*** (1.17)	-4.28*** (1.10)	-4.10*** (1.18)	-5.12*** (1.11)	-5.23*** (1.15)
Openness	-7.32*** (1.04)	-3.42*** (0.67)	-3.60*** (0.73)	-3.66*** (0.68)	-2.78*** (0.94)	-2.94*** (0.83)	-3.38*** (0.71)	-3.50*** (0.65)
Income		-7.41*** (0.63)	-6.79*** (0.61)	-7.06*** (0.63)	-15.71*** (2.68)	-16.69*** (2.99)	-6.82*** (0.56)	-7.08*** (0.59)
Institutions			1.07*** (0.20)	1.12*** (0.23)	0.89*** (0.22)	0.97*** (0.23)	1.00*** (0.21)	1.06*** (0.24)
Gini index × Income					0.22*** (0.06)	0.24*** (0.07)		
L5.Gini index							0.06 (0.26)	0.06 (0.26)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4272	4272	3954	3954	3954	3954	3492	3492
Standardized beta	0.21	0.20	0.21	0.22	-0.03	-0.03	0.18	0.20

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table B.2: OLS regression results for the income share of the middle class and the average standardized usage lag (consumer technologies)

Dependent variable:	Average standardized usage lag: Consumer technologies only							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	-0.40*** (0.14)	-0.44*** (0.09)	-0.48*** (0.09)	-0.38** (0.15)	0.10 (0.21)	0.05 (0.22)	-0.09 (0.12)	-0.05 (0.14)
Human capital	-15.91*** (1.39)	-5.61*** (1.49)	-5.19*** (1.39)	-4.96*** (1.52)	-5.00*** (1.39)	-4.69*** (1.50)	-6.90*** (1.78)	-6.85*** (1.82)
Openness	-9.42*** (1.73)	-4.07*** (1.26)	-3.73*** (1.26)	-3.65*** (1.23)	-2.88** (1.24)	-3.14** (1.22)	-2.73* (1.50)	-2.73* (1.51)
Income		-9.01*** (0.77)	-8.05*** (0.77)	-8.38*** (0.81)	4.59 (4.42)	1.55 (5.03)	-8.10*** (1.09)	-8.38*** (1.13)
Institutions			1.08*** (0.25)	1.10*** (0.29)	0.94*** (0.26)	1.00*** (0.29)	1.14*** (0.34)	1.24*** (0.40)
Income share middle class × Income					-0.26*** (0.09)	-0.21* (0.11)		
L5.Income share middle class							-0.30** (0.13)	-0.24* (0.13)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1783	1783	1673	1673	1673	1673	934	934
Standardized beta	-0.15	-0.16	-0.17	-0.14	0.04	0.02	-0.04	-0.02

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Table B.3: OLS regression results for the Gini index and the average standardized usage lag (producer technologies)

Dependent variable:	Average standardized usage lag: Producer technologies only							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	0.09 (0.09)	0.07 (0.07)	0.05 (0.08)	0.04 (0.11)	0.26* (0.15)	0.21 (0.18)	0.65** (0.29)	0.63** (0.28)
Human capital	-14.14*** (1.05)	-5.49*** (1.59)	-5.09*** (1.55)	-4.09** (1.58)	-5.39*** (1.57)	-4.42*** (1.66)	-5.55*** (1.55)	-4.42*** (1.60)
Openness	-4.60*** (1.39)	-0.54 (1.56)	-1.33 (1.50)	-1.70 (1.46)	-1.71 (1.36)	-1.94 (1.37)	-1.53 (1.36)	-1.89 (1.34)
Income		-7.43*** (1.00)	-7.34*** (1.06)	-7.01*** (1.15)	-3.42 (2.83)	-3.91 (3.48)	-6.99*** (1.02)	-6.60*** (1.11)
Institutions			0.09 (0.33)	0.01 (0.35)	0.17 (0.32)	0.07 (0.34)	0.09 (0.33)	0.01 (0.34)
Gini index × Income					-0.10 (0.07)	-0.08 (0.08)		
L5.Gini index							-0.63** (0.28)	-0.61** (0.28)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4090	4090	3778	3778	3778	3778	3352	3352
Standardized beta	0.05	0.04	0.03	0.02	0.15	0.12	0.38	0.36

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table B.4: OLS regression results for the income share of the middle class and the average standardized usage lag (producer technologies)

Dependent variable:	Average standardized usage lag: Producer technologies only							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	-0.02 (0.11)	-0.09 (0.10)	-0.08 (0.11)	-0.06 (0.14)	-0.07 (0.19)	-0.04 (0.21)	-0.05 (0.16)	-0.08 (0.18)
Human capital	-14.86*** (1.14)	-5.68*** (1.54)	-5.35*** (1.60)	-4.19*** (1.60)	-5.34*** (1.59)	-4.18*** (1.58)	-4.67** (2.03)	-3.52* (1.95)
Openness	-4.09*** (1.23)	0.81 (1.30)	0.42 (1.41)	0.06 (1.48)	0.44 (1.44)	0.07 (1.51)	0.30 (1.78)	0.20 (1.85)
Income		-8.03*** (0.97)	-8.00*** (1.03)	-7.56*** (1.07)	-7.76* (4.29)	-7.29 (4.83)	-8.57*** (1.45)	-8.26*** (1.47)
Institutions			-0.16 (0.34)	-0.40 (0.37)	-0.16 (0.34)	-0.40 (0.36)	-0.50 (0.43)	-0.88* (0.44)
Income share middle class × Income					-0.00 (0.08)	-0.01 (0.10)		
L5.Income share middle class							-0.00 (0.14)	0.03 (0.17)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1746	1746	1636	1636	1636	1636	920	920
Standardized beta	-0.01	-0.04	-0.04	-0.02	-0.03	-0.02	-0.02	-0.04

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Table B.5: IV regression results for the Gini index and the average standardized usage lag (consumer technologies)

Dependent variable:	Average standardized usage lag: Consumer technologies					
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: First stage regressions					
Redistribution	-41.97***	-42.19***	-44.35***	-34.56***	-23.50**	-12.39
	(3.82)	(3.80)	(3.94)	(6.01)	(10.18)	(10.48)
Human capital	-1.45	-1.77	-2.10*	-0.50	-2.10*	-0.48
	(0.89)	(1.21)	(1.20)	(1.18)	(1.16)	(1.18)
Openness	-0.24	-0.39	-0.24	0.12	-0.05	0.31
	(0.55)	(0.67)	(0.71)	(0.58)	(0.77)	(0.58)
Income		0.28	-0.12	0.18	0.79	1.21
		(0.69)	(0.68)	(0.73)	(0.79)	(0.93)
Institutions			-0.64***	-0.24	-0.71***	-0.31
			(0.21)	(0.24)	(0.22)	(0.25)
Income × Redistribution					-7.35**	-8.06**
					(3.47)	(3.32)
	Panel B: Second stage regressions					
Gini index	0.71***	0.58***	0.55***	0.73***	-0.24	0.05
	(0.14)	(0.10)	(0.10)	(0.19)	(0.46)	(0.55)
Human capital	-13.20***	-5.22***	-4.28***	-4.52***	-4.35***	-3.93***
	(1.38)	(1.25)	(1.18)	(1.27)	(1.09)	(1.21)
Openness	-6.97***	-3.25***	-3.41***	-3.64***	-2.64**	-2.95***
	(0.92)	(0.65)	(0.76)	(0.75)	(1.06)	(0.97)
Income		-7.30***	-6.70***	-6.95***	-18.11***	-16.40**
		(0.65)	(0.63)	(0.69)	(6.58)	(6.84)
Institutions			1.08***	1.09***	0.84***	0.96***
			(0.20)	(0.24)	(0.24)	(0.23)
Income × Gini index					0.28*	0.24
					(0.16)	(0.17)
Region FE	No	No	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4272	4272	3954	3954	3954	3954
Fstat	120.773	123.137	126.816	33.085	9.390	5.702
Standardized beta	0.35	0.28	0.27	0.36	-0.12	0.02

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Fstat denotes the F statistic for weak identification. Standardized beta shows the standardized coefficient for the Gini.

Table B.6: RE regression results for the Gini index and the average standardized usage lag

Dependent variable:	Average standardized usage lag				
	(1)	(2)	(3)	(4)	(5)
Gini index	0.41***	0.38***	0.34***	0.26	0.38
	(0.10)	(0.08)	(0.08)	(0.23)	(0.25)
Human capital	-10.99***	-2.59**	-2.63**	-2.56**	-3.03***
	(1.43)	(1.22)	(1.21)	(1.24)	(1.14)
Openness	-3.48***	-1.05	-1.49*	-1.41	-2.15***
	(0.73)	(0.76)	(0.88)	(0.98)	(0.81)
Income		-7.29***	-6.91***	-8.25**	-6.22***
		(0.80)	(0.76)	(3.79)	(0.76)
Institutions			0.28	0.27	0.40
			(0.25)	(0.24)	(0.25)
Income × Gini index				0.03	
				(0.09)	
L.Gini index					-0.06
					(0.25)
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	958	958	886	886	794
Standardized beta	0.24	0.22	0.20	0.15	0.23

Note: Random effects model with 5-year panel data. Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table B.7: FE regression results for the Gini index and the average standardized usage lag

Dependent variable:	Average standardized usage lag				
	(1)	(2)	(3)	(4)	(5)
Gini index	0.38*	0.59***	0.49**	0.96*	0.55**
	(0.21)	(0.19)	(0.20)	(0.50)	(0.28)
Human capital	-2.60	5.89	5.36	5.40	5.78
	(4.91)	(3.97)	(4.28)	(4.20)	(4.77)
Openness	-1.29	0.53	0.70	0.57	0.30
	(1.22)	(1.29)	(1.36)	(1.31)	(1.42)
Income		-10.45***	-9.48***	-0.65	-9.95***
		(2.21)	(2.23)	(7.76)	(2.49)
Institutions			0.01	-0.00	0.15
			(0.39)	(0.38)	(0.44)
Income × Gini index				-0.25	
				(0.18)	
L.Gini index					0.02
					(0.27)
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	958	958	886	886	794
Standardized beta	0.22	0.34	0.29	0.56	0.33

Note: Fixed effects model with 5-year panel data. Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Appendix C: Derivations and Proofs

Derivation of equation (1.4)

Utility is

$$U(c(i)) = \int_0^\infty i^{-\gamma} 0.5[s^2 - (s - c(i))^2]\mathrm{d}i,$$

which is constrained by

$$e = \int_0^\infty p(i)c(i)\mathrm{d}i$$

and the non-negativity constraints $c(i) \geq 0$. Therefore, the Lagrangian function reads

$$\mathcal{L} = i^{-\gamma} 0.5[s^2 - (s - c(i))^2] - \lambda[p(i)c(i) - e] + \mu c(i), \quad \forall i$$

and leads to the following set of optimality conditions:

$$\frac{\partial \mathcal{L}}{\partial c(i)} = i^{-\gamma}(s - c(i)) - \lambda p(i) + \mu = 0 \tag{1.19}$$

$$\mu c(i) = 0 \tag{1.20}$$

$$p(i)c(i) = e \tag{1.21}$$

$$\mu \geq 0 \tag{1.22}$$

$$c(i) \geq 0 \tag{1.23}$$

Using (1.19), multiplying by $c(i)$, and using (1.20) gives

$$c(i)[i^{-\gamma}(s - c(i)) - \lambda p(i)] = -\mu c(i) = 0. \tag{1.24}$$

Combining (1.19) and (1.22) yields

$$i^{-\gamma}(s - c(i)) - \lambda p(i) = -\mu \leq 0. \tag{1.25}$$

Then, from (1.24), for goods that are consumed (i.e. $c(i) > 0$), it follows that $i^{-\gamma}(s-c(i)) = \lambda p(i)$ and, for prices being equal to marginal cost ($p(i) = mc(i) = 1$, where $p(i)$ is chosen as the numeraire) and assuming symmetry in production, one can derive consumption of good i as

$$c(i) = s - \lambda p(i) i^{\gamma} = s - \lambda i^{\gamma}.$$

Derivation of equation (1.6)

From the budget constraint it is clear that e equals the total amount of goods consumed, i.e. $e = \int_0^N c(i)\mathrm{d}i$ because $p(i) = 1$. Using (1.5), that gives

$$\begin{aligned}
e &= \int_0^N c(i) \\
&= \int_0^N s\left[1 - \left(\frac{i}{N}\right)^\gamma\right]\mathrm{d}i \\
&= s\int_0^N \left[1 - \left(\frac{i}{N}\right)^\gamma\right]\mathrm{d}i \\
&= s\left(i - \frac{i^{\gamma+1}}{\gamma+1}N^{-\gamma}\Big|_0^N\right) \\
&= s(N - N^{\gamma+1}N^{-\gamma}(\gamma+1)^{-1} - 0) \\
&= s\frac{\gamma}{\gamma+1}N
\end{aligned}$$

and therefore

$$N = \underbrace{\frac{1+\gamma}{s\gamma}}_{\equiv k} e$$

and

$$c(i) = s\left[1 - \left(\frac{i}{ke}\right)^\gamma\right].$$

Derivation of equation (1.8)

Aggregate consumption of good i is becomes:

$$\begin{aligned}
C(i) &= \int_{e_{min}(i)}^{\infty} c(i)g(e)\mathrm{de} \\
&= \int_{e_{min}(i)}^{\infty} s\left[1-\left(\frac{i}{ke}\right)^{\gamma}\right]\frac{\alpha e_m^{\alpha}}{e^{\alpha+1}}\mathrm{de} \\
&= \frac{\alpha e_m^{\alpha} s}{k^{\gamma}}\int_{e_{min}(i)}^{\infty} e^{-\alpha-1-\gamma}(k^{\gamma}e^{\gamma}-i^{\gamma})\mathrm{de} \\
&= \frac{\alpha e_m^{\alpha} s}{k^{\gamma}}\left(\int_{e_{min}(i)}^{\infty} e^{-\alpha-1}k^{\gamma}-i^{\gamma}e^{-\alpha-1-\gamma}\mathrm{de}\right) \\
&= \frac{\alpha e_m^{\alpha} s}{k^{\gamma}}\left(k^{\gamma}\int_{e_{min}(i)}^{\infty} e^{-\alpha-1}\mathrm{de}-i^{\gamma}\int_{e_{min}(i)}^{\infty} e^{-\alpha-1-\gamma}\mathrm{de}\right) \\
&= \frac{\alpha e_m^{\alpha} s}{k^{\gamma}}\left(\left[-\frac{k^{\gamma}}{\alpha e^{\alpha}}-\frac{i^{\gamma}e^{-\alpha-\gamma}}{-\alpha-\gamma}\right]\Bigg|_{e_{min}(i)}^{\infty}\right)+Cons \\
&= \left[-\frac{e_m^{\alpha}s}{e^{\alpha}}-\frac{\alpha e_m^{\alpha}si^{\gamma}e^{-\alpha-\gamma}}{k^{\gamma}(-\alpha-\gamma)}\right]\Bigg|_{e_{min}(i)}^{\infty}+Cons \\
&= \left[\frac{\alpha i^{\gamma}se^{-\alpha-\gamma}e_m^{\alpha}}{k^{\gamma}(\alpha+\gamma)}-\frac{se_m^{\alpha}}{e^{\alpha}}\right]\Bigg|_{e_{min}(i)}^{\infty}+Cons \\
&= \frac{e_m^{\alpha}s}{e_{min}(i)^{\alpha}}-\frac{\alpha e_m^{\alpha}si^{\gamma}e_{min}(i)^{-\gamma-\alpha}}{(\alpha+\gamma)k^{\gamma}}+Cons
\end{aligned}$$

Now, one can use the fact that $k=\frac{1+\gamma}{s\gamma}$. Also, one can determine e_{min}. The minimum income required to consume good i is the level of e makes (1.6) equal to zero. Hence, $e_{min}(i)=\frac{i}{k}=\frac{is\gamma}{1+\gamma}$. Using this in the above expression gives:

$$\begin{aligned}
C(i) &= s\left(\frac{e_m(1+\gamma)}{is\gamma}\right)^{\alpha}-\frac{\alpha e_m^{\alpha}i^{\gamma}s(is\gamma)^{-\alpha-\gamma}(1+\gamma)^{\alpha+\gamma}}{(1+\gamma)^{\gamma}(s\gamma)^{-\gamma}(\alpha+\gamma)} \\
&= e_m^{\alpha}(1+\gamma)^{\alpha}i^{-\alpha}\gamma^{-\alpha}s^{1-\alpha}\left(1-\frac{\alpha}{\alpha+\gamma}\right) \\
&= s\frac{\gamma}{\alpha+\gamma}\left(\frac{e_m(1+\gamma)}{i\gamma s}\right)^{\alpha} \\
&= \frac{\gamma}{\alpha+\gamma}\left(\frac{e_m}{e_{min}(i)}\right)^{\alpha}
\end{aligned}$$

Derivation of equation (1.10)

Using (1.9) in (1.8) gives

$$C(i) = \underbrace{\frac{\gamma}{\alpha+\gamma}}_{(1)} \underbrace{\left(\frac{\alpha-1}{\alpha}\right)^{\alpha}}_{(2)} \underbrace{B^{\alpha}}_{(3)}$$

where $B \equiv \frac{\bar{e}}{e_{min}(i)}$. Then,

$$\frac{\partial C(i)}{\partial \alpha} = (1)'(2)(3) + (1)(2)'(3) + (1)(2)(3)',$$

due to the chain rule and

$$\begin{aligned} (1)' &= -\gamma(\alpha+\gamma)^{-2}, \\ (2)' &= \left(\frac{\alpha-1}{\alpha}\right)^{\alpha}\left[\ln(\alpha-1) + \frac{\alpha}{\alpha-1} - \ln\alpha - 1\right] \\ &= \left(\frac{\alpha-1}{\alpha}\right)^{\alpha}\left[\ln\left(\frac{\alpha-1}{\alpha}\right) + \frac{1}{\alpha-1}\right], \\ (3)' &= B^{\alpha}\ln B, \end{aligned}$$

such that

$$\begin{aligned} \frac{\partial C(i)}{\partial \alpha} &= -\frac{\gamma}{(\alpha+\gamma)^2}\left(\frac{\alpha-1}{\alpha}\right)^{\alpha} B^{\alpha} \\ &+ \frac{\gamma}{\alpha+\gamma} B^{\alpha}\left(\frac{\alpha-1}{\alpha}\right)^{\alpha}\left[\ln\left(\frac{\alpha-1}{\alpha}\right) + \frac{1}{\alpha-1}\right] \\ &+ \frac{\gamma}{\alpha+\gamma}\left(\frac{\alpha-1}{\alpha}\right)^{\alpha} B^{\alpha}\ln B \\ &= \left(\frac{\alpha-1}{\alpha}\right)^{\alpha} B^{\alpha}\frac{\gamma}{\alpha+\gamma}\left[-\frac{1}{\alpha+\gamma} + \ln\left(\frac{\alpha-1}{\alpha}\right) + \frac{1}{\alpha-1} + \ln B\right] \\ &= \left(\frac{\alpha-1}{\alpha}\right)^{\alpha} B^{\alpha}\frac{\gamma}{\alpha+\gamma}\left[\ln B + \ln\left(\frac{\alpha-1}{\alpha}\right) + \frac{\gamma+1}{(\alpha+\gamma)(\alpha-1)}\right]. \end{aligned}$$

Appendix D: Theory with a Log-normal Distribution of Incomes

Here, I derive the results reported in table 1.1 for a log-normal distribution of incomes.

Deriving total consumption

Individual consumption of good i remains unchanged,

$$c(i) = s\left[1 - \left(\frac{i}{ke}\right)^{\gamma}\right],$$

while the distribution of income is now given by

$$g(e) = \frac{1}{e\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln(e) - \mu)^2}{2\sigma^2}\right).$$

Total consumption is yielded by integrating $c(i)$ over $g(e)$:

$$\begin{aligned}
C(i) &= \int_{e_{min}(i)}^{\infty} c(i)g(e)\mathrm{d}e \\
&= \int_{e_{min}(i)}^{\infty} s\left[1 - \left(\frac{i}{ke}\right)^{\gamma}\right] \frac{1}{e\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln(e) - \mu)^2}{2\sigma^2}\right)\mathrm{d}e \\
&= \frac{s}{\sigma\sqrt{2\pi}} \int_{e_{min}(i)}^{\infty} \left[e^{-1} - i^{\gamma}k^{-\gamma}e^{-\gamma-1}\right] \exp\left(-\frac{(\ln(e) - \mu)^2}{2\sigma^2}\right)\mathrm{d}e \\
&= -\frac{s}{\sigma k^{\gamma}\sqrt{2\pi}} \int_{e_{min}(i)}^{\infty} \left[i^{\gamma}e^{-\gamma-1} - k^{\gamma}e^{-1}\right] \exp\left(-\frac{(\ln(e) - \mu)^2}{2\sigma^2}\right)\mathrm{d}e \\
&= -\frac{s}{\sigma k^{\gamma}\sqrt{2\pi}} \int_{e_{min}(i)}^{\infty} \left[i^{\gamma}e^{-\gamma} - k^{\gamma}\right] \exp\left(-\frac{(\ln(e) - \mu)^2}{2\sigma^2}\right)\frac{1}{e}\mathrm{d}e
\end{aligned}$$

Now, define

$$u \equiv \ln(e)$$

and therefore

$$\mathrm{d}e = e\mathrm{d}u$$

and

$$e^{-\gamma} = \exp(\ln(e^{-\gamma})) = \exp(-\gamma\ln(e)) = \exp(-\gamma u).$$

Using this in the equation above yields

$$
\begin{aligned}
C(i) &= -\frac{s}{\sigma k^{\gamma}\sqrt{2\pi}} \int_{e_{min}(i)}^{\infty} \Big[i^{\gamma}\exp(-\gamma u) - k^{\gamma}\Big] \exp\Big(-\frac{(u-\mu)^2}{2\sigma^2}\Big)\mathrm{d}u \\
&= -\frac{s}{\sigma k^{\gamma}\sqrt{2\pi}} \int_{e_{min}(i)}^{\infty} \Big[i^{\gamma} - k^{\gamma}\exp(\gamma u)\Big] \exp\Big(-\frac{(u-\mu)^2}{2\sigma^2} - \gamma u\Big)\mathrm{d}u \\
&= \frac{s}{\sigma k^{\gamma}\sqrt{2\pi}} \int_{e_{min}(i)}^{\infty} \Big[k^{\gamma}\exp(\gamma u) - i^{\gamma}\Big] \exp\Big(-\frac{(u-\mu)^2}{2\sigma^2} - \gamma u\Big)\mathrm{d}u \\
&= \frac{s}{\sigma k^{\gamma}\sqrt{2\pi}} \int_{e_{min}(i)}^{\infty} k^{\gamma}\exp\Big(-\frac{(u-\mu)^2}{2\sigma^2}\Big) - i^{\gamma}\exp\Big(-\frac{(u-\mu)^2}{2\sigma^2} - \gamma u\Big)\mathrm{d}u \\
&= \frac{s}{\sigma k^{\gamma}\sqrt{2\pi}} \Big\{k^{\gamma} \int_{e_{min}(i)}^{\infty} \exp\Big(-\frac{(u-\mu)^2}{2\sigma^2}\Big)\mathrm{d}u - i^{\gamma} \int_{e_{min}(i)}^{\infty} \exp\Big(-\frac{(u-\mu)^2}{2\sigma^2} - \gamma u\Big)\mathrm{d}u\Big\}.
\end{aligned}
$$

Now, solve the second integral:

$$
\int \exp\Big(-\frac{(u-\mu)^2}{2\sigma^2} - \gamma u\Big)\mathrm{d}u = \int \exp\Big\{-\Big(\underbrace{\frac{u}{\sqrt{2}\sigma} - \frac{\sigma\big(\frac{\mu}{\sigma^2}-\gamma\big)}{\sqrt{2}}}_{=\frac{u-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}}\Big)^2 \underbrace{-\frac{\mu^2}{2\sigma^2} + \frac{\sigma^2\big(\frac{\mu}{\sigma^2}-\gamma\big)^2}{2}}_{\equiv K}\Big\}\mathrm{d}u
$$

Here, K is constant with respect to the integration variable u. Also, define

$$
v \equiv \frac{u-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}
$$

and therefore

$$
\mathrm{d}u = \sqrt{2}\sigma\mathrm{d}v.
$$

Using this in the equation above yields

$$
\begin{aligned}
\int \exp\Big(-\frac{(u-\mu)^2}{2\sigma^2} - \gamma u\Big)\mathrm{d}u &= \int \exp(-v^2+K)\sqrt{2}\sigma\mathrm{d}v \\
&= \sqrt{2}\sigma\exp(K)\int \exp(-v^2)\mathrm{d}v \\
&= \frac{\sqrt{\pi}\sigma\exp(K)}{\sqrt{2}} \underbrace{\int \frac{2\exp(-v^2)}{\sqrt{\pi}}\mathrm{d}v}_{=\mathrm{erf}(v)},
\end{aligned}
$$

where erf$(\cdot)$ denotes the Gaussian Error Function (Greene, 2011, p. 1090). Then, plugging back in v and K gives

$$\int \exp\left(-\frac{(u-\mu)^2}{2\sigma^2}-\gamma u\right)\mathrm{d}u = \frac{\sqrt{\pi}\sigma}{\sqrt{2}}\exp\left(\frac{\sigma^2\left(\frac{\mu}{\sigma^2}-\gamma\right)^2}{2}-\frac{\mu^2}{2\sigma^2}\right)\operatorname{erf}\left(\frac{u-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right).$$

Now, solve the first integral:

$$\int \exp\left(-\frac{(u-\mu)^2}{2\sigma^2}\right)\mathrm{d}u$$

Define

$$v \equiv \frac{u-\mu}{\sqrt{2}\sigma}$$

and therefore

$$\mathrm{d}u = \sqrt{2}\sigma\mathrm{d}v.$$

Using this in the equation above yields

$$\begin{aligned}\int \exp\left(-\frac{(u-\mu)^2}{2\sigma^2}\right)\mathrm{d}u &= \int \exp(-v^2)\sqrt{2}\sigma\mathrm{d}v \\ &= \sqrt{2}\sigma\int \exp(-v^2)\mathrm{d}v \\ &= \frac{\sqrt{\pi}\sigma}{\sqrt{2}}\underbrace{\int \frac{2\exp(-v^2)}{\sqrt{\pi}}\mathrm{d}v}_{=\operatorname{erf}(v)} \\ &= \frac{\sqrt{\pi}\sigma}{\sqrt{2}}\operatorname{erf}\left(\frac{u-\mu}{\sqrt{2}\sigma}\right).\end{aligned}$$

Now plug back the two solved integrals to the $C(i)$-equation. This gives

$$C(i) = \frac{s}{\sigma k^{\gamma}\sqrt{2\pi}}\left\{k^{\gamma}\int_{e_{min}(i)}^{\infty}\exp\left(-\frac{(u-\mu)^2}{2\sigma^2}\right)\mathrm{d}u - i^{\gamma}\int_{e_{min}(i)}^{\infty}\exp\left(-\frac{(u-\mu)^2}{2\sigma^2}-\gamma u\right)\mathrm{d}u\right\}$$

$$= \frac{s}{\sigma k^{\gamma}\sqrt{2\pi}}\left\{\left[k^{\gamma}\frac{\sqrt{\pi}\sigma}{\sqrt{2}}\,\mathrm{erf}\left(\frac{u-\mu}{\sqrt{2}\sigma}\right)\right.\right.$$

$$\left.\left.- i^{\gamma}\frac{\sqrt{\pi}\sigma}{\sqrt{2}}\exp\left(\frac{\sigma^2\left(\frac{\mu}{\sigma^2}-\gamma\right)^2}{2}-\frac{\mu^2}{2\sigma^2}\right)\mathrm{erf}\left(\frac{u-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right)\right]\Bigg|_{e_{min}(i)}^{\infty} + Cons\right\}$$

$$= \frac{s}{2}\left\{\left[\mathrm{erf}\left(\frac{u-\mu}{\sqrt{2}\sigma}\right) - \left(\frac{i}{k}\right)^{\gamma}\exp\left(\frac{\sigma^2\left(\frac{\mu}{\sigma^2}-\gamma\right)^2}{2}-\frac{\mu^2}{2\sigma^2}\right)\mathrm{erf}\left(\frac{u-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right)\right]\Bigg|_{e_{min}(i)}^{\infty}\right.$$

$$\left.+ Cons\right\}$$

$$= \frac{s}{2}\left\{\left[\mathrm{erf}\left(\frac{u-\mu}{\sqrt{2}\sigma}\right) - \left(\frac{i}{k}\right)^{\gamma}\exp\left(\frac{\gamma^2\sigma^2}{2}-\gamma\mu\right)\mathrm{erf}\left(\frac{u-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right)\right]\Bigg|_{e_{min}(i)}^{\infty} + Cons\right\}.$$

Next, undo the substitution $u = \ln(e)$:

$$C(i) = \frac{s}{2}\left\{\left[\mathrm{erf}\left(\frac{\ln(e)-\mu}{\sqrt{2}\sigma}\right) - \left(\frac{i}{k}\right)^{\gamma}\exp\left(\frac{\gamma^2\sigma^2}{2}-\gamma\mu\right)\mathrm{erf}\left(\frac{\ln(e)-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right)\right]\Bigg|_{e_{min}(i)}^{\infty}\right.$$

$$\left.+ Cons\right\}$$

Now, note that because one has to evaluate the error function from some value x, i.e. $e_{min}(i)$ to ∞ (and not from 0 to some finite value x), one has to use the complementary error function (cerf), and consumption becomes

$$C(i) = \frac{s}{2}\left[\mathrm{cerf}\left(\frac{\ln(e_{min}(i))-\mu}{\sqrt{2}\sigma}\right) - \left(\frac{i}{k}\right)^{\gamma}\exp\left(\frac{\gamma^2\sigma^2}{2}-\gamma\mu\right)\mathrm{cerf}\left(\frac{\ln(e_{min}(i))-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right)\right].$$

One can show that by using that $\mathrm{erf}(0) = 0, \mathrm{erf}(\infty) = 1, \mathrm{cerf}(0) = 1, \mathrm{cerf}(\infty) = 0$ (Press et al., 2007, p. 264).

Therefore,

$$C(i) = \frac{s}{2}\Bigg\{\Bigg[1-\left(\frac{i}{k}\right)^{\gamma}\exp\left(\frac{\gamma^2\sigma^2}{2}-\gamma\mu\right)$$
$$-\operatorname{erf}\left(\frac{\ln(e_{min}(i))-\mu}{\sqrt{2}\sigma}\right)+\left(\frac{i}{k}\right)^{\gamma}\exp\left(\frac{\gamma^2\sigma^2}{2}-\gamma\mu\right)\operatorname{erf}\left(\frac{\ln(e_{min}(i))-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right)\Bigg]$$
$$+Cons\Bigg\}$$
$$=\frac{s}{2}\Bigg\{1-\operatorname{erf}\left(\frac{\ln(e_{min}(i))-\mu}{\sqrt{2}\sigma}\right)-\left(\frac{i}{k}\right)^{\gamma}\exp\left(\frac{\gamma^2\sigma^2}{2}-\gamma\mu\right)$$
$$\left[1-\operatorname{erf}\left(\frac{\ln(e_{min}(i))-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right)\right]\Bigg\}$$
$$=\frac{s}{2}\left[\operatorname{cerf}\left(\frac{\ln(e_{min}(i))-\mu}{\sqrt{2}\sigma}\right)-\left(\frac{i}{k}\right)^{\gamma}\exp\left(\frac{\gamma^2\sigma^2}{2}-\gamma\mu\right)\operatorname{cerf}\left(\frac{\ln(e_{min}(i))-\mu+\sigma^2\gamma}{\sqrt{2}\sigma}\right)\right],$$

where the last line follows from the fact that $\operatorname{cerf}(x) = 1 - \operatorname{erf}(x)$ (Press et al., 2007, p. 264).

Now, to ease exposition, define the following expressions:

$$A \equiv \frac{\sigma^2\gamma^2}{2}-\gamma\mu$$
$$B \equiv \frac{\ln(e_{min}(i))-\mu}{\sqrt{2}\sigma}$$
$$C \equiv \frac{\gamma\sigma}{\sqrt{2}}$$

Using this and $e_{min}(i) = \frac{i}{k}$ in the expression for $C(i)$ leads to

$$C(i) = \frac{s}{2}\Big[\operatorname{cerf}(B) - e_{min}(i)^{\gamma}\exp(A)\operatorname{cerf}(B+C)\Big].$$

Taking derivative with respect to σ

In order to find the effect of a mean-preserving change in inequality on total consumption, I first need to replace μ with the mean of the distribution. For the log-normal,

$$\bar{e} = \exp\left(\mu + \frac{\sigma^2}{2}\right)$$

and therefore

$$\mu = \ln(\bar{e}) - \frac{\sigma^2}{2}.$$

Then, I can replace μ in the expression for consumption, i.e. redefine, A and B. Further, I introduce three further terms, D, E and F (used later):

$$\begin{aligned}
A &\equiv \frac{\sigma^2\gamma^2}{2} - \gamma\mu = \frac{\sigma^2\gamma^2}{2} + \frac{\gamma\sigma^2}{2} - \gamma\ln(\bar{e}) \\
B &\equiv \frac{\ln(e_{min}(i)) - \mu}{\sqrt{2}\sigma} = \frac{\ln(e_{min}(i)) + \frac{\sigma^2}{2} - \ln(\bar{e})}{\sqrt{2}\sigma} \\
C &\equiv \frac{\gamma\sigma}{\sqrt{2}} \\
D &\equiv \frac{\sqrt{2}\left[\frac{\sigma^2}{2} - \ln(e_{min}(i)) + \ln(\bar{e})\right]}{\sqrt{\pi}\sigma^2}\left[= -\frac{2}{\sigma\sqrt{\pi}}B + \frac{\sqrt{2}}{\sqrt{\pi}}\right] \\
E &\equiv \frac{\sqrt{2}\gamma}{\sqrt{\pi}} \\
F &\equiv \sigma\gamma^2 + \sigma\gamma
\end{aligned}$$

Then, I need to find the derivatives of $\exp(A)$, $\mathrm{cerf}(B)$ and $\mathrm{cerf}(B+C)$. Note that for the error function $[\mathrm{cerf}(u(x))]' = -\frac{2}{\sqrt{\pi}}\exp(-u(x)^2)u'(x)$, which follows directly from the definition of the error function.
The derivative of $\exp(A)$ with respect to σ is

$$\begin{aligned}
\frac{\partial\exp(A)}{\partial\sigma} &= \frac{\partial\exp\left(\frac{\sigma^2\gamma^2}{2} + \frac{\gamma\sigma^2}{2} - \gamma\ln(\bar{e})\right)}{\partial\sigma} \\
&= \exp\left(\frac{\sigma^2\gamma^2}{2} - \gamma + \frac{\gamma\sigma^2}{2} - \gamma\ln(\bar{e})\right)[\sigma\gamma^2 + \gamma\sigma] \\
&= \exp(A)[\sigma\gamma^2 + \gamma\sigma].
\end{aligned}$$

Second, the derivative of cerf(B) with respect to σ is

$$\begin{aligned}\frac{\partial\, \mathrm{cerf}(B)}{\partial\sigma} &= -\frac{2}{\sqrt{\pi}}\exp(-B^2)\Big(\frac{\frac{\sigma^2}{2}-\ln(e_{min}(i))+\ln(\bar{e})}{\sqrt{2}\sigma^2}\Big)\\ &= -\frac{\sqrt{2}[\frac{\sigma^2}{2}-\ln(e_{min}(i))+\ln(\bar{e})]}{\sqrt{\pi}\sigma^2}\exp(-B^2).\end{aligned}$$

Third, the derivative of cerf$(B+C)$ with respect to σ is

$$\begin{aligned}\frac{\partial\, \mathrm{cerf}(B+C)}{\partial\sigma} &= -\frac{2}{\sqrt{\pi}}\exp(-(B+C)^2)\frac{\partial\overbrace{\Big(\frac{\ln(e_{min}(i))-\ln(\bar{e})+\frac{\sigma^2}{2}+\sigma^2\gamma}{\sqrt{2}\sigma}\Big)}^{=B+C}}{\partial\sigma}\\ &= -\frac{2}{\sqrt{\pi}}\exp(-(B+C)^2)\Big((\sigma+2\gamma\sigma)[\sqrt{2}\sigma]^{-1}\\ &+[\ln(e_{min}(i))-\ln(\bar{e})+\frac{\sigma^2}{2}+\sigma^2\gamma](-1)[\sqrt{2}\sigma]^{-2}\sqrt{2}\Big)\\ &= -\frac{2}{\sqrt{\pi}}\exp(-(B+C)^2)\Big(\frac{\sigma+2\gamma\sigma}{\sqrt{2}\sigma}-\frac{\sqrt{2}[\ln(e_{min}(i))-\ln(\bar{e})+\frac{\sigma^2}{2}+\sigma^2\gamma]}{2\sigma^2}\Big)\\ &= -\frac{2}{\sqrt{\pi}}\exp(-(B+C)^2)\frac{\sigma^2+2\gamma\sigma^2-\ln(e_{min}(i))+\ln(\bar{e})-\frac{\sigma^2}{2}-\sigma^2\gamma}{\sqrt{2}\sigma^2}\\ &= -\frac{\sqrt{2}[\frac{\sigma^2}{2}+\gamma\sigma^2-\ln(e_{min}(i))+\ln(\bar{e})]}{\sqrt{\pi}\sigma^2}\exp(-(B+C)^2).\end{aligned}$$

Finally,

$$\begin{aligned}\frac{\partial C(i)}{\partial\sigma} =& \frac{s}{2}\Bigg\{\frac{\partial\, \mathrm{cerf}(B)}{\partial\sigma}-e_{min}(i)\Big[\frac{\partial\exp(A)}{\partial\sigma}\mathrm{cerf}(B+C)+\exp(A)\frac{\partial\, \mathrm{cerf}(B+C)}{\partial\sigma}\Big]\Bigg\}\\ =& \frac{s}{2}\Bigg\{-\frac{\sqrt{2}[\frac{\sigma^2}{2}-\ln(e_{min}(i))+\ln(\bar{e})]}{\sqrt{\pi}\sigma^2}\exp(-B^2)\\ &-e_{min}(i)^\gamma\Big[\exp(A)[\sigma\gamma^2+\sigma\gamma]\,\mathrm{cerf}(B+C)\\ &-\exp(A)\frac{\sqrt{2}[\frac{\sigma^2}{2}+\gamma\sigma^2-\ln(e_{min}(i))+\ln(\bar{e})]}{\sqrt{\pi}\sigma^2}\exp(-(B+C)^2)\Big]\Bigg\},\end{aligned}$$

which can be simplified further using the definitions used above:

$$\frac{\partial C(i)}{\partial\sigma} =$$
$$\frac{s}{2}\Bigg\{-D\exp(-B^2)-e_{min}(i)^\gamma\Big[\exp(A)F\,\mathrm{cerf}(B+C)-\exp(A)(D+E)\exp(-(B+C)^2)\Big]\Bigg\}$$

As in the main text with the Pareto distribution, the sign of this expression depends on the relative size of $B \equiv \frac{\bar{e}}{e_{min}(i)}$. Table D.1 reports the minimum values that B has to take such that higher inequality reduces total consumption in the economy. Note that for the log-normal distribution, the Gini index is given by $2\Phi\left(\sigma/\sqrt{2}\right)-1$, which is equal to $\text{erf}(\sigma/2)$ (Kleiber and Klotz, 2003; Press et al., 2007).

Table D.1: Minimum values for B such that inequality reduces consumption

		γ								
σ	Gini	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.40	0.22	1.42	1.40	1.38	1.36	1.34	1.32	1.31	1.29	1.28
0.60	0.33	1.42	1.39	1.36	1.33	1.30	1.28	1.26	1.24	1.23
0.80	0.43	1.33	1.29	1.25	1.22	1.19	1.17	1.15	1.12	1.11
1.00	0.52	1.17	1.13	1.09	1.06	1.03	1.01	0.98	0.97	0.95
1.20	0.60	0.98	0.94	0.90	0.88	0.85	0.83	0.81	0.79	0.77
1.40	0.68	0.78	0.74	0.72	0.69	0.67	0.65	0.63	0.62	0.60
1.60	0.74	0.59	0.56	0.54	0.52	0.50	0.49	0.47	0.46	0.45
1.80	0.80	0.43	0.41	0.39	0.38	0.36	0.35	0.34	0.33	0.32
2.00	0.84	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.23	0.22

Note: Gini is the Gini index implied by σ

Appendix E: Selected Regression Outputs

Internet access

Table E.1: OLS regression results for the Gini index

Dependent variable:	Internet users							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	-4.57*** (1.05)	-3.90*** (0.84)	-3.83*** (0.82)	-4.52*** (1.07)	8.10*** (1.93)	6.80*** (2.09)	1.22 (5.04)	1.43 (4.92)
Human capital	165.20*** (14.67)	78.25*** (17.88)	58.86*** (15.79)	67.41*** (16.08)	53.09*** (14.93)	57.30*** (15.69)	53.75*** (16.79)	62.63*** (16.65)
Openness	90.04*** (18.99)	56.26*** (15.98)	60.22*** (17.13)	59.48*** (15.36)	42.29*** (11.54)	45.63*** (11.47)	57.62*** (17.22)	58.25*** (15.85)
Income		73.98*** (10.93)	68.75*** (8.89)	73.82*** (8.84)	272.00*** (32.14)	270.60*** (33.50)	77.32*** (9.84)	81.69*** (9.73)
Institutions			-14.93*** (3.87)	-11.60** (4.52)	-9.68** (3.73)	-8.18** (4.00)	-14.17*** (3.99)	-11.17** (4.68)
Gini index × Income					-5.06*** (0.73)	-5.01*** (0.79)		
L5.Gini index							-5.10 (5.04)	-6.19 (5.09)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2646	2646	2622	2622	2622	2622	2494	2494
Standardized beta	-0.15	-0.13	-0.13	-0.15	0.27	0.22	0.04	0.05

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.2: OLS regression results for the Gini index

Dependent variable:	Usage lag of internet users							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	0.10***	0.07***	0.07***	0.09***	-0.27***	-0.24***	-0.29***	-0.31***
	(0.03)	(0.02)	(0.02)	(0.03)	(0.05)	(0.05)	(0.11)	(0.10)
Human capital	-4.69***	-2.48***	-1.94***	-2.12***	-1.89***	-1.97***	-1.82***	-2.03***
	(0.42)	(0.48)	(0.43)	(0.46)	(0.40)	(0.43)	(0.44)	(0.46)
Openness	-2.14***	-1.27***	-1.45***	-1.47***	-1.09***	-1.18***	-1.44***	-1.50***
	(0.35)	(0.30)	(0.30)	(0.28)	(0.25)	(0.24)	(0.32)	(0.30)
Income		-2.23***	-2.10***	-2.21***	-7.45***	-7.51***	-2.21***	-2.29***
		(0.30)	(0.23)	(0.23)	(0.75)	(0.81)	(0.26)	(0.25)
Institutions			0.40***	0.34***	0.27***	0.26**	0.37***	0.29**
			(0.10)	(0.11)	(0.10)	(0.10)	(0.10)	(0.11)
Gini index × Income					0.13***	0.14***		
					(0.02)	(0.02)		
L5.Gini index							0.36***	0.41***
							(0.10)	(0.10)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1871	1871	1848	1848	1848	1848	1800	1800
Standardized beta	0.16	0.10	0.10	0.14	-0.41	-0.36	-0.45	-0.47

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.3: OLS regression results for the income share of the middle class

Dependent variable:	Internet users							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	2.75 (1.73)	2.29* (1.24)	2.58** (1.24)	1.57 (1.99)	-14.88*** (3.00)	-13.00*** (3.02)	-2.94 (2.58)	-4.00 (2.86)
Human capital	174.12*** (20.35)	60.78*** (18.99)	51.99*** (17.71)	63.15*** (19.56)	59.00*** (18.27)	65.26*** (20.20)	55.44** (23.41)	69.95*** (23.73)
Openness	156.85*** (28.66)	100.46*** (22.70)	99.16*** (23.17)	91.86*** (22.72)	74.76*** (22.18)	74.65*** (22.09)	106.43*** (23.68)	99.17*** (23.13)
Income		105.92*** (11.82)	88.50*** (11.16)	96.96*** (11.46)	-268.51*** (60.44)	-222.45*** (63.42)	118.19*** (15.31)	125.22*** (15.34)
Institutions			-19.61*** (5.43)	-16.77*** (5.88)	-16.69*** (5.40)	-15.39*** (5.45)	-17.94** (7.59)	-21.05** (8.01)
Income share middle class × Income					7.45*** (1.29)	6.59*** (1.34)		
L5.Income share middle class							5.06** (2.29)	3.26 (2.47)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1223	1223	1219	1219	1219	1219	751	751
Standardized beta	0.06	0.05	0.06	0.03	-0.33	-0.28	-0.06	-0.08

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Table E.4: OLS regression results for the income share of the middle class

Dependent variable:	Usage lag of internet users							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	-0.05 (0.04)	-0.00 (0.03)	-0.01 (0.03)	-0.02 (0.05)	0.40*** (0.09)	0.37*** (0.09)	0.12* (0.07)	0.12 (0.08)
Human capital	-4.74*** (0.59)	-2.27*** (0.47)	-2.10*** (0.43)	-2.12*** (0.49)	-2.24*** (0.46)	-2.18*** (0.51)	-2.76*** (0.53)	-2.95*** (0.55)
Openness	-3.21*** (0.62)	-1.75*** (0.48)	-1.73*** (0.47)	-1.72*** (0.48)	-1.30*** (0.47)	-1.37*** (0.48)	-2.05*** (0.54)	-1.99*** (0.53)
Income		-3.02*** (0.28)	-2.58*** (0.28)	-2.62*** (0.30)	5.67*** (1.68)	5.43*** (1.76)	-2.76*** (0.40)	-2.84*** (0.41)
Institutions			0.46*** (0.14)	0.40*** (0.15)	0.40*** (0.15)	0.38*** (0.14)	0.48*** (0.18)	0.51*** (0.19)
Income share middle class × Income					-0.17*** (0.04)	-0.17*** (0.04)		
L5.Income share middle class							-0.09 (0.06)	-0.06 (0.06)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	968	968	965	965	965	965	626	626
Standardized beta	-0.06	-0.00	-0.01	-0.02	0.46	0.43	0.14	0.14

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Personal computers

Table E.5: OLS regression results for the Gini index

Dependent variable:	Personal computers							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	-3.88*** (0.86)	-3.44*** (0.73)	-3.59*** (0.71)	-5.27*** (0.91)	8.83*** (1.86)	7.24*** (1.99)	-5.52 (3.73)	-4.95 (3.68)
Human capital	101.07*** (15.28)	44.82*** (16.08)	34.68** (16.57)	49.39*** (16.58)	29.55** (14.76)	39.16** (15.67)	38.40** (18.39)	51.44*** (18.09)
Openness	83.39*** (14.27)	57.85*** (12.98)	54.87*** (13.11)	57.66*** (12.53)	42.33*** (12.34)	45.09*** (10.68)	51.21*** (12.76)	54.58*** (12.30)
Income		50.48*** (10.52)	48.50*** (9.94)	52.86*** (9.97)	256.20*** (31.39)	265.11*** (32.04)	54.66*** (11.34)	59.64*** (11.44)
Institutions			-6.32* (3.35)	-6.94* (3.63)	-0.72 (3.15)	-2.49 (3.09)	-5.84 (3.77)	-7.54* (4.09)
Gini index × Income					-5.23*** (0.73)	-5.42*** (0.76)		
L5.Gini index							1.85 (3.82)	-0.40 (3.83)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1800	1800	1775	1775	1775	1775	1640	1640
Standardized beta	-0.21	-0.18	-0.20	-0.29	0.48	0.40	-0.30	-0.26

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.6: OLS regression results for the Gini index

Dependent variable:	Usage lag of personal computers							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	0.16*** (0.04)	0.10*** (0.03)	0.10*** (0.03)	0.15*** (0.04)	-0.52*** (0.07)	-0.47*** (0.07)	0.19 (0.15)	0.22 (0.14)
Human capital	-4.39*** (0.65)	-2.37*** (0.72)	-1.79** (0.69)	-2.10*** (0.64)	-1.75*** (0.57)	-1.83*** (0.55)	-1.84** (0.72)	-2.19*** (0.67)
Openness	-3.19*** (0.46)	-1.91*** (0.38)	-1.91*** (0.37)	-2.02*** (0.36)	-1.63*** (0.35)	-1.71*** (0.31)	-1.87*** (0.37)	-1.99*** (0.36)
Income		-3.17*** (0.65)	-3.01*** (0.61)	-3.15*** (0.55)	-12.37*** (1.16)	-12.31*** (1.14)	-3.11*** (0.65)	-3.24*** (0.58)
Institutions			0.33* (0.19)	0.36** (0.18)	0.10 (0.15)	0.21 (0.14)	0.33* (0.20)	0.36* (0.19)
Gini index × Income					0.25*** (0.03)	0.24*** (0.03)		
L5.Gini index							-0.08 (0.14)	-0.06 (0.14)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1267	1267	1243	1243	1243	1243	1205	1205
Standardized beta	0.23	0.14	0.15	0.22	-0.75	-0.68	0.27	0.31

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.7: OLS regression results for the income share of the middle class

Dependent variable:	Personal computers							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	3.16* (1.64)	2.92** (1.37)	2.80** (1.39)	4.25** (1.63)	-13.68*** (3.71)	-10.45*** (3.61)	3.06 (2.55)	2.40 (3.19)
Human capital	125.30*** (24.46)	41.23* (22.35)	43.36* (23.92)	66.56*** (22.74)	48.01** (22.96)	65.99*** (22.81)	40.33 (36.48)	54.02* (32.26)
Openness	134.44*** (32.01)	86.91*** (29.22)	90.17*** (32.63)	89.28*** (29.51)	68.09** (30.22)	72.56*** (27.51)	73.67* (42.19)	82.28** (38.19)
Income		77.67*** (13.89)	79.36*** (14.54)	93.07*** (14.48)	-266.51*** (70.62)	-232.40*** (71.09)	117.74*** (21.80)	129.14*** (20.33)
Institutions			2.56 (5.88)	-1.88 (6.10)	5.19 (5.71)	-0.07 (5.63)	12.12 (12.74)	0.94 (11.49)
Income share middle class × Income					7.16*** (1.49)	6.67*** (1.47)		
L5.Income share middle class							0.53 (2.41)	3.39 (2.10)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	820	820	816	816	816	816	460	460
Standardized beta	0.11	0.10	0.10	0.14	-0.47	-0.36	0.10	0.07

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Table E.8: OLS regression results for the income share of the middle class

Dependent variable:	Usage lag of personal computers							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	-0.13** (0.06)	-0.00 (0.05)	-0.00 (0.05)	-0.05 (0.05)	0.69*** (0.13)	0.66*** (0.12)	-0.06 (0.07)	-0.07 (0.08)
Human capital	-5.25*** (0.95)	-2.75*** (0.71)	-2.72*** (0.78)	-2.93*** (0.70)	-2.78*** (0.72)	-2.84*** (0.64)	-3.04*** (1.12)	-3.18*** (1.13)
Openness	-5.24*** (1.00)	-2.82*** (0.77)	-2.91*** (0.87)	-3.02*** (0.86)	-2.42*** (0.81)	-2.55*** (0.80)	-2.80** (1.10)	-2.99*** (1.11)
Income		-4.55*** (0.45)	-4.50*** (0.49)	-4.52*** (0.47)	9.94*** (2.63)	10.06*** (2.45)	-4.85*** (0.65)	-4.85*** (0.65)
Institutions			0.05 (0.25)	0.16 (0.24)	-0.05 (0.22)	0.09 (0.20)	0.15 (0.43)	0.21 (0.43)
Income share middle class × Income					-0.29*** (0.05)	-0.29*** (0.05)		
L5.Income share middle class							0.04 (0.07)	-0.01 (0.07)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	661	661	657	657	657	657	385	385
Standardized beta	-0.13	-0.00	-0.00	-0.05	0.66	0.63	-0.05	-0.06

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Mobile phones

Table E.9: OLS regression results for the Gini index

Dependent variable:	Mobile phone subscriptions							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	-1.97 (1.53)	-0.72 (1.10)	-1.26 (1.00)	1.48 (1.54)	-2.37 (2.42)	-1.11 (2.66)	-14.66** (6.37)	-14.33** (6.48)
Human capital	206.79*** (21.03)	58.80** (24.73)	45.13** (21.98)	29.24 (22.80)	45.75** (22.04)	31.88 (22.84)	53.60** (23.84)	38.47 (24.52)
Openness	137.85*** (32.42)	77.60** (34.08)	46.65** (18.78)	38.41** (15.29)	48.25** (19.72)	41.49** (15.91)	42.42** (18.80)	32.30** (15.85)
Income		129.35*** (15.89)	129.64*** (14.28)	127.76*** (14.09)	110.84** (43.20)	82.79* (44.29)	135.57*** (15.17)	133.55*** (15.13)
Institutions			-9.02* (5.37)	-5.59 (5.18)	-9.52* (5.49)	-6.38 (5.22)	-7.94 (5.49)	-4.97 (5.30)
Gini index × Income					0.47 (0.99)	1.15 (1.04)		
L5.Gini index							13.05** (6.29)	15.96** (6.61)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2959	2959	2923	2923	2923	2923	2730	2730
Standardized beta	-0.04	-0.01	-0.02	0.03	-0.04	-0.02	-0.27	-0.26

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.10: OLS regression results for the Gini index

Dependent variable:	Usage lag of mobile phone subscriptions							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	0.05 (0.03)	0.01 (0.02)	0.02 (0.02)	-0.01 (0.03)	-0.10** (0.04)	-0.11** (0.05)	0.14 (0.11)	0.14 (0.11)
Human capital	-5.00*** (0.47)	-1.29** (0.53)	-0.67* (0.40)	-0.54 (0.44)	-0.57 (0.40)	-0.40 (0.45)	-0.77* (0.43)	-0.64 (0.46)
Openness	-3.23*** (0.67)	-1.49*** (0.44)	-1.30*** (0.31)	-1.24*** (0.28)	-1.13*** (0.27)	-1.12*** (0.27)	-1.25*** (0.31)	-1.17*** (0.28)
Income		-3.33*** (0.33)	-3.19*** (0.24)	-3.22*** (0.25)	-5.31*** (0.81)	-5.12*** (0.83)	-3.30*** (0.26)	-3.33*** (0.27)
Institutions			0.46*** (0.10)	0.43*** (0.10)	0.41*** (0.09)	0.40*** (0.10)	0.44*** (0.10)	0.41*** (0.10)
Gini index × Income					0.05*** (0.02)	0.05** (0.02)		
L5.Gini index							-0.12 (0.10)	-0.16 (0.11)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2409	2409	2385	2385	2385	2385	2193	2193
Standardized beta	0.07	0.02	0.03	-0.01	-0.16	-0.17	0.22	0.22

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.11: OLS regression results for the income share of the middle class

Dependent variable:	Mobile phone subscriptions							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	3.69 (2.47)	2.88 (1.79)	3.44* (1.81)	-2.12 (2.18)	6.70 (5.08)	2.97 (5.16)	5.38 (4.21)	3.58 (4.22)
Human capital	185.28*** (24.18)	17.15 (26.27)	13.52 (26.56)	-6.07 (22.85)	12.67 (26.42)	-5.93 (22.59)	-34.76 (38.70)	-49.53 (36.38)
Openness	173.82*** (34.47)	91.81*** (32.37)	77.69** (32.10)	61.66** (29.84)	81.96** (33.84)	67.27** (31.14)	61.95 (41.84)	48.36 (39.40)
Income		156.33*** (17.20)	153.13*** (17.37)	146.72*** (17.56)	220.61** (101.54)	259.32** (99.53)	186.04*** (29.34)	182.66*** (29.08)
Institutions			-5.28 (7.15)	-0.15 (6.59)	-5.90 (7.30)	-0.72 (6.54)	7.05 (11.18)	16.83 (10.45)
Income share middle class × Income					-1.40 (2.19)	-2.32 (2.15)		
L5.Income share middle class							1.74 (3.85)	-0.86 (3.93)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1346	1346	1339	1339	1339	1339	816	816
Standardized beta	0.04	0.04	0.04	-0.03	0.08	0.04	0.06	0.04

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Table E.12: OLS regression results for the income share of the middle class

Dependent variable:	Usage lag of mobile phone subscriptions							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	-0.05 (0.05)	-0.03 (0.03)	-0.05 (0.03)	0.02 (0.04)	0.13** (0.06)	0.17*** (0.06)	-0.13** (0.05)	-0.11** (0.05)
Human capital	-4.63*** (0.54)	-0.36 (0.48)	-0.12 (0.44)	0.15 (0.45)	-0.15 (0.43)	0.19 (0.47)	0.01 (0.54)	0.25 (0.58)
Openness	-4.66*** (0.86)	-2.00*** (0.56)	-1.78*** (0.55)	-1.64*** (0.57)	-1.53*** (0.54)	-1.47** (0.56)	-2.18*** (0.80)	-2.07** (0.83)
Income		-4.05*** (0.27)	-3.76*** (0.23)	-3.71*** (0.25)	-0.13 (1.32)	-0.20 (1.37)	-4.20*** (0.33)	-4.17*** (0.34)
Institutions			0.35*** (0.13)	0.30** (0.13)	0.32** (0.13)	0.28** (0.13)	0.11 (0.19)	0.00 (0.21)
Income share middle class × Income					-0.08*** (0.03)	-0.07** (0.03)		
L5.Income share middle class							0.03 (0.04)	0.05 (0.05)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1010	1010	1005	1005	1005	1005	536	536
Standardized beta	-0.05	-0.03	-0.05	0.02	0.15	0.20	-0.15	-0.13

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Cars

Table E.13: OLS regression results for the Gini index

Dependent variable:	Cars in use							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	-5.37***	-5.13***	-5.31***	-4.76***	4.95**	2.24	-4.04	-1.89
	(1.02)	(0.84)	(0.77)	(1.24)	(2.00)	(2.21)	(3.40)	(3.25)
Human capital	159.41***	80.54***	62.92**	59.30**	32.43	33.71	58.46**	54.55**
	(16.47)	(23.71)	(24.70)	(23.33)	(24.50)	(23.92)	(26.17)	(24.04)
Openness	-3.14	-30.58	-11.08	-9.79	-26.78**	-19.56*	-15.20	-12.80
	(19.39)	(19.04)	(16.40)	(11.94)	(11.80)	(10.93)	(16.59)	(12.24)
Income		60.84***	51.02***	56.98***	241.04***	195.97***	57.53***	62.89***
		(13.09)	(12.13)	(11.54)	(42.89)	(45.88)	(13.18)	(12.43)
Institutions			-15.63***	-13.24***	-12.86***	-11.79***	-15.90***	-13.41***
			(3.29)	(3.60)	(2.79)	(3.13)	(3.57)	(3.93)
Gini index × Income					-4.49***	-3.33***		
					(0.91)	(1.01)		
L5.Gini index							-1.44	-2.89
							(3.42)	(3.30)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3146	3146	2834	2834	2834	2834	2510	2510
Standardized beta	-0.29	-0.27	-0.28	-0.25	0.26	0.12	-0.21	-0.10

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.14: OLS regression results for the Gini index

Dependent variable:	Usage lag of cars in use							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	0.74***	0.71***	0.74***	0.49***	-0.90***	-0.61**	0.74	0.33
	(0.14)	(0.11)	(0.10)	(0.17)	(0.25)	(0.26)	(0.47)	(0.47)
Human capital	-21.40***	-9.54***	-6.93**	-5.96**	-1.92	-1.93	-6.50**	-5.54**
	(1.75)	(2.86)	(3.02)	(2.40)	(2.74)	(2.40)	(3.18)	(2.41)
Openness	-0.91	3.20	0.41	0.48	2.86*	2.02	0.96	0.89
	(2.97)	(2.83)	(2.82)	(1.79)	(1.58)	(1.34)	(2.79)	(1.78)
Income		-9.14***	-7.59***	-8.16***	-38.10***	-30.11***	-8.24***	-8.66***
		(1.81)	(1.67)	(1.41)	(5.41)	(6.04)	(1.81)	(1.49)
Institutions			2.34***	1.97***	1.90***	1.74***	2.37***	1.98***
			(0.48)	(0.51)	(0.39)	(0.43)	(0.51)	(0.55)
Gini index × Income					0.72***	0.53***		
					(0.11)	(0.13)		
L5.Gini index							0.04	0.15
							(0.47)	(0.46)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3103	3103	2803	2803	2803	2803	2479	2479
Standardized beta	0.28	0.26	0.27	0.18	-0.33	-0.23	0.27	0.12

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.15: OLS regression results for the income share of the middle class

Dependent variable:	Cars in use							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	7.09*** (2.22)	7.15*** (1.56)	7.65*** (1.49)	6.26*** (1.92)	-5.07 (3.27)	-1.59 (3.67)	0.58 (2.21)	0.55 (1.57)
Human capital	186.96*** (26.89)	67.92* (35.61)	48.16 (35.85)	47.99 (37.22)	31.98 (36.80)	35.11 (38.36)	38.58 (46.62)	34.69 (44.62)
Openness	19.78 (30.14)	-26.10 (31.46)	-17.91 (28.68)	-24.82 (26.53)	-37.65 (27.51)	-34.88 (26.70)	-42.91 (39.83)	-39.91 (36.56)
Income		94.73*** (18.21)	82.48*** (16.71)	91.29*** (18.49)	-177.51** (68.09)	-83.65 (66.14)	119.51*** (25.21)	122.91*** (27.71)
Institutions			-21.39*** (4.57)	-20.48*** (4.81)	-18.56*** (4.18)	-18.93*** (4.56)	-22.58*** (7.12)	-24.27*** (7.42)
Income share middle class × Income					5.60*** (1.55)	3.75** (1.52)		
L5.Income share middle class							7.04*** (1.85)	7.66*** (2.38)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1322	1322	1207	1207	1207	1207	664	664
Standardized beta	0.24	0.25	0.26	0.21	-0.17	-0.05	0.02	0.02

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Table E.16: OLS regression results for the income share of the middle class

Dependent variable:	Usage lag of cars in use							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	-1.06*** (0.29)	-1.06*** (0.18)	-1.16*** (0.17)	-0.55* (0.31)	1.02** (0.40)	0.74* (0.37)	-0.37* (0.22)	0.01 (0.26)
Human capital	-23.02*** (2.19)	-6.33 (4.20)	-3.15 (4.06)	-1.38 (3.43)	-0.20 (3.84)	0.74 (3.28)	0.64 (4.77)	2.34 (3.91)
Openness	-6.33 (4.01)	0.20 (4.03)	-0.98 (3.41)	-0.16 (2.50)	2.27 (3.01)	1.49 (2.48)	0.36 (3.40)	0.06 (2.81)
Income		-13.37*** (2.52)	-11.33*** (2.25)	-11.19*** (1.97)	33.40*** (7.77)	17.74** (8.43)	-14.74*** (3.11)	-13.82*** (2.73)
Institutions			3.33*** (0.64)	2.99*** (0.67)	2.86*** (0.56)	2.74*** (0.61)	4.08*** (0.91)	3.90*** (0.84)
Income share middle class × Income					-0.96*** (0.18)	-0.62*** (0.20)		
L5.Income share middle class							-0.97*** (0.23)	-0.59** (0.24)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1281	1281	1178	1178	1178	1178	635	635
Standardized beta	-0.27	-0.27	-0.29	-0.14	0.26	0.19	-0.09	0.00

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Electricity production

Table E.17: OLS regression results for the Gini index

Dependent variable:	Electricity production in gWh							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	-0.12***	-0.12***	-0.12***	-0.18***	0.31**	0.27**	0.05	0.03
	(0.04)	(0.04)	(0.04)	(0.05)	(0.12)	(0.13)	(0.12)	(0.12)
Human capital	3.19***	1.10*	1.04	1.46**	0.56	0.75	0.93	1.35*
	(0.45)	(0.62)	(0.63)	(0.67)	(0.67)	(0.73)	(0.70)	(0.71)
Openness	1.16***	0.12	0.15	0.25	-0.51	-0.35	0.10	0.25
	(0.43)	(0.33)	(0.37)	(0.35)	(0.55)	(0.48)	(0.38)	(0.36)
Income		1.78***	1.81***	1.95***	9.45***	10.01***	1.97***	2.11***
		(0.44)	(0.47)	(0.51)	(2.78)	(2.97)	(0.52)	(0.56)
Institutions			-0.04	-0.03	0.13	0.11	-0.03	-0.03
			(0.11)	(0.11)	(0.11)	(0.12)	(0.12)	(0.12)
Gini index × Income					-0.19***	-0.20***		
					(0.06)	(0.07)		
L5.Gini index							-0.18	-0.22*
							(0.13)	(0.13)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3892	3892	3577	3577	3577	3577	3144	3144
Standardized beta	-0.23	-0.22	-0.22	-0.32	0.55	0.48	0.09	0.06

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.18: OLS regression results for the Gini index

Dependent variable:	Usage lag of electricity production in gWh							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gini index	0.22 (0.17)	0.14 (0.14)	0.10 (0.15)	0.13 (0.21)	0.04 (0.38)	0.07 (0.41)	-0.05 (0.44)	-0.07 (0.44)
Human capital	-25.62*** (1.87)	-14.37*** (2.08)	-14.59*** (2.23)	-14.36*** (2.30)	-14.52*** (2.27)	-14.28*** (2.39)	-13.94*** (2.28)	-13.70*** (2.34)
Openness	-6.60*** (1.05)	-0.12 (1.34)	-0.05 (1.56)	-0.25 (1.67)	0.04 (1.54)	-0.17 (1.60)	-0.29 (1.35)	-0.55 (1.46)
Income		-12.13*** (1.45)	-12.41*** (1.54)	-12.20*** (1.61)	-13.59** (6.08)	-13.30* (6.78)	-12.61*** (1.56)	-12.35*** (1.64)
Institutions			-0.26 (0.36)	-0.38 (0.39)	-0.28 (0.34)	-0.41 (0.40)	-0.17 (0.35)	-0.33 (0.40)
Gini index × Income					0.03 (0.16)	0.03 (0.19)		
L5.Gini index							0.15 (0.36)	0.20 (0.34)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3304	3304	3046	3046	3046	3046	2694	2694
Standardized beta	0.09	0.05	0.04	0.05	0.01	0.03	-0.02	-0.03

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the Gini index.

Table E.19: OLS regression results for the income share of the middle class

Dependent variable:	Electricity production in gWh							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	0.10**	0.13**	0.13**	0.21***	-0.55**	-0.45*	0.13	0.20**
	(0.05)	(0.05)	(0.05)	(0.07)	(0.24)	(0.24)	(0.09)	(0.08)
Human capital	4.29***	1.34	1.42*	1.93**	1.32	1.63*	1.32	1.48
	(0.71)	(0.85)	(0.86)	(0.83)	(0.88)	(0.88)	(1.14)	(1.07)
Openness	1.60**	0.10	0.03	0.10	-0.83	-0.61	-0.48	-0.24
	(0.71)	(0.59)	(0.67)	(0.65)	(0.80)	(0.77)	(0.88)	(0.89)
Income		2.51***	2.52***	2.71***	-12.00**	-12.07**	3.83***	3.85***
		(0.80)	(0.85)	(0.89)	(4.88)	(4.96)	(1.40)	(1.43)
Institutions			-0.06	-0.05	0.12	0.12	0.12	0.13
			(0.12)	(0.12)	(0.15)	(0.15)	(0.22)	(0.21)
Income share middle class × Income					0.30***	0.31***		
					(0.11)	(0.12)		
L5.Income share middle class							-0.01	0.07
							(0.05)	(0.06)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1733	1733	1612	1612	1612	1612	904	904
Standardized beta	0.11	0.14	0.14	0.23	-0.59	-0.47	0.13	0.19

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Table E.20: OLS regression results for the income share of the middle class

Dependent variable:	Usage lag of electricity production in gWh							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income share middle class	-0.20 (0.23)	-0.25 (0.16)	-0.20 (0.17)	-0.24 (0.21)	-0.17 (0.47)	-0.17 (0.46)	-0.04 (0.21)	-0.10 (0.22)
Human capital	-25.52*** (1.83)	-13.65*** (2.02)	-14.10*** (2.00)	-12.83*** (2.14)	-14.10*** (2.00)	-12.81*** (2.15)	-10.84*** (2.26)	-9.68*** (2.36)
Openness	-5.22*** (1.40)	2.17 (1.51)	2.16 (1.63)	1.48 (1.67)	2.19 (1.67)	1.56 (1.68)	1.93 (1.79)	1.50 (1.78)
Income		-12.53*** (1.42)	-12.94*** (1.46)	-12.30*** (1.44)	-12.30 (9.56)	-10.82 (10.91)	-13.62*** (1.66)	-13.27*** (1.63)
Institutions			-0.53 (0.32)	-0.87** (0.38)	-0.53* (0.31)	-0.89** (0.41)	-0.80** (0.34)	-1.15*** (0.37)
Income share middle class × Income					-0.01 (0.19)	-0.03 (0.22)		
L5.Income share middle class							-0.20 (0.15)	-0.19 (0.16)
Region FE	No	No	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1519	1519	1421	1421	1421	1421	797	797
Standardized beta	-0.06	-0.08	-0.06	-0.07	-0.05	-0.05	-0.01	-0.03

Note: Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***. Standardized beta shows the standardized coefficient for the income share of the middle class.

Chapter 2

Inequality, Openness, and Growth through Creative Destruction

Joint with Ulrich Schetter and Maik T. Schneider

2.1 Introduction

In recent years, many countries have seen a rise in income inequality, and the causes and consequences of this development are at the forefront of academic and policy discussions worldwide. A prominent concern is that income inequality might undermine social cohesion and the long-run growth prospects of countries. Several channels of how income inequality affects growth have been put-forward in the literature: Inequality might affect growth via differential propensities to save between income groups (Kaldor, 1955), via credit constraints that limit the ability of poor households to invest in the built-up of their human capital (Galor and Zeira, 1993; Galor and Moav, 2004), or via their impact on the political process and hence institutions (Alesina and Rodrik, 1994; Gersbach, Schetter and Schneider, 2018; Persson and Tabellini, 1994). In this paper, we consider yet another channel: the demand for quality.

Rich households demand higher quality versions of the same goods when compared to poorer households. As a consequence, the income distribution is a key determinant of the demand for quality, and income inequality will feed back into the incentives for firms to invest in costly quality upgrading of their products. It is well understood that income inequality therefore matters for innovation and growth. Theoretical work typically finds a positive effect of increasing the income of the rich via the implied higher demand for product innovations.[8] The literature so far has, however, analyzed this channel from inequality to growth in closed economies. We consider a developing country and argue that this channel is typically smaller in an open economy and may even be reversed.[9]

In an open economy not at the frontier, rich households can satisfy their demand for high quality via importing. Indeed, we will document below that developing countries tend to import higher qualities than they produce domestically. Importantly, this implies that domestic innovators of high qualities have to compete against foreign high-quality providers. And while increasing the income of the rich is good for innovation in the closed economy because it raises their willingness-to-pay for quality upgrading, it may actually be bad in the open economy because the richest households—those who typically benefit most from an increase in inequality[10]—anyways satisfy their demand via importing. And because a higher willingness-to-pay for quality also implies that importing high quality from abroad is more attractive, i.e. foreign competition gets fiercer for the share of the population who actually demand domestic high qualities if their

[8]See, for example, Foellmi and Zweimüller (2006).

[9]In what follows, we use the term developing economy to describe an economy that is lagging behind the world technology frontier but perfectly symmetric to the rest of the world in all other dimensions. We are explicitly interested in the innovation channel and shut down all other frictions, such that the economy we have in mind resembles an emerging economy rather than a least developed country. Therefore, while most of the existing literature on inequality and R&D deals (implicitly) with a country at the technology frontier, we are explicitly interested in an economy that is not operating at the technology frontier.

[10]See Atkinson, Piketty and Saez (2011) for an overview on findings on the increase in top incomes.

income increases. As a consequence, we argue that for developing countries the effect of inequality on growth is smaller in an open when compared to a closed economy. We show that this theoretical prediction holds up in the data, both when considering the growth of export quality at the industry level and when considering the growth of GDP per capita.

To study the effect of inequality on innovation and growth, we develop a theoretical model with growth through quality upgrading and non-homothetic preferences for quality. There are two types of households: poor and rich. Households spend their income on a homogeneous good and a continuum of differentiated goods. They can choose the quality of each differentiated good, but they always consume exactly one physical unit of each differentiated good, and there is a complementarity between the quantity of the homogeneous good and the quality of each differentiated good. Richer households then demand more of the homogeneous good and higher qualities of the differentiated goods. Production uses labor as the only input. There are constant returns to scale in the production of quantity of the homogeneous good and quality of one unit of a differentiated good. Production of quality of a given differentiated good is, however, constrained by the set of available blueprints for quality versions of that good. For each differentiated good, there is a set of previously developed qualities that are freely available. Firms can invest in R&D in order to increase the upper bound on quality for one specific differentiated good. Successful innovators earn a one-period patent for all new qualities. There is free-entry into R&D, implying that profits are zero in equilibrium.

To characterize the equilibrium in the closed economy, we solve the decision problem of an innovating firm. We show that this decision problem boils down to a problem of optimal non-linear monopoly pricing over quality, but with two key differences when compared to the textbook case[11]: First, there is an endogenous upper bound on quality. Second, the shape of a consumer's payoff function from one specific differentiated good depends on the full general equilibrium. The costly quality upgrading implies that firms may find it optimal to pool rich and poor households if differences in income and / or the population share of the rich are

[11] See, for example, Bolton and Dewatripont (2005).

small. The dependence of the payoff function on the full general equilibrium allows for interesting general equilibrium feedback effects on the innovation decision by firms. We will get back to this point in a second when discussing the small open economy.

Assuming that the upper bound on qualities inherited from the previous period is the same across all differentiated goods, we show that the unique equilibrium is a symmetric equilibrium where innovation is the same across all sectors. Depending on parameter values, in this equilibrium all monopolists may pool households or separate rich from poor households. In the latter case, non-homothetic preferences over quality give rise to multi-quality firms, analogous to Latzer (2018). We then move on to characterize the effect of a change in inequality on growth in the closed economy. We distinguish a change of the variance of the income distribution from a change of its skewness, holding constant the average income in the economy, and show that the relationship between inequality and growth is far from being trivial. A ceteris paribus increase in the skewness, for example, typically has a positive effect on growth initially as it increases the income of the rich, then a negative effect on growth because it decreases the share of the rich, and eventually again a positive effect when the share of the rich is sufficiently small such that firms prefer to pool households. Yet, one robust comparative statics emerges: In a separating equilibrium, a ceteris paribus increase in the variance has an unambiguously positive effect on growth. This reflects the previously-mentioned fact that an increase in the income of the rich increases their willingness-to-pay for quality. This case is of particular relevance for our comparison of the closed economy to the open economy because in our model an increase in the variance reflects a Lorenz-dominating shift of the income distribution, and because in a separating equilibrium innovation is driven by the desire of the firms to serve a minority of rich households. This is arguably the empirically and economically most relevant set-up to confront the growth effects of inequality in the closed and the open economy.[12]

To analyze these effects for open economies, we then consider a small open

[12] See Foellmi, Wuergler and Zweimüller (2014) for evidence that the rich class consumes newly innovated goods. Van der Weide (2014), Milanovic (2016), or Piketty, Saez and Zucman (2018) provide evidence that mostly the very rich have profited from increases in income inequality.

economy (SOE) variant of our model. The rest of the world (ROW) is technologically more advanced—i.e. it has already developed blueprints for higher quality versions of the differentiated goods when compared to the SOE—but it is otherwise perfectly symmetric to the SOE. Trade between the SOE and the ROW is subject to an iceberg trade cost, which is the same across all sectors. Interestingly, the opportunity of rich households to import high qualities from abroad fundamentally changes the growth effects of a ceteris paribus increase in the variance of the income distribution. We show that initially, while inequality is low, innovating domestic firms find it optimal to match the offer of foreign competitors for the rich. They do so by lowering the price, i.e. the threat of foreign entry has no direct effect on the optimal quality and, hence, innovation. It will, however, have general equilibrium effects on innovation: For one thing, the lower price for the high quality versions of *all* differentiated goods allows rich households to economize on their spending for the differentiated goods and increase their consumption of the homogeneous good which, in turn, will boost their demand for quality due to the complementarity between the two. This is a positive *demand effect.* For another, foreign competition implies that firm profits are lower in equilibrium, which generally is believed to have a negative *pro-competitive effect* on innovation. As we increase inequality further, rich households would like to import increasingly high quality from abroad, and eventually it is no longer profitable for domestic innovators to match the offer of foreign competitors due to the high cost of innovation. At that point, they stop serving rich households, who instead import high qualities from abroad. In turn, the SOE exports the homogeneous good and/or low qualities of the differentiated goods, i.e. the SOE imports higher quality than it exports, in line with our motivating facts below. The key observation is that this has a direct negative *business stealing effect* on growth. Moreover, any additional increase in the income of the rich will no longer have a positive price effect on innovation, which is the key force underlying a positive relationship between inequality and growth in closed economies.

In summary, our theory suggests that the possibility to import high qualities has important effects on the nexus between inequality and innovation-based growth. In particular, our theory suggests that for developing countries this relationship is smaller in an open when compared to a closed economy and may even be negative. To test whether this theoretical prediction holds up in the data, we perform two sets of growth regressions: First, standard growth regressions using growth in GDP per capita as the dependent variable. Second, industry-level growth regressions using growth in export quality taken from Feenstra and Romalis (2014) as the dependent variable. In these regressions, we then control for an interaction of inequality and openness—defined either as a continuous or as an indicator variable. Across a broad range of specifications, using either a battery of country controls or country fixed effects, we find that for developing countries this interaction term is significantly negative in the industry-level regressions, and typically still negative even if no longer significant in all country-level regressions, in line with our theoretical prediction.

2.1.1 Motivating facts on imported high qualities

A key premise of our work is that rich households in developing countries can satisfy their demand for high quality via importing. In this section we briefly present anecdotal evidence and stylized facts in support of this premise.

There is plenty of anecdotal evidence that well-off consumers in countries where high-quality products are not produced domestically satisfy their demand by importing high qualities from rich countries. One prominent example are the Intershops in the former Democratic Republic of Germany. These shops accepted only so called Forumschecks as a method of payment which were typically not available to the common people. As an article in the German news outlet Leipziger Volkszeitung describes it[13], Intershops offered Western products that were either not at all available in East Germany or at low quality only. The market for luxury goods in China provides another, more recent, example. According to Reuters[14], Chinese shoppers make up a third of global spendings on luxury goods, which makes them the largest group. Most of these luxury goods are foreign brands, i.e. affluent Chinese citizens increasingly satisfy their demand for high quality

[13] Andreas Dunte, Einkaufen wie im Westen, *Leipziger Volkszeitung*, 01. MAR 2014.
[14] Adam Jourdan, China luxury sales rebound as millennials snap up cosmetics, handbags: report, *Reuters*, 17. JAN 2018.

goods (in this case, luxury articles) by importing them, and luxury companies, "are counting on China for the lion's share of their sales growth".[15] Even for North Korea, we find some evidence that the elite can shop foreign luxury brands in department stores, as CNN writes.[16]

As we show next, the view that elites in developing countries satisfy their demand for high quality via importing is also in line with data on export quality. It is well known that rich countries both export and import higher qualities when compared to poor countries.[17] While this points to non-homotheticities in demand, we are more interested in knowing whether poor countries import higher qualities than they export, i.e. in comparing the import to the export quality of developing countries, assuming that export quality is a good proxy for qualities made available locally by domestic firms. To this end, figure 2.1 locates each country in a graph with GDP per capita on the horizontal axis and the share of industries with import quality larger than export quality on the vertical axis. Data on import and export quality are taken from Feenstra and Romalis (2014).[18] The graph on the left-hand-side includes only country-industry pairs where we observe both, export and import quality. The graph on the right-hand-side sets quality equal to zero in case of no imports or exports, respectively, in a country-industry pair. Figure 2.1 clearly shows that in the majority of industries poor countries import higher quality than they export. This is particularly true for the right-hand-side figure which is arguably more appropriate to show that poor countries satisfy demand for high quality goods via importing. Interestingly, both shares are also—on balance—the higher the poorer a country. These findings suggest that, indeed, rich households in poor countries satisfy their demand

[15] See Robert Williams, Europe's Biggest Luxury Brands Are Nervous About China, *Bloomberg Businessweek*, 18. OCT 2018.

[16] David McKenzie, Where North Korea's elite go for banned luxury goods, *CNN*, 17. JUL 2017.

[17] See Schott (2004), Hallak (2006), Khandelwal (2010), Bastos and Silva (2010), Feenstra and Romalis (2014), Flach (2016), Schetter (2018).

[18] We scale import and export qualities such that the value weighted sum of qualities over all countries (in each year and industry) equals one. This makes import and export qualities comparable. All data refer to the year 2005. The figure only includes industries that produce differentiated goods, according to the (conservative version of the) index developed by Rauch (1999). We exclude resource-rich countries as well as micro states with less than one million inhabitants.

for high quality via importing. As we document in appendix F, they are robust to using unit values as measure of import and export quality.

— Figure 2.1 about here —

To corroborate this finding, we show the distribution of the share of industries for which import quality exceeds export quality. As our argument concerns developing economies, we exclude OECD countries. Figure 2.2 illustrates that in a vast majority of industries in non-OECD countries, import quality is higher than export quality.

— Figure 2.2 about here —

2.1.2 Literature

Our paper is related to several strands of literature.

Our main focus is on understanding how inequality impacts the growth prospects of a country via the demand for product innovation. These effects are subject to a large and growing literature. Matsuyama (2002) shows in a model of learning by doing that the effect of inequality on growth may be non-monotonic and that conventional measures of inequality such as the Gini-coefficient are not a sufficient statistic for these effects. Foellmi and Zweimüller (2006) consider a model of expanding varieties where new varieties address consumers' needs following their preference hierarchy. Inequality stimulates growth via an associated higher demand for luxury goods. Foellmi, Wuergler and Zweimüller (2014) consider product and process innovations, where process innovation prepares "luxury goods" for mass production, in line with product cycles observed from the data. Latzer (2018) presents a Schumpeterian growth model featuring agents with non-homothetic preferences over quality. She shows how the desire to better discriminate between consumers of different incomes ("surplus appropriation effect") induces incumbents to invest in R&D and can give rise to multi-quality firms in equilibrium.[19] All of these models share in common that they are consid-

[19] This is in contrast to canonical Schumpeterian models (Aghion and Howitt, 1992) where the replacement effect (Arrow, 1962) outweighs the efficiency effect (Gilbert and Newbery, 1982; Reinganum, 1983).

ering closed economies. And while a change in the income distribution may have non-trivial overall effects on growth, it is the case that a ceteris paribus increase in the income of the rich is beneficial for innovation because it increases their willingness-to-pay for innovated goods. We show that this channel may be very different, and may in fact be reversed, in a small open economy.[20]

Our paper is thus also related to the large literature analyzing the growth-effects of international trade (e.g. Grossman and Helpman (1991*a*), Acemoglu (2003), Galor and Mountford (2008), Nunn and Trefler (2010) and Acemoglu, Gancia and Zilibotti (2015), Arkolakis et al. (2018), Gersbach, Schetter and Schmassmann (2018)). Openness to trade leads to higher competition as foreign competitors enter the market. This might reduce R&D incentives for domestic firms and therefore lead to lower growth (Aghion and Howitt, 1992, 1996). At the same time, however, technology spillovers might arise as externalities from international trade (Eaton and Kortum, 1999; Grossman and Helpman, 1991*b*). In line with this, empirical studies rather find a positive relationship between competition and growth (Blundell, Griffiths and Reenen, 1999; Nickell, 1996; Schmitz, 2005), and more recent papers suggest a U-shaped relationship between competition and growth (Aghion et al., 2009, 2005; Hashmi, 2013).[21] The key novelty of our work is that we analyze how these opposing effects of international trade openness interact with inequality in shaping a country's growth prospects in the context of a SOE model with non-homothetic preferences for quality.[22,23]

[20] See also Matsuyama (2019), who discusses how globalization and market integration can weaken or strengthen demand channels present in a closed economy.

[21] Amiti and Khandelwal (2013) show that lower import tariffs (i.e. more competition) lead to quality upgrading for products close to the frontier (escape competition effect), but discourages upgrading for products further away from the frontier (Schumpeterian appropriability argument).

[22] Our work is thus also, but less closely, related to the literature that incorporates non-homothetic preferences into models of international trade (e.g. Flam and Helpman (1987), Stokey (1991), Matsuyama (2000), Fajgelbaum, Grossman and Helpman (2011), Fieler (2011), Jaimovich and Merella (2012), or Foellmi, Grossmann and Kohler (2018)). None of these papers studies the effects of within-country inequality for innovation and growth which is our main focus.

[23] Our work also adds a novel perspective to the discussions on infant industry protection. The theoretical literature on infant industry protection emphasizes the importance of learning-externalities either within or across industries (Greenwald and Stiglitz, 2006; Hausmann and Rodrik, 2003; Krugman, 1987; Krugman and Elizondo, 1996; Lucas, 1988; Matsuyama, 1992; Melitz, 2005; Puga and Venables, 1999; Rodrik, 2004; Young, 1991). Our model also features

Focusing on developing countries, we show that the growth effects of inequality are generally smaller in open economies than in closed economies because international trade allows rich households to satisfy their demand for high qualities via importing. We then show that this theoretical prediction holds up in growth regressions using either growth in GDP per capita or industry-level growth in export quality taken from Feenstra and Romalis (2014) as the dependent variable. In doing so, we also add to the empirical literature analyzing the linkages from income inequality to economic growth. This literature tends to find a negative effect, but the evidence is far from being conclusive. The early literature indicated a detrimental effect of inequality on growth (cf. the overview in Bénabou (1996)). More recently, Easterly (2007) finds detrimental effects of inequality on growth, highlighting its impact on schooling and institutions, while Ostry, Berg and Tsangarides (2014) identify negative effects conditional on redistribution. Voitchovsky (2005) finds that inequality at the top is found to be positively related to growth, while inequality further down the income distribution is negatively related to growth, and Halter, Oechslin and Zweimüller (2014) show that inequality may be beneficial for short-run growth but detrimental to long-run growth. Barro (2000) finds a detrimental effect of inequality for developing countries, but not so for industrialized countries. Brueckner and Lederman (2018), on the other hand, document that transitional growth is boosted by income inequality in countries with a lower initial income, while the opposite is true for countries with high initial income. None of these studies considers how the growth effects of inequality depend on a country's openness, which is our main focus here.

The remainder of this paper is organized as follows. Section 2.2 introduces the model and section 2.3 solves for the equilibrium. In section 2.4 we consider the closed economy and section 2.5 looks at a small open economy. Section 2.6 forms the empirical part of the paper. Finally, section 2.7 concludes.

an externality from innovation on aggregate productivity, and a potentially detrimental effect of trade on growth, which is the basis for infant industry protection. We argue, however, that this effect critically depends on the income distribution in developing countries. See Lee (1996), Davis and Weinstein (2002), Redding and Sturm (2008), Harrison and Rodríguez-Clare (2010), Kline and Moretti (2013), or Juhász (2018) for empirical evidence on the importance of initial conditions for the location of industries because of agglomeration economies and on the effectiveness of infant industry protection.

2.2 Model

To study the growth-effects of inequality in an open economy, we now develop a model with non-homothetic preferences for quality and Schumpeterian growth through quality upgrading. In this and the following sections, we begin with considering the closed-economy, which will form the basis for the small-open-economy variant introduced in section 2.5.

2.2.1 Households

The economy is populated by a continuum of infinitely-lived households of measure 1, $h \in [0,1]$. Households derive utility from consumption of a continuum of differentiated goods, $i \in [0,1]$, and a homogeneous good, z. Each differentiated good i represents one distinct consumption need of households that can be satisfied by consumption of one of the available quality versions of the good $q_i(t) \in \mathcal{Q}_i(t)$.[24] In particular, if at time t household $h \in [0,1]$ consumes a bundle $\left\{q_i^h(t)\right\}_{i\in[0,1]}$ of the differentiated goods and $z^h(t)$ units of the homogeneous good, then its instantaneous utility is given by

$$u\left(\left\{q_i^h(t)\right\}_{i\in[0,1]}, z^h(t)\right) = \int_0^1 \left(q_i^h(t)\right)^{1-\beta} di \; \left(z^h(t)\right)^{\beta} , \tag{2.1}$$

and total lifetime utility sums up to

$$U\left(\left\{q_i^h(t)\right\}_{i,t\in[0,1]\times[0,\infty)}, \left\{z^h(t)\right\}_{t\in[0,\infty)}\right) = \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho}\right)^t u\left(\left\{q_i^h(t)\right\}_{i\in[0,1]}, z^h(t)\right) .$$

Households maximize their utility subject to their inter-temporal budget constraint

$$a^h(t+1) = (1+r(t))a^h(t) + I^h(t) - \int_0^1 p_i(q_i^h(t);t)\, di \; - p_z(t)z^h ,$$

[24]Hence, there is an infinite degree of substitution between different quality versions of the same good.

and the no-Ponzi-game condition

$$\lim_{t\to\infty} a^h(t+1)\prod_{t=0}^{\infty}\frac{1}{1+r(t)} = 0$$

In the above, $p_i(q;t)$ denotes the date t price of quality q of differentiated good i, $p_z(t)$ denotes the date t price of the homogeneous good, $a^h(t)$ are household h's total asset holdings at the beginning of period t, $I^h(t)$ denotes its total per-period income net of interest earnings, and $r(t)$ is the per-period interest rate. There will be no aggregate investment opportunities in the economy,[25] implying that total net asset holdings will be zero, i.e. at any point in time we have[26]

$$\int_0^1 a^h(t)\, dh = 0 \ .$$

Households differ in their endowment with effective labor, ω^h, that they inelastically supply to the labor market earning a wage rate of w per unit of effective labor, which we choose to be the numéraire, i.e. we have $w(t) = 1$ at all times. To simplify the exposition, we will further assume that all household have $a^h(0) = 0$ at $t = 0$. As we will show in section 2.3 below, the economy will immediately jump on a balanced growth path. Along this balanced growth path, asset holdings will then always be 0 for all households and each household just consumes his per-period income I^h. In what follows, we will simplify the notation by ignoring the dependence of all variables on time t unless explicitly stated otherwise.

2.2.2 Homogeneous good production

The production technology for the homogeneous good is given by

$$z = a_z A L_z \ ,$$

[25] A free-entry condition will guarantee that profits are always equal to zero, see section 2.2.3.

[26] The main focus of our work is on how income inequality impacts aggregate growth via demand-induced quality upgrading. While we could in principle allow for aggregate savings, e.g. by introducing capital as a second factor of production, this would not affect our main mechanism of interest above and beyond any potential effect on the income distribution. We therefore simplify the exposition by ignoring this possibility throughout.

where A denotes the aggregate state of technology, as detailed below, L_z denotes effective labor input, and a_z is a time-invariant productivity parameter. There is perfect competition in the market for the homogeneous good, implying that its equilibrium price is

$$p_z = \frac{1}{a_z A} \ .$$

2.2.3 Differentiated good production and innovation

One unit of quality q_i of variety i can be produced using the following linear technology

$$q_i = a_q A L_i \ ,$$

where L_i denotes effective labor input and a_q is a time-invariant productivity parameter.

Blueprints for different quality versions of each differentiated good i are inherited from the previous period up to the threshold quality level $\bar{q}_i(t-1)$. These blueprints are publicly available and there is a competitive fringe of firms that might enter the market.

Blueprints for new, higher-quality versions of each differentiated good can be developed through innovation. Innovation entails two types of cost, both in terms of effective labor: An endogenously chosen fixed cost f_i to set-up a research lab, and research cost

$$h\left(\frac{\bar{q}_i(t)}{\bar{q}_i(t-1)}\right) \tag{2.2}$$

to push the technological frontier for product i from $\bar{q}_i(t-1)$ to $\bar{q}_i(t)$, where $h(\cdot)$ is C^2 and satisfies: $h(1) = 0$, $h'(1) = 0$, and $h''(\cdot) > 0$. Successful innovation results in a one-period patent for all qualities $q_i \in (\bar{q}_i(t-1), \bar{q}_i(t)]$. There is free entry into innovation and firms engage in a patent race. Our main interest is in understanding how inequality impacts endogenous quality upgrading. We will therefore simplify matters by assuming that the firm with highest set-up investments f_i will always win the patent race. In the only subgame perfect equilibrium there will then be just one firm per differentiated good that engages in innovation, and the total set-up costs of this firm, f_i, are equal to its subsequent monopoly profits.[27]

With the expiration of patents, production knowledge accumulated in the research and development process and in the production of new, high-quality varieties spills over to the entire economy.[28] Such spillovers give rise to the following aggregate technology $A(t+1)$

$$A(t+1) = \int_0^1 \bar{q}_i(t)\, di \ .$$

In what follows, we will consider the case of a common inherited quality level $\bar{q}_i(t-1) = \bar{q}(t-1)\ \forall\, i \in [0,1]$. In a symmetric equilibrium, this will then give rise to the following law of motion for aggregate technology[29]

$$A(t+1) = \frac{\bar{q}(t)}{\bar{q}(t-1)} A(t) \ .$$

In what follows, we will simplify notation by assuming that $A(t) = \bar{q}(t-1)$.

2.3 Equilibrium

In this section, we analyze the equilibrium in the closed economy. We begin with considering the decision problem of an innovating firm.

[27] Allowing for positive profits by innovating firms would not directly effect the optimal choice of $\bar{q}_i(t)$ and, hence, aggregate growth, which is our main focus of interest. Profits would, however, have a general equilibrium feedback effect on innovation via their implications for the income distribution. While it is possible to incorporate such feedback loops, it would complicate the analysis without adding anything of substance to our main insights. We therefore consider the analytically more tractable case with zero profits in equilibrium. A free entry condition and, hence, zero profits in equilibrium is a common assumption in endogenous growth models. In these models, higher investment costs in R&D typically result in higher innovation probabilities and, hence, growth. We will get back to this point in section 2.5 below and for now focus on our main growth channel of interest: the endogenous quality margin.

[28] Note that for each differentiated good i the current threshold quality level $\bar{q}_i(t)$ will actually be produced in equilibrium as shown in section 2.3.

[29] In section 2.3 we will show that in case of a common inherited quality level $\bar{q}_i(t-1)$ the unique equilibrium is symmetric.

2.3.1 Firms' decision problem

An innovating firm needs to decide on whether and how much to invest in research and development in order to expand the set of blueprints for qualities available from its current level $\bar{q}_i(t-1)$ to some new level $\bar{q}_i(t) > \bar{q}_i(t-1)$. This decision, of course, will be driven by the profit potential associated with these new blueprints. The competitive fringe for all pre-existing qualities $q_i \leq \bar{q}_i(t-1)$ pushes down their price to marginal cost, i.e.

$$p_i(q) = \frac{1}{a_q A} q \; , \quad \forall \, q \leq \bar{q}_i(t-1) \; ,$$

implying zero variable profits on these qualities. By contrast, an innovating firm can freely set the price $p_i(q)$ for all qualities $q \in (\bar{q}_i(t-1), \bar{q}_i(t)]$. The innovating firm then chooses $\bar{q}_i(t)$ and $\{p_i(q)\}_{\bar{q}_i(t-1)}^{\bar{q}_i(t)}$ to maximize its total profits

$$\Pi_i = \int_{\bar{q}_i(t-1)}^{\bar{q}_i(t)} \left[p_i(q) - \frac{1}{a_q A} q \right] D_i(q; p_i) \, dq - h\left(\frac{\bar{q}_i(t)}{\bar{q}_i(t-1)} \right) \; , \tag{2.3}$$

taking as given the demand for quality q of good i, $D_i(q; p_i)$, where we use p_i to denote the set of prices for each quality of differentiated good i, $p_i := \{p_i(q)\}_{q \in \mathcal{Q}_i}$. As we show in appendix H, this decision problem boils down to the following:

Lemma 1. *The decision problem of innovating firm i is equivalent to:*[30]

$$\max_{\{q_i(\theta), p_i(\theta)\}_{\theta \in \Theta}, \bar{q}_i(t)} \quad \int_{\theta \in \Theta} \left[p_i(\theta) - \frac{1}{a_q A} q_i(\theta) \right] f_\theta(\theta) \, d\theta - h\left(\frac{\bar{q}_i(t)}{\bar{q}_i(t-1)} \right)$$

$$s.t. \quad \theta v(q_i(\theta)) - p_i(\theta) \geq argmax_{q \in [0, \bar{q}_i(t-1)]} \left\{ \theta v(q) - \frac{1}{a_q A} q \right\} \tag{IR}$$

$$\theta v(q_i(\theta)) - p_i(\theta) = argmax_{\hat{\theta} \in \Theta} \left\{ \theta v(q_i(\hat{\theta})) - p_i(\hat{\theta}) \right\} \tag{IC}$$

$$q_i(\theta) \leq \bar{q}_i(t),$$

$\forall \, \theta \in \Theta$, where $v(q) := q^{1-\beta}$ and where the incumbent considers type $\theta^h := \frac{p_z z^h}{\beta Q^h}$, $Q^h := \int_0^1 {q_i^h}^{1-\beta} \, di$, of household h as exogenously given. θ^h is private knowledge

[30] With a slight abuse of notation we use the integral sign to denote a finite sum in case of a discrete set Θ.

to the households and is distributed according to $f_\theta(\theta)$ *with support* Θ*, with this PDF being common knowledge.*

Lemma 1 is the counterpart of the standard assumption in monopolistic competition models according to which the individual firm has no impact on aggregate outcomes. It reduces the incumbent firm's decision problem to one of optimal non-linear pricing over qualities with an endogenous choice of the upper bound on qualities and where the distribution of household types is given by the endogenous distribution of θ. The set of constraints in lemma 1 is a reflection of the revelation principle, according to which the optimal set of contracts is one contract for each type of households such that each household has an incentive to truthfully reveal his type. Accordingly, the first set of constraints requires that contracts are *individually rational* (IR), that is each household must prefer his contract over his best outside option, which is in our case to consume the respective best option from the set of qualities that are available at marginal cost. The second set of constraints requires that contracts are *incentive compatible* (IC), i.e. every household must prefer his respective contract over the contract designed for each other type in the economy. Finally, the last constraint dictates that all qualities must be feasible, i.e. they cannot exceed the current technological frontier for the respective good.

The decision problem in lemma 1 differs in two important ways from the textbook case of non-linear monopoly pricing over qualities: First, it includes an endogenous upper bound on quality. As we will see, this has important implications for firm behavior and, in particular, it may or may not be optimal to pool households at the top to economize on costs of innovation. Second, the endogeneity of θ introduces feedback effects from the overall economy on the firms' behavior. These feedback effects have to be taken into account throughout. They will be of particular interest in the small open economy variant below.

As we show in lemma 2, θ is an increasing function of household income and hence of their endowment with effective labor.

Lemma 2. θ^h *is strictly increasing in* I^h*.*

The proof of lemma 2 is given in appendix H.

We will now proceed with analyzing the incumbents' decision problem and, hence, the equilibrium in our economy in detail. Throughout, we will focus on the case of two types of labor, $\omega^h \in \{\omega^H, \omega^L\}$, as it is analytically tractable and allows discussing the main growth effects of inequality in a transparent way.

2.3.2 Two types: $\{\omega^H, \omega^L\}$

Let $\omega^H \geq \omega^L$ be the endowment with effective labor of high and low types, respectively. Similarly, let a superscript ^{H} and ^{L} identify contracts designed for high and low types, respectively. Let λ denote the share of high types in the economy. Then, with two types of households only, the decision problem of incumbent firm i simplifies to:

$$\begin{aligned}
\max_{q_i^H, p_i^H, q_i^L, p_i^L, \bar{q}_i(t)} \quad & \lambda\left(p_i^H - \frac{1}{a_q A} q_i^H\right) + (1-\lambda)\left(p_i^L - \frac{1}{a_q A} q_i^L\right) - h\left(\frac{\bar{q}_i(t)}{\bar{q}_i(t-1)}\right) \\
\text{s.t.} \quad & \theta^h v(q_i^h) - p_i^h \geq \operatorname{argmax}_{q \in [0, \bar{q}_i(t-1)]} \left\{\theta^h v(q) - \frac{1}{a_q A} q\right\} && \text{(IR)} \\
& \theta^H v(q_i^H) - p_i^H \geq \theta^H v(q_i^L) - p_i^L && (\text{IC}^{\text{H}}) \\
& \theta^L v(q_i^L) - p_i^L \geq \theta^L v(q_i^H) - p_i^H && (\text{IC}^{\text{L}}) \\
& q_i^h \leq \bar{q}_i(t),
\end{aligned}$$

where $h \in \{L, H\}$. As we discuss in section 2.2, every household splits his budget between a certain amount of the standard good z and a certain quality of each of the differentiated goods. Due to the complementarity between the standard good and the differentiated goods and the decreasing marginal utility in z, the richer households have a higher willingness-to-pay for quality. If all qualities were offered at marginal costs, each household possesses an optimal quality level at which he wishes to consume the differentiated good, and these optimal quality levels are a direct mapping from the households' incomes. On the contrary, given a certain technological level $\bar{q}(t-1)$, we can define the income level $\hat{I} := 1/[a_q(1-\beta)]$ for which a household would choose quality $\bar{q}(t-1)$ as their optimal quality priced at marginal costs. This implies that only households with income higher than $\hat{I}$ may be interested in innovations in quality while households with income lower than this threshold will always consume their ideal and already available quality priced at marginal costs. Using this, we can characterize the unique equilibrium in the economy as follows:

Proposition 1. *There is a unique equilibrium satisfying for* $h = \{H, L\}$*:* $q_i^{h^e} = q^{h^e}$ *and* $p_i^{h^e} = p^{h^e}\ \forall i \in [0,1]$*. Depending on parameter values, this equilibrium can be characterized according to one of the following cases:*

(i) $\boldsymbol{I^L \leq I^H \leq \hat{I}}$ **:**
$q^{L^e} = (1-\beta)a_q A I^L$, $p^{L^e} = \frac{1}{a_q A} q^{L^e}$
$q^{H^e} = (1-\beta)a_q A I^H$, $p^{H^e} = \frac{1}{a_q A} q^{H^e}$

(ii) $\boldsymbol{I^H > \hat{I} \geq I^L}$ **:**
$q^{L^e} = (1-\beta)a_q A I^L$, $p^{L^e} = \frac{1}{a_q A} q^{L^e}$
$q^{H^e} > \bar{q}(t-1)$ and p^{H^e} are the unique solutions to:

$$\frac{I^H - p^{H^e}}{\beta}\left[1 - \left(\frac{\bar{q}(t-1)}{q^{H^e}}\right)^{1-\beta}\right] + \frac{1}{a_q} = p^{H^e}$$

$$\lambda\frac{1-\beta}{\beta}\left(I^H - p^{H^e}\right) - \lambda\frac{1}{a_q}\frac{q^{H^e}}{\bar{q}(t-1)} - \frac{q^{H^e}}{\bar{q}(t-1)}h'\left(\frac{q^{H^e}}{\bar{q}(t-1)}\right) = 0$$

(iii) $\boldsymbol{I^H > I^L > \hat{I}}$ **:**

(A) If the solution to the system of equations in part (B) involves $q^L \leq \bar{q}(t-1)$, there is a separating equilibrium with $q^{L^e} = \bar{q}(t-1), p^{L^e} = \frac{1}{a_q}$ and where q^{H^e}, p^{H^e} are the solutions to the equations shown in (ii).

(B) There is a separating equilibrium where q^{L^e}, p^{L^e}, q^{H^e}, and p^{H^e} are the unique solutions to:

$$\frac{I^L - p^{L^e}}{\beta}\left[1 - \left(\frac{\bar{q}(t-1)}{q^{L^e}}\right)^{1-\beta}\right] + \frac{1}{a_q} = p^{L^e}$$

$$\frac{I^H - p^{H^e}}{\beta}\left[1 - \left(\frac{q^{L^e}}{q^{H^e}}\right)^{1-\beta}\right] + p^{L^e} = p^{H^e}$$

$$I^L - \lambda\left(I^H - p^{H^e}\right)\left(\frac{q^{L^e}}{q^{H^e}}\right)^{1-\beta} - (1-\lambda)\frac{\beta}{(1-\beta)a_q}\frac{q^{L^e}}{\bar{q}(t-1)} = p^{L^e}$$

$$\lambda\frac{1-\beta}{\beta}\left(I^H - p^{H^e}\right) - \lambda\frac{1}{a_q}\frac{q^{H^e}}{\bar{q}(t-1)} - \frac{q^{H^e}}{\bar{q}(t-1)}h'\left(\frac{q^{H^e}}{\bar{q}(t-1)}\right) = 0\ .$$

(C) If the solution to the system of equations in part (B) involves $q^L \geq q^H$, there is a pooling equilibrium, i.e. $q^{L^e} = q^{H^e} = q^{P^e}$ and $p^{L^e} = p^{H^e} = p^{P^e}$ which are the unique solutions to:

$$\frac{I^L - p^{P^e}}{\beta}\left[1 - \left(\frac{\bar{q}(t-1)}{q^{P^e}}\right)^{1-\beta}\right] + \frac{1}{a_q} = p^{P^e}$$

$$\frac{1-\beta}{\beta}\left(I^L - p^{P^e}\right) - \frac{1}{a_q}\frac{q^{P^e}}{\bar{q}(t-1)} - \frac{q^{P^e}}{\bar{q}(t-1)}h'\left(\frac{q^{P^e}}{\bar{q}(t-1)}\right) = 0\ .$$

The proof of proposition 1 is given in appendix H. The intuition of the equilibrium is as follows. In the first case, the technological level in the economy is high enough so that the optimal quality levels of households of both income levels are available and be consumed at marginal costs. As a consequence, there are no innovation incentives and economic growth is zero. In case (ii), only the low income households can find their optimal quality among the already available ones while the high income households would wish to consume at higher qualities than currently available. This implies that the firm can make profits from offering higher quality and hence has an incentive to push up the techological frontier. This leads to positive growth driven by the demand of the rich households. In the situation depicted in (iii) the existing technological level is so low that both the high and the low income households will not be able to consume at marginal cost their most desired quality level. The firm will then have innovation incentives to satisfy the quality demands of the households and in maximizing its profits has to decide how much to invest in quality innovation and whether to offer two different quality levels for the different household types. In the first case (A), the firm innovates to cater to the quality demand of the rich households, while the poor households consume the best already existing quality at marginal costs. The reason is that if the firm offered another quality level for the low income households, it would be favorable for the rich households to consume at this lower quality level as well or the firm had to reduce the price for the high quality to keep the rich households consuming the higher quality. The corresponding losses in profits from the rich customer base do not compensate for the gain in profits from the poorer households. In (B) the share of the poor is sufficiently large that it is no longer optimal to ignore them while income differences between the poor and the rich are sufficiently high such that it is beneficial to push out the technological level further to offer high qualities for the rich and lower qualities, but still higher than $\bar{q}(t-1)$ for the poor. This is a separating equilibrium where both types of households are served by innovating firms, i.e. we observe multi-quality firms in equilibrium.[31] Finally, the share of the rich and income differences are not large

[31] See Latzer (2018) for a detailed account of the endogenous emergence of multi-quality firms in such an environment.

enough in case (C), such that it is optimal for firms to pool households.

Proposition 1 characterizes the equilibrium qualities and prices of the differentiated goods consumed by poor and rich households, respectively. Equipped with these, we can use the household budget constraints to derive the respective consumption levels of the homogeneous goods. This completes the characterization of the unique equilibrium in the economy. Note that all expressions in proposition 1 involve only, $\frac{q^{L\,e}}{\bar{q}(t-1)}$, $\frac{q^{H\,e}}{\bar{q}(t-1)}$, p^{L^e}, p^{H^e}, and time-invariant parameters, i.e. the aggregate growth rate $g^e = \frac{q^{H\,e}}{\bar{q}(t-1)}$ is constant over time.

Corollary 1. *There is a unique balanced growth path which is reached instantaneously.*

We will now analyze how a change in the income distribution impacts the equilibrium outcomes in proposition 1 and, in particular, q^{H^e} which governs growth in our case. To simplify notation, we will throughout dispose of the superscript ^{e} to indicate equilibrium outcomes.

2.4 Inequality and Growth: The Closed Economy

Without loss of generality, we will normalize endowments with effective labor such that

$$E[\omega] = \lambda\omega^H + (1-\lambda)\omega^L = 1 \equiv \bar{w} \ .$$

We will be interested in analyzing the impact of an increase in inequality on growth in our economy. To this end, we will consider two separate cases: An increase in the variance of the income distribution and an increase in its skewness, which impacts top-income inequality. To separate changes in the variance of the income distribution from changes in its skewness, we will therefore choose

$$\omega^H = 1 + \sigma\sqrt{\frac{1-\lambda}{\lambda}}$$
$$\omega^L = 1 - \sigma\sqrt{\frac{\lambda}{1-\lambda}} \ ,$$

where $\sigma \geq 0$.[32] It follows then that

$$
\begin{aligned}
VAR(\omega) &= \sigma^2 \\
SK(\omega) &= \frac{1-2\lambda}{\sqrt{\lambda(1-\lambda)}} \,.
\end{aligned}
$$

Proposition 2. *Changes in the variance and skewness, respectively, of the income distribution have the following effect on economic growth:*

(i) Case with $\hat{I} \geq \bar{w}$

σ: *Monotonously increasing.*

λ: *Hump shaped with* $\lim_{\lambda \to 0} q^H = 0$ *and* $q^H = 0 \; \forall \; \lambda \geq \frac{1}{1+\left[(\hat{I}-1)/\sigma\right]^2}$.

The hump peaks at the unique solution p^H, q^H, λ *to*

$$
p^H = \frac{\left(1+\sigma\sqrt{\frac{1-\lambda}{\lambda}}\right)\left(1-\left(\frac{q^H}{\bar{q}(t-1)}\right)^{\beta-1}\right)+\frac{\beta}{a_q}}{1+\beta-\left(\frac{q^H}{\bar{q}(t-1)}\right)^{\beta-1}}
$$

$$
p^H = 1+\sigma\sqrt{\frac{1-\lambda}{\lambda}} - \frac{\beta}{(1-\beta)}\left[\frac{q^H}{\bar{q}(t-1)a_q} - \frac{q^H}{\bar{q}(t-1)\lambda}h'\left(\frac{q^H}{\bar{q}(t-1)}\right)\right]
$$

$$
\sqrt{\frac{\lambda}{1-\lambda}} = \frac{1+\beta-\left(\frac{\bar{q}(t-1)}{q^H}\right)^{1-\beta}}{1-\beta}\frac{q^H}{\bar{q}(t-1)}h'\left(\frac{q^H}{\bar{q}(t-1)}\right)\frac{2}{\sigma}
$$

(ii) Case with $\hat{I} < \bar{w}$

σ: *U-shaped with lowest growth at change from pooling to separating equilibrium.*

λ: *Decreasing for* λ *small such that pooling equilibrium, then hump shaped in the separating equilibrium. For very convex functions* $h(\cdot)$*, there may be two humps with the minimum between the peaks being at the point where innovating firms stop serving the poor households.*

[32] Our specification of wealth endowments relates to Foellmi, Wuergler and Zweimüller (2014) and Latzer (2018) as follows. As in Foellmi, Wuergler and Zweimüller (2014) and Latzer (2018), an increase in σ increases the income gap and leaves the share of poor households unchanged. Therefore, an increase in σ always increases inequality and a policy reducing σ leads to a Lorenz-dominating shift. On the other hand, an increase in income concentration (i.e. a decrease in λ) in our setting also reduces the income gap. Hence, a change in λ leads to a Lorenz-crossing shift, as we cannot disentangle changes in income concentration and the income gap when varying λ. Unlike the specification in Foellmi, Wuergler and Zweimüller (2014) and Latzer (2018), therefore, λ is not monotonously related to measures of inequality (see footnote 36).

The proof of proposition 2 is given in appendix H.[33]

The central element for innovation incentives is the value of quality innovations to the firm. This value depends on the market size and the willingness to pay for higher quality. The former is reflected by what share of the households have incomes above $\hat{I}$ while the latter depends on how much larger these incomes are than $\hat{I}$. Proposition 2 distinguishes two cases. In case one the average wage is below the income level $\hat{I}$ necessary to have a willingness to pay a premium for a quality above the currently available $\bar{q}(t-1)$. As a consequence, with an equal distribution of wages, the households would consume their existing optimal quality level priced at marginal costs. This implies that there are no innovation incentives and consequently no growth with an equal distribution of incomes. Increasing the variance in incomes means increasing the incomes of a share λ of the population at the expense of the remaining $1-\lambda$ households. Innovation and economic growth become positive when the rich share of society realizes incomes larger than $\hat{I}$. Innovation incentives increase further the larger the income of the high income earners becomes, as their willingness to pay for quality increases while the market size remains constant at λ. For this reason higher variance σ implies higher economic growth as stated in the proposition.

When varying the skewness of the income distribution by changing λ for a given positive standard deviation σ, we trigger two opposing effects on innovation incentives. First note that as w^L must be below the average wage $\bar{w}$, which is, in the first case in proposition 2, below $\hat{I}$ by assumption. Hence, the low income households will be able to consume their most preferred qualities at marginal costs and innovation incentives entirely depend on the rich part of society. Decreasing λ increases the income of the high income households, thereby increasing their willingness to pay for quality and hence innovation incentives. However, at the same time the market size λ of high income households declines as well, reducing innovation incentives for the firm. When decreasing λ at high levels of lambda, the former effect increasing the willingness to pay for quality dominates the declining market share, while the opposite holds true for small values of λ. This pattern in

[33] The statements for a separating equilibrium where both types are still served are partially based on numerical solutions for a broad range of parameter specifications, see appendix H.

innovation incentives explains the hump-shaped relation between a reduction in λ and economic growth as illustrated in figure 2.3.

— Figure 2.3 about here —

The results in the second part of proposition 2 are based on the same economic intuition. However, as $\hat{I} < \bar{w}$, at an equal distribution of income the households would like to consume higher quality levels than $\bar{q}(t-1)$, implying positive gains from innovation. Hence economic growth would be positive with an equal distribution of incomes.

In our discussion of the effects of varying variance and skewness of the distribution on innovation and growth, we will now have to consider the different types of equilibria described in proposition 1. Increasing the variance starting from an equal income distribution implies that initially a pooling equilibrium will persist, but with the low income households showing a lower willingness to pay for quality and thereby leading to lower equilibrium quality and prices. At higher variance, the willingness to pay for quality of high income households is large enough to justify additional investments in quality upgrading on the side of innovating firms notwithstanding the fact that only a fraction $\lambda < 1$ of households are rich, and there will be a separating equilibrium. In the separating equilibrium, innovation incentives are centrally driven by the willingness to pay of the rich. This is where innovation incentives and growth are increasing in σ. Taken together, there is a U-shaped relationship between σ and growth, where the minimum is reached at the point where the economy switches from a pooling to a separating equilibrium, as shown in figure 2.4.

— Figure 2.4 about here —

With respect to variations in λ, both income levels increase in response to a lower λ, while the share of low income households increases at the expense of the high income households' share. Starting from a high λ the innovation incentives are driven by the market size and willingness to pay of the rich households and the relationship between λ and growth initially follows the hump shape characterized above. With λ declining the importance of the high income households for innovation will eventually decline and the firms will find it optimal to pool households. In this pooling equilibrium growth increases in response to a decrease λ due to its positive effect on the incomes of the poor. Taken together, this implies a rotated-S type relationship between λ and growth where, starting from $\lambda = 0$, growth initially decreases in λ, then increase and eventually decreases again, as shown in figure 2.5.[34,35]

— Figure 2.5 about here —

An immediate implication of these considerations is that growth is not monotonously related to a change in the Gini coefficient, in line with what has previously been found in the literature.[36] Interestingly, this may explain the mixed evidence on the growth effects of inequality found in empirical studies (see literature review). As we will see next, however, our theory suggests that in developing countries the growth effect of inequality is smaller in open when compared to closed economies.

[34] As we increase λ, we will eventually reach the point where $I^L = 0$. If we require a zero lower bound on I^L, we then cannot increase λ further and the graph in figure 2.5 is truncated from the right. It may then be that the graph gets truncated before we reach the peak, i.e. the truncated graph is U-shaped. For the parameter values chosen to draw the graph in figure 2.5 this is actually the case.

[35] As stated in proposition 2, for very convex functions $h(\cdot)$ it may be that the relationship between λ and growth is actually double peaked. In this case, the minimum between the peaks is reached at the point where innovating firms stop to serve the poor. We provide one such example in appendix H.

[36] With only two types of households, the Gini coefficient is given by

$$G(\sigma, \lambda) = \int_0^{1-\lambda} i(1 - I^L)\, di + \int_0^{\lambda} i(I^H - 1)\, di \ .$$

Solving the integrals, using the expressions for I^L and I^H from the main text, and rearranging terms, we get

$$G(\sigma, \lambda) = \sigma \sqrt{\lambda(1 - \lambda)} \ .$$

The Gini coefficient is monotonously increasing in σ and hump-shaped in λ, reaching its peak at $\lambda = \frac{1}{2}$. The statement then follows immediately from proposition 2.

2.5 Inequality and Growth: Small Open Economy

So far, we have considered a closed economy. Of course, in an open economy, national elites in developing countries may consume high-quality goods imported from abroad, which will feed back into the innovation incentives for domestic firms. We therefore consider next how the opportunity to trade impacts the identified link between inequality and growth. To this end we consider a small open economy (SOE) variant of our model. That is, the equilibrium at home has no impact on the world equilibrium. For simplicity, we assume that the rest of the world (ROW) is more developed than the SOE, but that it is perfectly symmetric to the SOE otherwise. Specifically, we assume that $a_z^{SOE} = a_z^{ROW} = a_z$, $a_q^{SOE} = a_q^{ROW} = a_q$, and that $\bar{q}^{SOE}(t-1) < \bar{q}^{ROW}(t-1)$.

Trade between the SOE and the ROW is subject to an iceberg trade cost $\tau > 1$ that is the same across all sectors. The symmetry of the set-up then implies that balanced trade is possible only if the SOE imports some high qualities $q > \bar{q}^{SOE}(t)$ from abroad and exports the homogeneous good z and, potentially, qualities $q \leq \bar{q}^{SOE}(t)$ of the differentiated goods. In turn, this requires that the SOE can price the homogeneous good competitively in the world market, i.e.[37]

$$p_z^{ROW} = \tau \frac{w^{SOE}}{a_z A^{SOE}} = \frac{w^{ROW}}{a_z A^{ROW}} \; . \tag{2.4}$$

The exact composition of exports from the SOE is a matter of indifference. Note, however, that export quality is lower than import quality, in line with our stylized facts from section 2.1.

In turn, foreign firms are willing to serve consumers in the SOE at their marginal costs, however scaled by the iceberg trade costs τ. If $q \leq \bar{q}^{ROW}(t-1)$, this will be the case because of the competitive fringe in the ROW. If $q >$

[37]Note that equation (2.4) implies that firms in the SOE have strictly lower marginal production costs for the homogeneous good and for all qualities $q \leq \bar{q}^{SOE}(t)$ than the marginal cost of firms from the ROW of serving customers in the SOE. It follows that, indeed, the only equilibrium with positive and balanced trade is one where the SOE imports high qualities and exports low qualities and / or the homogeneous good.

$\bar{q}^{ROW}(t-1)$, it follows because the SOE is small and, therefore, firms from the ROW do not have to redeem R&D costs from profits in the SOE.[38] The marginal costs for firms from the ROW of serving quality q to consumers in the SOE are: $\tau \frac{1}{a_q A^{ROW}} q w^{ROW}$. Using $w^{SOE} = 1$ again and noting that

$$w^{ROW} = \frac{\tau A^{ROW}}{A^{SOE}} w^{SOE}$$

by equation (2.4), these marginal costs—and, hence, the price at which imported qualities are offered to consumers in the SOE—can be restated as

$$p^f(q) = \tau^2 \frac{1}{a_q A^{SOE}} q \ ,$$

where here and below we use a superscript ^{f} to denote an offer from foreign firms to consumers in the SOE.

The availability of imported qualities will impact innovation incentives and, hence, growth in the SOE. In particular, imported qualities introduce a second set of individual rationality constraints for households in the SOE: Their contract offered by a domestic monopolist must now not only be preferable to their best choice among the domestic competitive fringe, but also to their best importing option.

We will now analyze how openness to trade impacts the growth effects of inequality. We will do this for the case where—in the closed economy—innovating firms choose their highest quality $\bar{q}(t)$ to satisfy the rich, i.e. those who gain if income inequality increases. We then consider a Lorenz-dominated shift of the income distribution. This is arguably the economically most interesting scenario and will also allow highlighting how the growth effects of inequality can be very different in an open economy.[39] In our world with two types only, this corresponds

[38] If trade costs are sufficiently small, pricing in the SOE of monopolistic firms from the ROW may be constrained by a threat of re-importing to the ROW (see e.g. Foellmi, Hepenstrick and Zweimüller (2018)). We leave such considerations out of account here. Note that we can always rule out a threat of re-importing if the SOE is sufficiently far from the technological frontier such that the imported qualities satisfy $q \leq \bar{q}^{ROW}(t-1)$.

[39] See, van der Weide (2014), Milanovic (2016), or Piketty, Saez and Zucman (2018).

to an increase of σ in a separating equilibrium.[40,41] We begin with introducing the augmented decision problem of innovating firms and some preliminary considerations thereon.

2.5.1 Preliminary considerations

The above discussions imply for the decision problem of innovating firm i in the SOE:[42]

$$\begin{aligned}
\max_{q_i^H, p_i^H, q_i^L, p_i^L, \bar{q}_i(t)} \quad & \lambda \left(p_i^H - \frac{1}{a_q A} q_i^H \right) + (1-\lambda) \left(p_i^L - \frac{1}{a_q A} q_i^L \right) - h \left(\frac{\bar{q}_i(t)}{\bar{q}_i(t-1)} \right) \\
\text{s.t.} \quad & \theta^h v(q_i^h) - p_i^h \geq \operatorname{argmax}_{q \in [0, \bar{q}_i^{SOE}(t-1)]} \left\{ \theta^h v(q) - \frac{1}{a_q A} q \right\} && \text{(IR)} \\
& \theta^h v(q_i^h) - p_i^h \geq \operatorname{argmax}_{q>0} \left\{ \theta^h v(q) - \tau^2 \frac{1}{a_q A} q \right\} && \text{(IRf)} \\
& \theta^H v(q_i^H) - p_i^H \geq \theta^H v(q_i^L) - p_i^L && (\mathrm{IC^H}) \\
& \theta^L v(q_i^L) - p_i^L \geq \theta^L v(q_i^H) - p_i^H && (\mathrm{IC^L}) \\
& q_i^h \leq \bar{q}_i(t),
\end{aligned}$$

where $h \in \{L, H\}$. In the following discussions, it will come in handy to simplify the above decision problem by solving for the value of the best importing option of a household of type θ^h. In particular, household h's best importing option is to choose quality $q^{h,f}$ such that

$$\theta^h v'(q^{h,f}) = \frac{\tau^2}{a_q A} \; .$$

[40] In a pooling equilibrium, the choice of $\bar{q}(t)$ is governed by the taste for quality of the poor, i.e. those who lose out as income inequality increases. See section 2.3 and the proof of proposition 1.

[41] With more than two types, there may be heterogeneity of income among the "rich". In such case, it will—due to the cost of innovation—typically not be optimal for the firms to separate the minority of very rich households and they will prefer to pool different types of rich households at the top. This is arguably interesting from a real-world perspective. Note that such a pooling equilibrium differs in important ways from the pooling equilibrium in our two-type world. In particular, in the multi-type case, the households with lowest income that are still pooled at the top will typically gain as income inequality increases, while in our two-type case the low type necessarily looses as we increase σ.

[42] Analogously to the best option from the domestic competitive fringe, we assume that in case of indifference the household consumes the domestic quality and not an imported quality.

It immediately follows that his optimal import quality is

$$q^{h,f} = \left[\frac{(1-\beta)\theta^h a_q A}{\tau^2}\right]^{\frac{1}{\beta}} ,$$

and that

$$\theta^h v(q^{h,f}) - \frac{q^{h,f}\tau^2}{a_q A} = \left[\theta^h\right]^{\frac{1}{\beta}} \left[\bar{q}(t-1)\right]^{\frac{1-\beta}{\beta}} \underbrace{\left[\frac{a_q(1-\beta)}{\tau^2}\right]^{\frac{1-\beta}{\beta}} \beta}_{:=\chi(\tau)} . \qquad (2.5)$$

Hence, we can simplify (IRf) as follows

$$\theta^h v(q_i^h) - p_i^h \geq \left[\theta^h\right]^{\frac{1}{\beta}} \left[\bar{q}(t-1)\right]^{\frac{1-\beta}{\beta}} \chi(\tau) , \quad h \in \{L, H\} . \qquad \text{(IRf')}$$

Clearly, the trade costs $\tau > 1$ imply that it is never optimal to import quality $q < \bar{q}^{SOE}(t-1)$. Moreover, $\chi(\tau)$ is a decreasing function of τ, i.e. the lower trade costs the larger the value of the respective best importing option for households, as to be expected.

We are interested in how the possibility of rich households to import high quality from abroad impacts the growth effects of inequality. In this regard, we will from now on operate under the following assumption:

Assumption 1.

$$\tau \geq \underline{\tau} := \left[\frac{\beta^{\frac{2\beta-1}{\beta}} \left[1 - \frac{1}{a_q}\right]^{1/\beta} \left[a_q(1-\beta)\right]^{\frac{1-\beta}{\beta}}}{1 - \frac{1}{a_q}(1+\beta)}\right]^{\frac{\beta}{2(1-\beta)}}$$

As we show in the following lemma, assumption 1 rules out that low types may find it attractive to import their differentiated goods from abroad, i.e. that constraint (IRf) is binding for the low types.

Lemma 3. *Let assumption 1 be satisfied. Then constraint (IRf) is either redundant or binding for the high types.*

The proof of lemma 3 is given in appendix H.

We will now fix some $\tau \geq \underline{\tau}$ and study the growth effects of inequality. In equilibrium, the optimal solution to the firms' decision problem and, hence, growth will again depend on whether $I^h > \hat{I} := \frac{1}{a_q(1-\beta)}$ for $h \in \{L, H\}$, as households with income $I^h \leq \hat{I}$ will always find it optimal to consume a quality from the domestic competitive fringe. We will consider the case where $\hat{I} < \bar{w}$. In this case, $I^h > \hat{I}$ for $h \in \{L, H\}$ as long as σ is small, and $I^L \leq \hat{I}$ for σ large enough, i.e. this case involves the most intricate trade-offs and it is similar to the case of $\hat{I} > \bar{w}$ for large σ.

2.5.2 Inequality and growth: Small open economy

In this section, we analyze the growth effects of inequality in the small open economy. As discussed above, we will consider a case where (IRf) is eventually binding for the high types in a separating equilibrium. We will then analyze equilibrium innovation and hence, growth, for sequentially increasing values of σ.

Starting from $\sigma = 0$, constraint (IRf) is not binding for either of the households by assumption: This is illustrated in the top-left graph of figure 2.6 below. This figure shows a household's payoff from three different consumption choices for the differentiated good as a function of its type θ: The payoff when consuming $\bar{q}(t-1)$, $\theta v(\bar{q}(t-1)) - \frac{1}{a_q}$ (orange dashed line); the payoff when consuming the optimal pooling contract offered by innovating domestic firms, $\theta v(q^P) - p^P$ (blue solid line); and the payoff from the respective best importing option, $[\theta]^{\frac{1}{\beta}} [\bar{q}(t-1)]^{\frac{1-\beta}{\beta}} \chi(\tau)$ (red dotted line). Individual rationality for the low types implies that the orange and the blue line intersect at θ^L which is equal to θ^H in this case. Clearly, this intersection lies above the red dotted line, i.e. both types strictly prefer contract (q^P, p^P) over their best importing option.

— Figure 2.6 about here —

As we increase σ, this will not affect the orange dashed line or the red dotted line in the top-left graph of figure 2.6. It will, however, decrease θ^L, q^P, and p^P (see proposition 2)—i.e. it will shift the blue solid line upwards and make it less steep in a way such that its intersection with the orange dotted line moves to the left—and, most importantly, it will increase θ^H. As long as ($\mathrm{IRf^H}$) is non-binding, a change in σ will trivially have the same effect on growth as in the closed economy: Growth initially declines while still in a pooling equilibrium and eventually increases when σ and, hence, income differences are large enough, such that innovating firms find it optimal to separate low types from high types. This separating equilibrium is illustrated in the top-right graph of figure 2.6. The green dash-dotted line shows a household's payoff from consuming quality q^H, $\theta v(q^H) - p^H$, as a function of θ. As before, ($\mathrm{IR^L}$) implies that the orange dashed and the blue solid line intersect at θ^L. In addition, ($\mathrm{IC^H}$) implies that the blue solid and the green dash-dotted line intersect at θ^H. Clearly, both types still prefer their respective contract over their best importing option.

As we continue to increase σ, however, θ^H will keep on increasing and eventually be high enough such that high types are indifferent between consuming q^H and their best importing option.[43] This is illustrated in the bottom-left graph of figure 2.6 for a scenario, where this indifference occurs only after innovating domestic firms stopped serving the poor. At this point, if we continue to increase σ, constraint (IRf) will be strictly binding for the high types.[44]

How will innovating firms—and, hence, the economy—respond if their optimal contract for the rich is no longer feasible due to import competition? We will discuss this for the case where firms would, in the closed economy, still serve the poor. The case where they already stopped serving them then follows.[45] We know from appendix H, that in the separating equilibrium, contracts (q^H, p^H)

[43] Of course, with two-types only, for τ and λ high enough, ($\mathrm{IRf^H}$) will never be binding while $I^L \geq 0$. We focus on the economically interesting case where ($\mathrm{IRf^H}$) is eventually binding while $I^L \geq 0$ and trade may occur. Note that for any $\tau \geq \underline{\tau}$ we can find a λ small enough such that this will indeed be the case.

[44] In fact, in the case where innovating firms stopped serving the poor, ($\mathrm{IRf^H}$) is strictly binding for all larger σ for the following reasons: The payoff associated with the optimal contract for the high types is in the closed economy determined by the intersection of the green dash-dotted line and the orange dashed line. The orange dashed line will not change in response to a variation of σ, while the green dash-dotted line shifts down and becomes steeper. Importantly, as θ^H increases in equilibrium, the new intersection between the two lines necessarily is to the right of the previous intersection. The result then follows from noting that any point further to the right on the orange dashed line is necessarily below the red dotted line, because the red dotted line must cross the orange dashed line from below at the point where they both intersect with the green dash-dotted line.

[45] See also footnote 46.

and (q^L, p^L) satisfy the following optimality conditions

$$\theta^L \left(v(q_i^L) - v(\bar{q}(t-1))\right) + \frac{1}{a_q} = p_i^L \tag{2.6}$$

$$\theta^H \left(v(q_i^H) - v(q_i^L)\right) + p_i^L = p_i^H \tag{2.7}$$

$$\theta^L v'(q_i^L) - \lambda\theta^H v'(q_i^L) - (1-\lambda)\frac{1}{a_q A} \leq 0 \tag{2.8}$$

$$\lambda\theta^H v'(q_i^H) - \lambda\frac{1}{a_q A} - h'\left(\frac{q_i^H}{\bar{q}(t-1)}\right)\frac{1}{\bar{q}(t-1)} = 0\ , \tag{2.9}$$

where condition (2.8) holds with equality whenever $q_i^L > \bar{q}(t-1)$. Now, if the solution to conditions (2.6) to (2.9) is no longer feasible because it violates (IRf$^{\mathrm{H}}$), domestic firms may, in principle, find it optimal to stop serving the rich and, in fact, this will eventually be the case for σ high enough, as we will see later on. Initially—when (IRf$^{\mathrm{H}}$) is marginally binding—this will, however, not be the case, because in the closed economy firms make strictly positive profits from serving the rich. To keep serving the high types, however, the firms need to marginally improve the value of the contract for the rich. To achieve this, they will lower the price p^H but, ceteris paribus, not change quality q^H. This follows from condition (2.9), which defines q^H as a function of θ^H and equates the total marginal utility from increasing q^H, $\lambda\theta^H v'(q^H)$, to the total marginal cost, $\lambda\frac{1}{a_q A} + h'\left(\frac{q_i^H}{\bar{q}(t-1)}\right)\frac{1}{\bar{q}(t-1)}$. Hence, a change in q^H can never be optimal: It will increase (decrease) the willingness to pay of the rich by less (more) then it will increase (decrease) the marginal cost of delivering quality to the rich.

At the same time, lowering p^H will relax constraint (IC$^{\mathrm{H}}$), and, hence, it will allow mitigating the distortion of the low types. In particular, condition (2.8) trades off the marginal gain of the low types from a higher q^L, $(1-\lambda)\theta^L v'(q_i^L)$, against the marginal cost of increasing q^L, $(1-\lambda)\frac{1}{a_q A}$, and the cost of marginally tightening (IC$^{\mathrm{H}}$), $\lambda\theta^L v'(q_i^L) - \lambda\theta^H v'(q_i^L)$. If (IC$^{\mathrm{H}}$) is slack, this latter effect is no longer present, and innovating firms can earn higher profits by increasing q^L and p^L, holding constant $\theta^L v(q^L) - p^L$ (i.e. guaranteeing that (IR$^{\mathrm{L}}$) remains binding), up to the point where (IC$^{\mathrm{H}}$) is again binding.[46]

[46]If in the closed economy innovating firms just stopped serving the poor, i.e. if the solution

Note that while these responses do not impact q^H directly, they have general equilibrium effects on growth: On the one hand, the lower p^H for all differentiated goods will, ceteris paribus, increase θ^H and therefore induce firms to increase q^H.[47] On the other hand, lower mark-ups are associated with lower profits net of the fixed innovation cost f_i. We will get back to how this will feed back into aggregate growth below.

As we keep on increasing σ and, hence, θ^H, ($\mathrm{IRf^H}$) tightens further,[48] and this will have the same qualitative effect on q^H and p^H. Eventually, however, θ^H and, hence, foreign competition will be strong enough such that it is no longer profitable to serve the rich.[49] The rich will then satisfy their demand for high qualities via importing, and the SOE will import higher quality than domestically available, in line with our stylized facts. In fact, as we show in the following proposition, rich households import quality that is even higher than what domestic firms would offer to them in the limiting case where it is just profitable to serve them.

If domestic firms no longer find it optimal to serve rich households, they may

to conditions (2.6) to (2.9) entailed q^L in the left neighborhood of $\bar{q}(t-1)$, then the relaxation of ($\mathrm{IC^H}$) in the SOE may induce firms to continue serving the low types. Otherwise, if firms stopped serving poor households in the no-trade equilibrium, the fact that (IRf) is binding for the high types will have no effect on the low-types. In either case, the changes to contract (q^H, p^H) are as described above.

[47]Note that the higher q^L and p^L in the SOE when compared to the closed economy implies that θ^L is lower. Combined with the fact that θ^H is higher, this rules out the theoretical possibility that firms may find it optimal to pool types in the SOE while they would separate them in the closed economy.

[48]This is always true if firms stopped serving the poor because first, the value of the contract for the rich in the closed economy is determined by the orange dashed line in the bottom-right graph of figure 2.6. And second, the distance between this line and the value of the best importing option as given by the red dotted line is increasing in θ.

[49]To see that it must eventually be no longer beneficial to serve the rich, note that in the closed economy the value of contract (q^H, p^H) for the rich is in figure 2.6 bounded from above by a straight line. In particular, if firms already stopped serving the poor, firms optimally set prices such that ($\mathrm{IR^H}$) holds with equality, which implies that the value of the contract is just on the orange dashed line. If they are still serving the poor, the value of the contract is determined by the blue solid line which changes as we change σ. Note, however, that it is bounded from above by a line with intercept $-\frac{1}{a_q}$ and slope $v(\hat{q}^P)$, where we use $\hat{q}^P$ to denote the optimal quality in the pooling equilibrium with $\sigma = 0$. For this line and the orange dashed line, respectively, there exists a threshold $\bar{\theta}$ such that the distance between the convex red dotted curve and the respective straight line is such that high types can only be made indifferent between the domestic contract and the best importing option by setting $p^H = \frac{q^H}{a_q}$, the variable cost of producing q^H, and it is for sure not profitable to serve the rich.

either stop innovating altogether or keep on innovating to serve the poor, depending on parameter values. In either case, $\bar{q}(t)$ will be lower when compared to the closed economy.

We summarize these insights in the following proposition:

Proposition 3. *In the SOE, for small values of σ, the only equilibrium is a no-trade equilibrium, i.e. equilibrium outcomes are as in the closed economy. For some intermediate σ, constraint (IRf^H) is binding, and innovating firms block entry from foreign competitors by lowering p^H. Profits net of fixed cost f are lower and, in equilibrium, q^H higher than in the closed economy. For σ high enough, this will no longer be profitable and domestic firms stop serving rich households. High qualities are then imported from abroad and $\bar{q}(t)$ drops. When rich households start importing high qualities, they import higher qualities than the corresponding $\bar{q}(t)$ in a closed economy.*

Most parts of proposition 3 follow from the previous discussions. We show in appendix H that, indeed, imported qualities are higher than the corresponding $\bar{q}(t)$ in a closed economy.

Proposition 3 implies that the growth effects of inequality are very different in the SOE when compared to the closed economy. In the closed economy, an increase in σ has a positive effect on growth whenever firms find it optimal to separate rich households from the poor. The underlying forces are simple: An increase in σ raises the taste for quality on the side of the rich. This, in turn, has a positive *price effect* on innovation as it induces firms to upgrade quality more to satisfy this demand. This price effect is the key driver underlying a demand-driven positive relationship between inequality and growth in a closed economy.

In the SOE, the nexus from inequality to growth is more nuanced. If inequality is high enough such that (IRf$^{\mathrm{H}}$) is binding, firms initially block entry of foreign competitors by lowering p^H. While the threat of foreign competition does not induce firms to change q^H directly, we have seen that the lower p^H on the side of all firms increases θ^H and therefore has a positive general equilibrium effect on q^H. This positive *demand effect* is rooted in the fact that—due to international competition—firms charge smaller mark-ups for high qualities.[50] Lower mark-ups

[50]In our model, a smaller mark-up ultimately results in higher demand as mark-ups are fully

are, however, also associated with lower operating profits on the side of the firm. This will lower the R&D investment cost in the patent race, f. To focus on growth driven by the endogenous quality margin and its relationship to inequality, we have so far assumed that these costs are purely wasteful. More generally, however, we may assume that higher investments f result in a higher innovation rate and, hence, growth.[51] The fact that (IRf$^{\text{H}}$) is binding will then have a negative *pro-competitive effect* on growth via lower mark-ups and, hence, profits on the side of the innovating firms.[52]

As inequality increases further, it is eventually high enough such that domestic firms no longer find it optimal to serve rich households, implying that the foreign competition has a negative *business stealing effect* on innovation and, hence, economic growth. This business stealing effect gets bigger as we further increase σ. In particular, an increase in σ raises the taste for quality on the side of the rich. As discussed above, this price effect is the key driver underlying a demand-driven positive relationship between inequality and growth in the closed economy. The key observation is that this channel is no longer present in the SOE if rich households satisfy their demand for high quality via importing.[53] We summarize these

absorbed by the fixed cost of innovation. Note, however, that the same would also be true with positive profits as long as a smaller mark-up on the side of the firms is not passed on one-for-one to rich households via dividend payments.

[51] This is analogous to the assumption typically made in endogenous growth models where higher investments in R&D result in higher propensities to innovate.

[52] A simple way of introducing a positive link from f_i to growth into our model would be to endogenize the period length. In particular, we may assume that the fixed cost of investment, f, are inversely related to the time it takes a firm to innovate and develop blueprints for higher qualities. If, in addition, a new innovator will only be able to build on existing know-how once the preceding innovator starts selling his new varieties, then the time length between two innovations is endogenous and, in particular, depends on the profit potential from successful innovations. Of course, the shorter time to replacement by a new innovator will, in itself, have a negative effect on profits associated with innovations and, hence, growth. Still, it must be that if (IRf$^{\text{H}}$) is binding in the SOE and therefore profits are lower when compared to the closed economy, that this has a negative effect on the rate of innovation and, hence, growth.

[53] The fact that the SOE imports high qualities from abroad if domestic firms no longer serve the rich—and, in fact, these imported qualities are higher than what domestic firms would otherwise have offered—may well have a positive international knowledge spillover effect on the SOE. Such an effect may, for example, be reflected in, ceteris paribus, lower cost of innovation or higher aggregate productivity in future. While such spillovers should mitigate the business stealing effect in reality, they should not overcompensate for this negative effect under the arguably weak assumption that learning is higher from domestic production when compared to importing of high qualities.

insights in the following corollary.

Corollary 2. *In the small open economy, higher inequality impacts growth trough various channels: It strengthens the* pro-competitive effect *of international trade. This will lower the gains from innovation (-) and have a positive general equilibrium* demand effect *on innovation (+). It will eventually induce domestic firms to stop serving the rich who then import high qualities from abroad. This has a negative* business stealing effect *(-) on growth. If rich households satisfy their demand for high quality via importing, a further increase in inequality will no longer have a positive price effect on innovation.*

In general, in the SOE the overall the growth effects of inequality will depend on the relative sizes of the different effects. Note, however, that our stylized facts from section 2.1.1 indicate that developing countries do indeed import higher qualities from abroad than what they can produce domestically. The business stealing effect and the lack of a positive price effect for the rich then suggest that—when compared to the closed economy—the effect of inequality on growth should be smaller in the SOE and may even be negative. This is even more so if we are willing to assume that the overall effect of lower profits on the side of innovators on growth will be negative. In the next section, we will confront this theoretical finding with the data.

2.6 Growth Regressions

In this section, we test whether our main theoretical prediction that for developing countries the growth effect of inequality is smaller in an open when compared to a closed economy holds up in the data. To this end, we now perform two sets of growth regressions: First, industry-level growth regressions using growth in export quality taken from Feenstra and Romalis (2014) as the dependent variable. These are our main regressions as growth in quality is closest to our theoretical model and as the industry-level data provides us with enough variation to identify our main effects of interest. Second, to better compare our results to previous work in the literature, we perform standard growth regressions using growth in GDP per capita as the dependent variable.

To perform these regressions, we need data on growth at the country-industry and at the country level, respectively, as well as data on inequality, openness, and distance from the frontier along with other control variables. We begin with introducing our data, before turning to the model specification and results.

2.6.1 Data

Data Sources — To measure quality upgrading at the country-industry level, we use data on export quality at the SITC4 industry classification level taken from Feenstra and Romalis (2014), i.e. we use export quality to proxy for domestic production capabilities. To measure growth in GDP per capita, we use data on real per capita GDP taken from the Penn World Table (PWT), version 9.0 (Feenstra, Inklaar and Timmer, 2015).

To measure inequality, we use Gini indices in our baseline specification. Gini indices are taken from Solt (2016), as this source combines data from various other databases and makes comparable the Gini indices across countries. We use the Gini index after redistribution. We provide robustness checks using the income shares of the top 10% and top 20%, respectively, in appendix G. For these income shares, we rely on data stemming from the World Development Indicators (WDI) (The World Bank, 2018).

Our main theoretical prediction relies on the possibility to import high qualities from abroad, i.e. it applies to countries not at the frontier. To classify a country-industry pair and a country, respectively, as being not at the frontier, we use our data on export quality and GDP per capita from above. We then generate an indicator for whether a country's export quality in a given industry belongs to the bottom 75% within that industry across countries in the year 2000. Analogously, in our country-level regressions, we classify a country as being developing if its GDP per capita in USD belongs to the bottom 75% in the year 2000. We present robustness checks using alternative specifications for distance from the frontier in appendix G.

To measure a country's openness in a given industry, we combine data on imports by industry taken from Feenstra and Romalis (2014) with data on nominal

GDP taken from the WDI. From this data, we then compute the share of total imports in a given industry and year over GDP and normalize this share by the average share across countries in the same industry to control for cross-industry heterogeneity in size.[54] In our country-level regressions, we use the share of total imports over GDP taken from the WDI. We present robustness checks using alternative measures for openness in appendix G.

In our regressions without country fixed effects, we further include a series of country-level controls following Barro (2015). We take data for life expectancy, fertility, consumer price inflation, and the terms of trade from the WDI. From Barro and Lee (2013) we take years of schooling for males and females. The PWT provide us with data on investment shares and government consumption shares. Finally, we take a measure of political rights combining data from Freedom House (2016) and Bollen (1980) and standardize it to be between zero and one.

Descriptive statistics — Merging the country level data to the industry specific data gives us a data panel tracking industry-country pairs over time. The industry level export and import data are available for the years 1985–2010. Therefore our panel spans 25 years, and we use the same years also for the country-level regressions. We collapse the panel to a five year frequency, such that we have six periods in our panel. We decided to reduce the frequency to five years to increase the variation in the data. For each five year period, we keep the last value available not to lose observations with a data point in 2004 but not in 2005, for example. We exclude resource-rich countries (i.e. countries whose share of resource rent exceeds 20% on average) as well as micro states with a population of less that one million, averaged over all years.[55] The panel then covers 131 countries and a total of 485 industries.[56] Table 2.1 provides descriptive statistics

[54] We use this way to control for average industry-size because output data is not available at the disaggregated country-industry level.

[55] Data on resource rents as a share of GDP are taken from the WDI and data on total population from the PWT.

[56] Note that the total number of industries in the original data is 1646. However, for some countries and industries, there are several measures of units, and hence some industries appear more than once. We will focus on kilograms as the unit measure, since this is the most common in the data. Furthermore, we exclude industries producing homogenous goods, according to the conservative version of the Rauch (1999) index, as quality differs very little in these sectors.

for the variables.

— Table 2.1 about here —

2.6.2 Specification and results

Equipped with this data, we estimate the following industry-level regressions.

$$\ln\left(\frac{q^s_{x,c,t}}{q^s_{x,c,t-j}}\right) = \beta_1 \ln(q^s_{x,c,t-j}) + \beta_2 Open^s_{c,t-j} + \beta_3 Ineq_{c,t-j} + \beta_4 Dist^s_c$$
$$+\beta_5[Open^s_{c,t-j} \times Ineq_{c,t-j}] + \beta_6[Open^s_{c,t-j} \times Dist^s_c] + \beta_7[Ineq_{c,t-j} \times Dist^s_c]$$
$$+\beta_8[Open^s_{c,t-j} \times Ineq_{c,t-j} \times Dist^s_c]$$
$$+controls, \quad (2.10)$$

where $q^s_{x,c,t}$ is export quality in country c, year t and sector (or industry) s. $Open^s_{c,t-j}$ is our measure of openness at the sectoral level, $Ineq_{c,t-j}$ is a measure of inequality, i.e. the Gini index in our baseline specification, and $Dist^s_c$ is an indicator whether sector s in country c has a large distance to the technology frontier. Finally, *controls* is a set of control variables which includes industry times year fixed effects and either the large set of country controls following Barro (2015) or country fixed effects. As explained above, we use a data panel with a five year frequency (i.e. $j = 5$ and the data are collapsed to a frequency of five years).

To align our results with previous research on growth and inequality, we also estimate the specified regression equation using per capita GDP data at the country level, i.e. we replace quality upgrading by growth in GDP per capita, and use the measures for openness and distance to frontier at the country level as described above. The other control variables are the same as in our industry-level regressions with year fixed effects replacing the industry times year fixed effects.

Our prime interest is in the sum of coefficients β_5 and β_8, which measures the effect of inequality and openness for a developing country. We expect the sum of the coefficients to be negative, i.e. the cross-derivative with respect to inequality and openness is expected to be negative: Given a country is developing, higher

This will reduce the number of industries to 485 industries.

inequality should have a smaller effect on growth in an open than in a closed economy. Indeed, the effect of inequality on growth might even be negative in an open economy.

We estimate equation (2.10) using OLS fixed effects regressions. The main results for the different specifications are reported in table 2.2.

— Table 2.2 about here —

The results show that, as expected, we find conditional convergence for both industry level export quality as well as aggregate GDP growth. For the variables of interest, namely openness, inequality, and level of development, the results for the individual effects are inconclusive. In particular, the effects of inequality on quality upgrading or growth in GDP per capita are unclear, in line with what we find in our model and with the inconclusive evidence from earlier contributions. However, as the bottom of the table shows, the effect of inequality and more openness is negative for developing countries. In all specifications the coefficient of interest is negative, and for the industry level regressions statistically significant. The results in table 2.2 therefore provide suggestive evidence that for developing countries, openness reduces the effect of inequality on quality upgrading (or growth in income at the aggregate), as our model suggests. Once a country is away from the technological frontier, high inequality and the possibility of the rich class to import high quality goods from abroad reduce innovation incentives for domestic producers. A series of robustness tests confirm these findings. These robustness tests are documented in appendix G.

Overall, our empirical exercise provides suggestive evidence for the effects predicted by our model. The regressions show that there is a non-trivial effect of inequality on quality upgrading or growth in per capita GDP, while for developing countries, openness combined with inequality seems to be negatively related to these outcomes.

2.7 Conclusion

In this paper, we have analyzed how inequality impacts growth in developing countries in the context of a Schumpeterian model with growth through quality upgrading and non-homothetic demand for quality. We show that the growth effects are very different in an open when compared to a closed economy: An increase in the income of the rich boosts their willingness-to-pay for high qualities which stimulates innovation and growth in the closed economy. In the open economy, however, rich households may satisfy their demand for high quality via importing, in which case an increase in their income will no longer have a beneficial effect on innovation. Even worse, an increase in income inequality will raise the attractiveness of imported high qualities for the rich and will thus imply that a broader range of households satisfies their demand for quality via importing. It has therefore a detrimental effect on the business opportunities of domestic innovators.

These observations have so far gone unnoticed in the literature. We believe that they are of first order importance for our understanding of the growth prospects of developing countries and that they are of immediate policy relevance. Future work may set out to to study the robustness of our findings in alternative environments, and to scrutinize policy implications for trade, industrial, or redistributive policies, for example.

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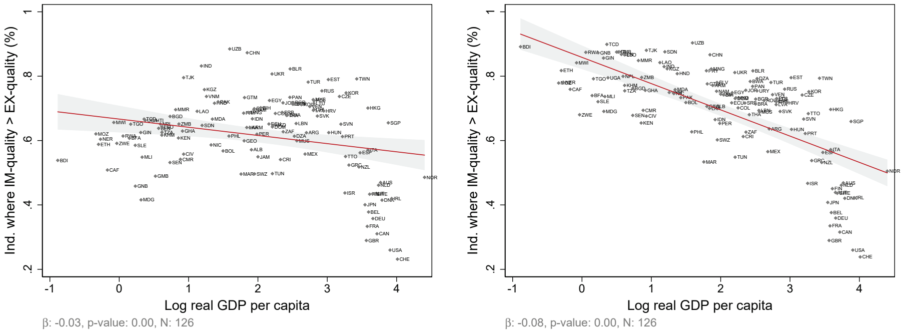
Figures and Tables

Figure 2.1: Relative import quality and income, overall

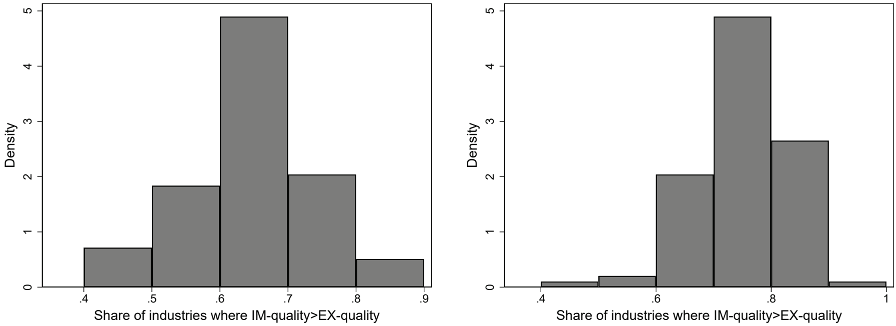
(a) Complete observations **(b) All observations**



Note: Share of industries by country, for the year 2005, where import quality exceeds export quality. Industries that produce homogenous goods as well as resource-rich countries and micro states are excluded. The left panel includes observations for which we have data on both import and export quality, while the right panel keeps all observations and sets quality to zero if quality is not observed.

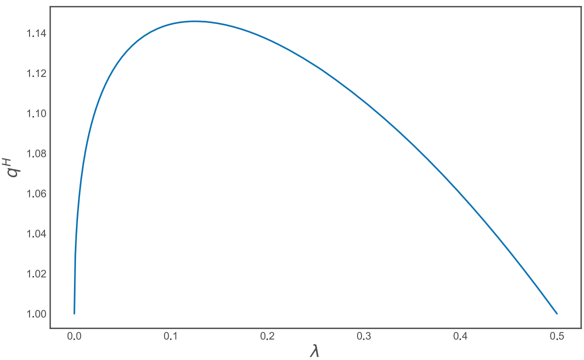
Figure 2.2: Distribution of relative import quality

(a) Complete observations **(b) All observations**



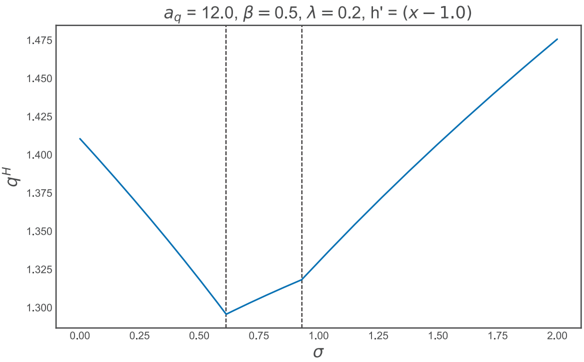
Note: Distribution of the share of industries by country, for the year 2005 and non-OECD countries, where import quality exceeds export quality. Industries that produce homogenous goods as well as resource-rich countries and micro states are excluded. The left panel includes observations for which we have data on both import and export quality, while the right panel keeps all observations and sets quality to zero if quality is not observed.

Figure 2.3: q^H for different values of λ



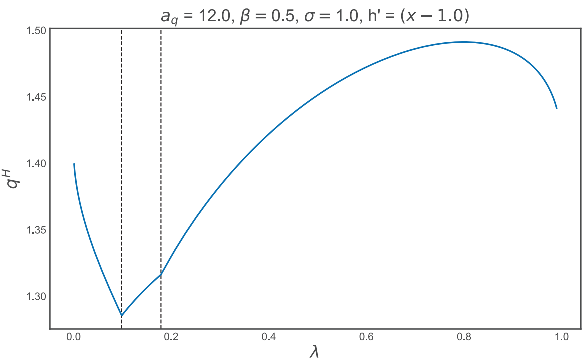
Note: The figure shows the q^H that jointly solves equations (2.30) (increasing) and (2.31) (decreasing) for different values of λ. The remaining parameters are set as follows: $a_q = 1.0$, $\beta = 0.5$, and $\sigma = 1.0$.

Figure 2.4: q^H as a function σ



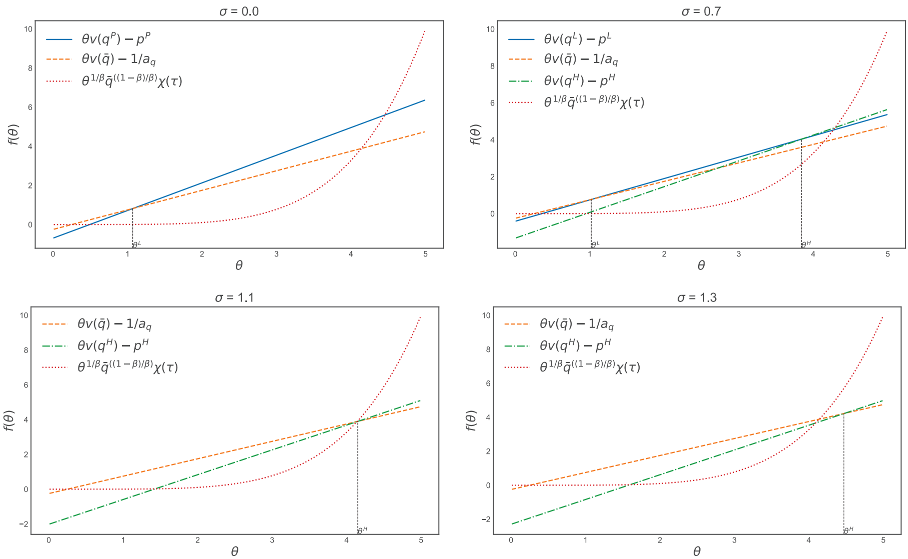
Note: The figure shows the equilibrium values of q^H for different values of σ and where $\hat{I} < \bar{\omega}$. The dashed lines indicate changes in the type of equilibrium, first from a pooling to a separating equilibrium and then to a separating equilibrium where only rich households are served by innovating firms. The specification of the parameters is indicated in the figure. The patterns are qualitatively the same for other parameter specifications.

Figure 2.5: q^H as a function λ



Note: The figure shows the equilibrium values of q^H for $\hat{I} < \bar{\omega}$ in proposition 1. The dashed lines indicate the changes to a different case. The specification of the parameters is indicated in the figures.

Figure 2.6: Illustration of lemma 3



Note: The figures illustrates lemma 3 for different values of σ. The remaining parameter values are $a_q = 4.0$, $\beta = 0.2$, $\lambda = 0.2$, and $\tau = 3.0$. Furthermore, $h'(x) = x - 1.0$.

Table 2.1: Descriptive statistics main variables

Variable	Mean	Std. dev.	Min.	Max.	N
Part I: Macro variables:					
Country export quality	0.83	0.13	0.52	1.44	735
Country import quality	1.06	0.09	0.83	1.47	735
Import share	0.26	0.27	0.00	3.31	704
Real GDP	0.48	1.41	0.00	15.27	704
Population	45.59	148.93	0.73	1340.97	704
Real GDP per capita	12.30	13.44	0.31	81.69	704
Gini	0.39	0.09	0.20	0.62	616
Income share top 20%	0.48	0.08	0.33	0.71	360
Income share top 10%	0.32	0.08	0.19	0.62	360
Life expectancy	66.20	10.73	31.98	82.98	727
Fertility	3.42	1.93	0.96	8.18	727
Schooling (female)	6.78	3.28	0.37	13.23	655
Schooling (male)	7.60	2.83	1.11	13.36	655
Investment share	0.19	0.09	0.01	0.66	704
Government share	0.19	0.09	0.05	0.74	704
Democracy index	0.58	0.36	0.00	1.00	727
CPI inflation	0.50	5.68	-0.04	117.50	628
Terms of trade	1.08	0.51	0.15	5.62	668
Part II: Industry variables:					
Export quality	1.25	1.48	0.00	134.35	191448
Import quality	1.17	0.61	0.03	24.51	263124
Import share	0.00	0.00	0.00	0.26	250597
Import share (adjusted)	0.01	0.03	0.00	1.00	250597

Note: The export and import quality data, as well as the sectoral import shares, are taken from Feenstra and Romalis (2014). The country import shares are taken from the PWT. Real GDP is measured in trillion USD, population in millions and real GDP per capita in 1000 USD. The Gini index is measure after redistribution. Life expectancy is measured at birth in years, fertility is number of births per woman, schooling is measured in years. The democracy index is standardized between zero and one. Terms of trade is the ratio of the export value index and the import value index.

Table 2.2: Baseline results from panel regressions

Dependent variable in t:	Growth t to $t+1$ in export quality				Growth t to $t+1$ in GDP per capita			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log export quality	-0.73***	-0.73***	-0.67***	-0.75***				
	(0.01)	(0.01)	(0.01)	(0.01)				
Log GDP per capita					-0.09***	-0.09***	-0.48***	-0.51***
					(0.01)	(0.02)	(0.05)	(0.05)
Openness	0.00**	0.01	0.01***	-0.01	0.01	-0.11	0.04	-0.25
	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)	(0.12)	(0.03)	(0.27)
Inequality	-0.27***	-0.48**	0.50***	1.06***	-0.13	0.53*	1.20**	0.46
	(0.03)	(0.21)	(0.12)	(0.17)	(0.12)	(0.30)	(0.49)	(1.05)
Distance	-0.35***	-0.30***			0.05**	0.40***		
	(0.01)	(0.08)			(0.02)	(0.15)		
Openness × Inequality		-0.01		0.06***		0.37		0.50
		(0.03)		(0.02)		(0.32)		(0.82)
Openness × Distance		0.02		0.04***		0.18		0.48*
		(0.01)		(0.00)		(0.13)		(0.28)
Inequality × Distance		-0.15		-0.94***		-1.00**		-0.04
		(0.23)		(0.06)		(0.40)		(1.31)
Openness × Inequality × Distance		-0.06*		-0.13***		-0.50		-1.01
		(0.04)		(0.01)		(0.35)		(0.85)
Control variables	Yes	Yes	No	No	Yes	Yes	No	No
Industry × Year FE	Yes	Yes	Yes	Yes	No	No	No	No
Year FE	No	No	No	No	Yes	Yes	Yes	Yes
Country FE	No	No	Yes	Yes	No	No	Yes	Yes
Key coefficient		-0.07		-0.07		-0.14		-0.50
Wald test		0.00		0.00		0.44		0.02
Observations	95211	95211	125287	121769	379	379	486	486

Note: Openness is the log of the relative (adjusted) import share (and the country's import share for the country level regressions), Inequality is the Gini index in levels, Distance indicates whether the export quality of an industry was amongst the lower 75% in the year 2000 for the industry level regressions and whether a country's per capita GDP was amongst the lower 75% in the year 2000 for the country level regressions. Control variables is a series of control variables at the country level, as introduced in section 2.6. Key coefficient is the sum of the coefficients for the interaction between Openness and Gini and the interaction between Openness, Gini and Developing. The Wald test tests whether the sum of the two coefficients is zero and reports the p-value of this test. Standard errors are clustered at the industry×year level (for industry level analysis) or at the country level (for country level analysis), respectively. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***.

Appendix F: Alternative Specifications for Stylized Facts

In this section, we present alternative specifications for our stylized facts from the introduction.

In figure I.1, we use unit value data of exports and imports, provided by Gaulier and Zignago (2010), to measure export and import quality, respectively. Again we use data for the year 2005 and industries producing differentiated goods only. As figure I.1 shows, the finding that developing countries import high quality goods can be confirmed.

— Figure I.1 about here —

To compute the country-industry level unit prices, we sum the export (or import) values for trade flows across destination countries, starting with the highest unit value, until 50% of the trade flows are covered, and then divide this sum by the corresponding sum of quantities.[57] This gives a trade value weighted measure of export (or import) quality, where only higher qualities are considered, which is what we are ultimately interested in. As figure I.2 confirms, the results is robust to using a measure that is not weighted by trade values. Here, we just use the unit prices that are above the median of unit values across all destinations for a given export country and industry (and analogously for importing unit values), regardless of the trade volume.

— Figure I.2 about here —

Finally, figures I.3 and I.4 repeat the exercise by using qualities that are in the top quartile instead of being above the median (or using only 25% of the trade value, respectively). The figures reveal that our finding that poorer countries have to import high quality goods is robust to different definitions and measurements of the quality measure used.

[57]Note that the quality measure used to construct the figure included in the main text is available only at the export country-industry level, and not differentiated by destination country (and analogously for import data). That is why we cannot perform the same robustness checks shown here for the quality measure from Feenstra and Romalis (2014).

— Figure I.3 about here —

— Figure I.4 about here —

Appendix G: Robustness Checks for the Empirical Results

In this section, we present robustness tests to the empirical results presented in section 2.6.

Table I.1 shows the results for the regressions using different specifications for the distance to frontier measure.

— Table I.1 about here —

We vary the threshold level to define an industry or country as distant to frontier as well as the reference year. The first two columns use a threshold of 50% instead of 75% to classify a sector as not belonging to the technology frontier. In columns (3) and (4) we change the reference year from 2000 to 1985. As the growth rate in export quality has an impact on whether a sector is close to the frontier, we choose the first year of our data as the reference year to alleviate endogeneity problems stemming from potential reverse causality. The remaining columns repeat the exercise again for the country level data. Overall, the results indicate that the way how distance to frontier is defined does not crucially impact our results.

Table I.2 provides results for different specifications of the openness measure.

— Table I.2 about here —

Instead of using the continuous adjusted import share, we use a binary variable indicating whether a sector's openness is amongst the 75% highest across countries (first two columns). Furthermore, instead of taking the openness measure for every year, we define openness in the year 2000 and use this measure for all years (columns (3) and (4)). The results hold also if we use 1985 instead of 2000.[58] Columns (5) to (8) repeat the exercise for the country level. The table shows that as with the distance measure, our main results do not hinge on the exact definition of openness.

[58]Our result is also robust to using country-level instead of country-industry level measures for openness in our industry regressions.

Finally, we repeat the exercise of table 2.2 using different variables for inequality. Table I.3 gives an overview of the results.

— Table I.3 about here —

Columns (1) and (2) show the results using the share of incomes going to the top quantile as the inequality measure, while columns (3) and (4) use the share of incomes going to the top decile. Columns (5) to (8) show the results for the country level data. For the sectoral regressions, the estimated key coefficient remains negative in all specifications, while it becomes statistically insignificant once country fixed effects are included. For the country level, the results are robust as well. However, note that it is not straightforward to compare the results using these definitions of inequality to the results with the Gini index, as the regression sample has changed due to the limited data availability of income shares.

Appendix H: Proofs

Proof of lemma 1

To show the desired result, we proceed in three steps.

1. In every period household h chooses q_i^h and z^h to maximize

$$\max_{\{q_i^h\}_{i\in[0,1]}, z^h} \quad \left[\int_0^1 {q_i^h}^{1-\beta}\, di\right] {z^h}^{\beta}$$
$$\text{s.t.} \quad \int_0^1 p_i(q_i^h)\, di + p_z z^h \leq I^h \,,$$

where I^h denotes per-period income of household h which equals total expenditure of household h in the current period. The separability of the instantaneous utility function in combination with the fact that each differentiated good has measure 0 imply that the household will choose q_i^h to maximize

$$\max_{q_i^h} \quad {q_i^h}^{1-\beta} {z^h}^{\beta} - \mu^h p_i(q_i^h)\,, \tag{2.11}$$

where μ^h is the shadow value of income which, by the envelope theorem, is equal to

$$\mu^h = \frac{du^h(\cdot)}{dI^h} = \frac{\frac{\partial u^h}{\partial z^h}}{p_z} \tag{2.12}$$
$$= \frac{\beta Q^h {z^h}^{\beta-1}}{p_z} \,. \tag{2.13}$$

Substituting equation (2.12) for μ^h in decision problem (2.11), we get

$$\max_{q_i^h} \quad {q_i^h}^{1-\beta} {z^h}^{\beta} - \frac{\beta Q^h {z^h}^{\beta-1}}{p_z} p_i(q_i^h)\,,$$

which is equivalent to

$$\max_{q_i^h} \quad {q_i^h}^{1-\beta} \frac{z^h p_z}{\beta Q^h} - p_i(q_i^h) \,.$$

2. From the perspective of innovating firm i $\theta^h := \frac{z^h p_z}{Q^h \beta}$ is a sufficient statistic for household characteristics, which is exogenous to him and observed only by the household. θ is distributed according to $f_\theta(\theta)$, which will depend on the full general equilibrium in the economy.

Let Θ denote the set of pairwise distinct elements in $\left\{\theta^h\right\}_{h\in[0,1]}$. Then, by the revelation principle (cf. e.g. Mas-Colell, Whinston and Green (1995, Proposition 23.C.1)), the innovating firm can limit attention to truthful revelation mechanisms, i.e. for each $\theta \in \Theta$ a quality-price bundle $(q_i(\theta), p_i(\theta))$ such that households will find it optimal to truthfully reveal their type, that is

$$\theta v(q_i(\theta)) - p_i(\theta) = \text{argmax}_{\hat{\theta}\in\Theta} \left\{\theta v(q_i(\hat{\theta})) - p_i(\hat{\theta})\right\} \;, \quad \forall \theta \in \Theta \;, \tag{IC}$$

where $v(q_i) = {q_i}^{1-\beta}$ and $p_i(\theta) := p_i(q_i(\theta))$.

3. The competitive fringe implies that all qualities $q_i \leq \bar{q}_i(t-1)$ are offered at marginal cost, which, in turn, implies that every household must weakly prefer his offered contract $(q_i(\theta^h), p_i(\theta^h))$ to his best choice among all qualities $q \leq \bar{q}_i(t-1)$

$$\theta v(q_i(\theta)) - p_i(\theta) \geq \text{argmax}_{q\in[0,\bar{q}_i(t-1)]} \left\{\theta v(q) - \frac{1}{a_q A} q\right\} \;, \quad \forall \theta \in \Theta \;. \tag{IR}$$

The lemma then follows from combining the above with the firm's profit function (2.3), from noting that total demand for quality $\hat{q}$ is equal to the mass of households of type $\{\theta \in \Theta : q(\theta) = \hat{q}\}$, and from taking into account the endogenous choice of $\bar{q}_i(t)$. □

Proof of lemma 2

Consider any two types $\theta^H, \theta^L \in \Theta$. We show that

$$\theta^H > \theta^L \quad \Rightarrow \quad I^H > I^L \tag{i}$$

$$\theta^H = \theta^L \quad \Rightarrow \quad I^H = I^L \ . \tag{ii}$$

The result then follows.

(i) The following conditions are necessary for incentive compatibility for both types:

$$\theta^H v(q_i(\theta^H)) - p_i(\theta^H) \geq \theta^H v(q_i(\theta^L)) - p_i(\theta^L) \tag{IC^H}$$

$$\theta^L v(q_i(\theta^L)) - p_i(\theta^L) \geq \theta^L v(q_i(\theta^H)) - p_i(\theta^H) \ . \tag{IC^L}$$

Rearranging terms and combining the two conditions, we get

$$\theta^H \left[v(q_i(\theta^H)) - v(q_i(\theta^L))\right] \geq \theta^L \left[v(q_i(\theta^H)) - v(q_i(\theta^L))\right] \ .$$

Using $\theta^H > \theta^L$ along with the fact that $v'(\cdot) > 0$, we get

$$q_i(\theta^H) \geq q_i(\theta^L) \ \forall\, i \in [0,1] \ ,$$

and, hence

$$Q^H = \int_0^1 \left(q_i(\theta^H)\right)^{1-\beta} di \geq \int_0^1 \left(q_i(\theta^L)\right)^{1-\beta} di = Q^L \ . \tag{2.14}$$

Moreover, incentive compatibility requires that $p_i(\theta^H) \geq p_i(\theta^L) \ \forall\, i \in [0,1]$, implying that

$$\int_0^1 p_i(\theta^H)\, di \geq \int_0^1 p_i(\theta^L)\, di \ . \tag{2.15}$$

Finally, by the monotonicity of households' preferences, the budget constraint will always hold with equality, i.e. we have

$$p_z z^h = I^h - \int_0^1 p_i(\theta^h)\, di \quad \forall\, h \in [0,1] \ . \tag{2.16}$$

Combining (2.14), (2.15), and (2.16) with the definition of θ, we conclude

$$\theta^H > \theta^L \quad \Rightarrow \quad I^H > I^L \ .$$

(ii) It remains to show that

$$\theta^H = \theta^L \quad \Rightarrow \quad I^H = I^L \ .$$

We proceed by contradiction. Suppose there exist two types of households with $I^H > I^L$ satisfying $\theta^H = \theta^L$. Then it must be that $Q^H > Q^L$ and that $\int_0^1 p_i(\theta^H)\, di > \int_0^1 p_i(\theta^L)\, di$. Hence for some measurable subset $\hat{\mathfrak{I}} \subseteq [0,1]$ we must have that

$$q_i(\theta^H) > q_i(\theta^L) \quad \forall\, i \in \hat{\mathfrak{I}} \ ,$$

where incentive compatibility for both H and L requires

$$\theta^h v(q_i(\theta^H)) - p_i(\theta^H) = \theta^h v(q_i(\theta^L)) - p_i(\theta^L) \quad \forall\, i \in [0,1],\ h \in \{L,H\} \ . \tag{2.17}$$

This, however, contradicts profit maximization by innovating firms $i \in \hat{\mathfrak{I}}$. To see this, note that for firm i to offer two distinct contracts to one type of households, both contracts must yield the same profit to him. Consider, for concreteness, the case of $q_i(\theta^H) < \bar{q}_i(t)$.[59] Then, we must have

$$p_i(\theta^H) - p_i(\theta^L) = \frac{1}{a_q A}\left(q_i(\theta^H) - q_i(\theta^L)\right) \ . \tag{2.18}$$

(2.17), (2.18), and the concavity of $v(\cdot)$ imply that for every $\tilde{q}_i \in (q_i(\theta^L), q_i(\theta^H))$ there exists a $\tilde{p}_i \in (p_i(\theta^L), p_i(\theta^H))$ such that

$$\theta^h v(q_i(\theta^L)) - p_i(\theta^L) = \theta^h v(\tilde{q}_i) - \tilde{p}_i \ , \quad h \in \{L,H\}$$

[59] It is straightforward to extend the argument to the case of $q_i(\theta^H) = \bar{q}_i(t)$.

and

$$\tilde{p}_i - p_i(\theta^L) > \frac{1}{a_q A}\left(\tilde{q}_i - q_i(\theta^L)\right) \ .$$

The contract $(\tilde{q}_i, \tilde{p}_i)$ yields higher profits for the firm than both $(q_i(\theta^H), p_i(\theta^H))$ and $(q_i(\theta^L), p_i(\theta^L))$. It satisfies (IC) and (IR) for households L, H. Moreover, it weakly relaxes (IC) to all other households because it is less preferred than $(q_i(\theta^L), p_i(\theta^L))$ by all types $\theta < \theta^L$ and less preferred than $(q_i(\theta^H), p_i(\theta^H))$ by all types $\theta > \theta^H$. Hence, offering $(q_i(\theta^H), p_i(\theta^H))$ and $(q_i(\theta^L), p_i(\theta^L))$ cannot be profit maximizing. □

Proof of proposition 1

We begin with a preliminary observation and then prove each part of proposition 1 in turn.

Lemma 4. *The equilibrium price of quality q_i^h, $h \in \{L, H\}$, of any differentiated good $i \in [0,1]$ will never be below its marginal cost of production, i.e.*

$$p_i^h \geq \frac{q_i^h}{a_q A} \ , \quad h \in \{L, H\}.$$

Proof We proceed by contradiction. Suppose innovating firm i offers contracts (q_i^h, p_i^h) and $(q_i^{\hat{h}}, p_i^{\hat{h}})$, $h \neq \hat{h} \in \{L, H\}$, and where $p_i^h < \frac{q_i^h}{a_q A}$ and $p_i^{\hat{h}} \geq \frac{q_i^{\hat{h}}}{a_q A}$.[60] Contract (q_i^h, p_i^h) is loss making for firm i. Consider the following variant to these contracts:

$$\tilde{q}_i^{\hat{h}} = q_i^{\hat{h}}$$
$$\tilde{p}_i^{\hat{h}} = p_i^{\hat{h}}$$

[60] Note that the firm will never price both contracts below marginal cost because this would imply that it is making losses and staying out of business and making zero profits is always an option for the firm.

and

$$\tilde{q}_i^h = \underset{q \in \{[0, \bar{q}(t-1)], q_i^h, q_i^{\hat{h}}\}}{\arg\max} \{\theta^h v(q) - \tilde{p}_i^h\}$$

$$s.t. \quad \tilde{p}_i^h = \begin{cases} \frac{\tilde{q}_i^h}{a_q A}, & \text{if } \tilde{q}_i^h \in \{[0, \bar{q}(t-1)], q_i^h\} \\ \tilde{p}_i^{\hat{h}}, & \text{if } \tilde{q}_i^h = \tilde{q}_i^{\hat{h}} \end{cases} .$$

By construction, contract $(\tilde{q}_i^h, \tilde{p}_i^h)$ satisfies (IR) and (IC) for households h. Moreover, as either $\tilde{q}_i^h = q_i^h$ and $\tilde{p}_i^h > p_i^h$, or $(\tilde{q}_i^h, \tilde{p}_i^h)$ is a contract that has already been available previously, contract $(\tilde{q}_i^{\hat{h}}, \tilde{p}_i^{\hat{h}})$ satisfies (IR) and (IC) for household $\hat{h}$. Yet, contracts $(\tilde{q}_i^h, \tilde{p}_i^h)$, $(\tilde{q}_i^{\hat{h}}, \tilde{p}_i^{\hat{h}})$ yield strictly larger profits to firm i when compared to contracts (q_i^h, p_i^h) and $(q_i^{\hat{h}}, p_i^{\hat{h}})$, a contradiction to the latter being profit maximizing. □

(i) Suppose all qualities are offered at marginal cost. Then household $h \in \{H, L\}$ maximizes his instantaneous utility (2.1) subject to

$$\int_0^1 q_i^h \frac{1}{a_q A} di + z^h \frac{1}{a_z A} = I^h .$$

Standard derivations then imply that $q_i^h = q^h \; \forall i \in [0, 1]$ and that

$$q^h \frac{1}{a_q A} = (1 - \beta) I^h . \tag{2.19}$$

Now, the solution to (2.19) will be household h's consumed quality unless this quality level is not available or some other quality is sold at a price below marginal cost. By lemma 4, the latter will never happen in equilibrium. Moreover, the competitive fringe for pre-existing qualities implies that qualities $q_i \leq \bar{q}(t-1)$ will be offered at marginal cost in equilibrium. The result then follows from observing that the solution according to (2.19) is increasing in I^h, from noting that a household with income $\hat{I}$ would just find it optimal to consume quality $\bar{q}(t-1)$ if all qualities were offered at marginal cost, and from rearranging terms.

(ii) From the above we know that for all differentiated goods we have: $q^{L^e} = (1 - \beta) a_q A I^L$ and $p^{L^e} = \frac{1}{a_q A} q^{L^e}$ and that household H's preferred option among freely available qualities is $\bar{q}(t-1)$. Moreover, it will never be optimal for the firm to upgrade quality more than what is needed to serve the high types, i.e. we have $\bar{q}_i(t) = \max\{\bar{q}(t-1), q_i^H\}$. Hence, firm i's decision problem simplifies to

$$\max_{q_i^H, p_i^H} \quad \lambda \left[p_i^H - \frac{1}{a_q A} q_i^H \right] - h\left(\frac{q_i^H}{\bar{q}(t-1)} \right)$$
$$\text{s.t.} \quad \theta^H v(q_i^H) - p_i^H \geq \theta^H v(\bar{q}(t-1)) - \frac{1}{a_q A}\bar{q}(t-1) \; . \qquad (\mathrm{IR^H})$$

As the firm's profits are strictly increasing in p_i^H, $(\mathrm{IR^H})$ will always hold with equality in equilibrium. Rearranging $(\mathrm{IR^H})$, substituting in for p_i^H in the objective, and differentiating with respect to q_i^H, we get the following necessary conditions for profit maximization:

$$\theta^H v(q_i^H) - \theta^H v(\bar{q}(t-1)) + \frac{1}{a_q A}\bar{q}(t-1) = p_i^H \qquad (\mathrm{IR^H})$$
$$\lambda \theta^H v'(q_i^H) - \lambda \frac{1}{a_q A} - \frac{1}{\bar{q}(t-1)} h'\left(\frac{q_i^H}{\bar{q}(t-1)} \right) = 0 \; . \qquad (2.20)$$

Note that for every $\theta^H > 0$, the first order conditions $(\mathrm{IR^H})$ and (2.20) have at most one solution, implying that any equilibrium has to be symmetric across differentiated goods. Using the symmetry, $A = \bar{q}(t-1)$, the fact that $I^H - p^H = p_z z^H$, the definitions of θ and $v(\cdot)$, and rearranging terms, we get

$$\frac{I^H - p^H}{\beta}\left[1 - \left(\frac{\bar{q}(t-1)}{q^H} \right)^{1-\beta} \right] + \frac{1}{a_q} = p^H \qquad (2.21)$$
$$\lambda \frac{1-\beta}{\beta}\left(I^H - p^H \right) - \lambda \frac{1}{a_q}\frac{q^H}{\bar{q}(t-1)} - \frac{q^H}{\bar{q}(t-1)} h'\left(\frac{q^H}{\bar{q}(t-1)} \right) = 0 \; , \qquad (2.22)$$

which are the expressions shown in proposition 1. Finally, to see that these equations have a unique solution and that this solution involves $q^{H^e} > \bar{q}(t-1)$, observe that (2.21) describes an increasing relationship between p^H and q^H starting from $p^H = \frac{1}{a_q}$ and $q^H = \bar{q}(t-1)$ and converging to $p^H = \frac{I^H}{1+\beta} + \frac{\beta}{(1+\beta)a_q}$ as $q^H \to \infty$, while (2.22) describes a decreasing relationship between p^H and q^H starting from $p^H = I^H - \frac{\beta}{(1-\beta)a_q}$ and $q^H = \bar{q}(t-1)$, and reaching $p^H = 0$ at the solution of

$$\frac{1-\beta}{\beta}\lambda I^H = \frac{\lambda}{a_q}\frac{\hat{q}^H}{\bar{q}(t-1)} + \frac{\hat{q}^H}{\bar{q}(t-1)}h'\left(\frac{\hat{q}^H}{\bar{q}(t-1)}\right) .$$

The result then follows from $I^H > \frac{1}{a_q(1-\beta)}$.

(iii) We show existence and uniqueness of the equilibrium by construction. In particular, we follow the standard procedure for addressing this optimization problem, i.e. we eliminate ($\mathrm{IR^H}$) as it is redundant and consider the incumbent's maximization problem ignoring ($\mathrm{IC^L}$). Noting further that ($\mathrm{IR^L}$) and ($\mathrm{IC^H}$) are always binding[61], this yields the following first order conditions for profit maximization:

$$\theta^L\left(v(q_i^L) - v(\bar{q}(t-1))\right) + \frac{1}{a_q} = p_i^L \tag{2.23}$$

$$\theta^H\left(v(q_i^H) - v(q_i^L)\right) + p_i^L = p_i^H \tag{2.24}$$

$$\theta^L v'(q_i^L) - \lambda\theta^H v'(q_i^L) - (1-\lambda)\frac{1}{a_q A} \leq 0 \tag{2.25}$$

$$\lambda\theta^H v'(q_i^H) - \lambda\frac{1}{a_q A} - h'\left(\frac{q_i^H}{\bar{q}(t-1)}\right)\frac{1}{\bar{q}(t-1)} = 0 , \tag{2.26}$$

with the complementary slackness condition for (2.25) being

$$\left[\theta^L v'(q_i^L) - \lambda\theta^H v'(q_i^L) - (1-\lambda)\frac{1}{a_q A}\right]\left[q_i^L - \bar{q}(t-1)\right] = 0 . \tag{2.27}$$

For θ^L and θ^H given, these equations have exactly one solution. If this solution implies $q_i^H \geq q_i^L$, it characterizes the uniquely optimal choice of firm i. If it involves $q_i^H < q_i^L$, then the uniquely optimal choice is instead to pool consumers.[62] We will get back to this point later and characterize the separating equilibrium first, if it exists.

Note first that the fact that for θ^L and θ^H given, equations (2.23) to (2.27)

[61] If not, the firm could increase profits by raising p^L and / or p^H.

[62] This solution may involve $q_i^H < q_i^L$ because the cost of innovation are made dependent on q_i^H in the above first-order-conditions, i.e. these conditions apply only if $q_i^H \geq q_i^L$. If $q_i^H < q_i^L$ they ignore the fact that the cost of innovation would be governed by q_i^L in such case.

have a unique solution implies that there can only exist a symmetric separating equilibrium. This equilibrium can be derived by the following algorithm that takes into account the endogeneity of θ^h, $h \in \{L, H\}$, with respect to the equilibrium outcomes:

(1) For every $\hat{q}^L$, there is a unique $\hat{p}^L$ satisfying (2.23). For $\hat{q}^L$ and $\hat{p}^L$ given, (2.24) describes a monotonously increasing relation between p^H and q^H, starting at $\hat{q}^H = \hat{q}^L$ and $\hat{p}^H = \hat{p}^L$ and converging to $\hat{p}^H = \frac{I^H + \hat{p}^L \beta}{1+\beta}$ as $\hat{q}^H \to \infty$. (2.26), on the other hand, describes a monotonously decreasing relation between p^H and q^H, starting at $\hat{q}^H = \bar{q}(t-1)$ and $\hat{p}^H = I^H - \frac{\beta}{(1-\beta)a_q}$ and reaching $\hat{p}^H = 0$ at the solution of

$$\frac{1-\beta}{\beta}\lambda I^H = \frac{\lambda}{a_q}\frac{\hat{q}^H}{\bar{q}(t-1)} + \frac{\hat{q}^H}{\bar{q}(t-1)}h'\left(\frac{\hat{q}^H}{\bar{q}(t-1)}\right) .$$

Hence, for every $\hat{q}^L$, (2.23), (2.24), and (2.26) have at most one solution for $\hat{p}^L$, $\hat{p}^H$, $\hat{q}^H$.

(2) Start with $\hat{q}^L = \bar{q}(t-1)$ and follow the procedure as described above. Plug the derived $\hat{q}^L, \hat{q}^H, \hat{p}^L, \hat{p}^H$ into (2.25).[63] If inequality (2.25) is satisfied, $\hat{q}^L, \hat{q}^H, \hat{p}^L, \hat{p}^H$ are the unique equilibrium values (case A).

(3) If inequality (2.25) is violated, add some small $\Delta > 0$ to $\hat{q}^L$ and repeat procedure (1). Keep adding $\Delta > 0$ to $\hat{q}^L$ until (2.25) is satisfied.[64] If the inequality is strict, apply a bisection algorithm until convergence to the equilibrium values (case B).[65]

(4) The unique symmetric solution to equations (2.23)-(2.27) may imply $q^L < q^H$. In such case there exists no separating equilibrium, and the unique equilib-

[63]Note that by $I^H > \frac{1}{(1-\beta)a_q}$ there is indeed a solution for (2.23), (2.24), and (2.26) with $\hat{q}^L = \bar{q}(t-1)$.

[64]Note that by (2.23) increasing $\hat{q}^L$ results in a higher $\hat{p}^L$ and a lower $\hat{\theta}^L$. This does not affect (2.26), but shifts the solutions to (2.24) in the q^H, p^H diagram down and to the right, i.e. according to (2.24) every $\hat{q}^H$ is now associated with a lower $\hat{p}^H$. Together, this implies that the unique solution to (2.24) and (2.26) has now a higher $\hat{q}^H$ and a lower $\hat{p}^H$. Moreover, by (2.26), it is also associated with a higher $\hat{\theta}^H$. Now, a higher $\hat{q}^L$ in conjunction with a lower $\hat{\theta}^L$ and a higher $\hat{\theta}^H$ imply that the left hand side of (2.25) is decreasing.

[65]Note that this is indeed an equilibrium and in particular that the above reasoning also implies that no firm has an incentive to deviate by pooling types in its sector. This follows from the fact that given θ, i.e. given the equilibrium strategy of all other firms in the economy, the solution to equations (2.23) to (2.27) is uniquely optimal.

rium is a symmetric pooling equilibrium which is the solution to

$$\theta^L \left(v(q^P) - v(\bar{q}(t-1))\right) + \frac{1}{a_q} = p^P \tag{2.28}$$

$$\theta^L v'(q^P) - \frac{1}{a_q A} - \frac{1}{\bar{q}(t-1)} h'\left(\frac{q^P}{\bar{q}(t-1)}\right) = 0 \; . \tag{2.29}$$

Using the definitions of θ and $v(\cdot)$, along with the fact that $A = \bar{q}(t-1)$ yields the expressions given in proposition 1 (case C).

(5) Finally, it remains to be shown that an equilibrium according to case (A) and (B), respectively, is unique if it exists. To see this, assume that a symmetric separating equilibrium exists with $\hat{q}^L < \hat{q}^H$ and note first that the arguments in steps (1) to (3) above imply that if an equilibrium according to case (A) and (B) exists, there can be no other separating equilibrium. To see that there can also be no pooling equilibrium in such case, suppose that there exists some $\tilde{q}^L$ such that equations (2.23), (2.24), and (2.26) are simultaneously satisfied if $\tilde{q}^H = \tilde{q}^L = \tilde{q}$ for all i. As by assumption there is a symmetric separating equilibrium with $\hat{q}^H > \hat{q}^L$, step (3) then implies that for these values the inequality in condition (2.25) must be strict. This, in combination with the fact that equation (2.26) holds implies that the left-hand-side of equation (2.29) would be negative for this value, i.e. in a potential pooling equilibrium it must be that $q < \tilde{q}$. But for $q^L < \tilde{q}$ we know from the reasoning above implies that the unique symmetric solution to equations (2.23), (2.24), and (2.26) implies $q^H > q^L$, i.e. there can be no pooling equilibrium.

□

Proof of proposition 2

We consider each case in proposition 2 in turn.

$\boldsymbol{\sigma \uparrow}$ with $\boldsymbol{\frac{1}{a_q(1-\beta)} \geq 1}$ $\frac{1}{a_q(1-\beta)} \geq 1$ implies that for $\sigma = 0$ we have $I^H \leq \frac{1}{a_q(1-\beta)}$. Hence, by proposition 1(i) there will be zero growth in the economy up and until the point where $I^H = \frac{1}{a_q(1-\beta)}$, i.e. $\sigma = \left[\frac{1}{a_q(1-\beta)} - 1\right]\sqrt{\frac{\lambda}{1-\lambda}}$. As σ increases further, the economy starts growing, which follows from proposition

1(ii). Now, as σ and hence I^H increases, both (2.21) and (2.22) shift upwards. Note, however, that (2.22), which is downward sloping, shifts more, implying that g is monotonously increasing in σ.

$\lambda \downarrow$ with $\frac{1}{a_q(1-\beta)} \geq 1$ I^H and I^L are both increasing as we lower λ. Hence, there is an upper threshold $\bar{\lambda} := \frac{1}{1+\sigma^2}$, which is the λ associated with $I^L = 0$. We consider the case where $1+\sigma\sqrt{\frac{1-\bar{\lambda}}{\bar{\lambda}}} \leq \frac{1}{a_q(1-\beta)}$, implying that the highest feasible λ will be associated with $g = 0$. For the case of $1+\sigma\sqrt{\frac{1-\bar{\lambda}}{\bar{\lambda}}} > \frac{1}{a_q(1-\beta)}$, the hump will be truncated from the left.

As long as $1+\sigma\sqrt{\frac{1-\bar{\lambda}}{\bar{\lambda}}} < \frac{1}{a_q(1-\beta)}$, there will be zero growth in the economy. At the point $1+\sigma\sqrt{\frac{1-\bar{\lambda}}{\bar{\lambda}}} = \frac{1}{a_q(1-\beta)}$, as we decrease λ further, we will switch from an equilibrium according to proposition 1(i) to an equilibrium according to proposition 1(ii) and the economy starts growing. In this equilibrium, q^H, and hence growth, will be given by the unique solutions of the two equations as stated in proposition 1(ii). Using the definition of I^H and rearranging terms, these expressions can be restated as:

$$p^H = \frac{\left(1+\sigma\sqrt{\frac{1-\lambda}{\lambda}}\right)\left(1-\left(\frac{q^H}{\bar{q}(t-1)}\right)^{\beta-1}\right)+\frac{\beta}{a_q}}{1+\beta-\left(\frac{q^H}{\bar{q}(t-1)}\right)^{\beta-1}} \tag{2.30}$$

$$p^H = 1+\sigma\sqrt{\frac{1-\lambda}{\lambda}} - \frac{\beta}{(1-\beta)a_q}\frac{q^H}{\bar{q}(t-1)} - \frac{q^H}{\bar{q}(t-1)}h'\left(\frac{q^H}{\bar{q}(t-1)}\right)\frac{\beta}{(1-\beta)\lambda} \tag{2.31}$$

Now, as already discussed in the proof of proposition 1, (2.30) describes an increasing relationship between p^H and q^H starting from $p^H = \frac{1}{a_q}$ and $q^H = \bar{q}(t-1)$ and converging to $p^H = \frac{I^H}{1+\beta} + \frac{\beta}{(1+\beta)a_q}$ as $q^H \to \infty$, while (2.31) describes a decreasing relationship between p^H and q^H starting from $p^H = I^H - \frac{\beta}{(1-\beta)a_q}$ and $q^H = \bar{q}(t-1)$ and reaching $p^H = 0$ at the solution of

$$\frac{1-\beta}{\beta}\lambda I^H = \frac{\lambda}{a_q}\frac{\hat{q}^H}{\bar{q}(t-1)} + \frac{\hat{q}^H}{\bar{q}(t-1)}h'\left(\frac{\hat{q}^H}{\bar{q}(t-1)}\right).$$

Now, partially differentiating (2.30) and (2.31) with respect to λ yields

$$-\frac{\partial p^H}{\partial \lambda} = \frac{1-\left(\frac{q^H}{\bar{q}(t-1)}\right)^{\beta-1}}{1+\beta-\left(\frac{q^H}{\bar{q}(t-1)}\right)^{\beta-1}} \frac{\sigma}{2}\sqrt{\frac{\lambda}{1-\lambda}}\frac{1}{\lambda^2} \tag{2.30'}$$

$$-\frac{\partial p^H}{\partial \lambda} = \left[\frac{\sigma}{2}\sqrt{\frac{\lambda}{1-\lambda}} - \frac{\beta}{(1-\beta)}\frac{q^H}{\bar{q}(t-1)}h'\left(\frac{q^H}{\bar{q}(t-1)}\right)\right]\frac{1}{\lambda^2}\ . \tag{2.31'}$$

As λ decreases, the p^H associated with q^H according to equation (2.30) increases, where this increase is 0 at $q^H = \bar{q}(t-1)$ and monotonically converges to $\frac{1}{1+\beta}\frac{\sigma}{2}\sqrt{\frac{\lambda}{1-\lambda}}\frac{1}{\lambda^2}$ as $q^H \to \infty$. On the other hand, the p^H associated with q^H according to equation (2.31) increases strongest at $q^H = \bar{q}(t-1)$, where its increase is $\frac{\sigma}{2}\sqrt{\frac{\lambda}{1-\lambda}}\frac{1}{\lambda^2}$, and increases less for higher q^H and eventually even decreases. Hence, every λ is associated with a unique $\tilde{q}(\lambda)$ such that

$$\frac{1-\left(\frac{\tilde{q}(\lambda)}{\bar{q}(t-1)}\right)^{\beta-1}}{1+\beta-\left(\frac{\tilde{q}(\lambda)}{\bar{q}(t-1)}\right)^{\beta-1}} \frac{\sigma}{2}\sqrt{\frac{\lambda}{1-\lambda}}\frac{1}{\lambda^2} = \left[\frac{\sigma}{2}\sqrt{\frac{\lambda}{1-\lambda}} - \frac{\beta}{(1-\beta)}\frac{\tilde{q}(\lambda)}{\bar{q}(t-1)}h'\left(\frac{\tilde{q}(\lambda)}{\bar{q}(t-1)}\right)\right]\frac{1}{\lambda^2}$$

$$\Leftrightarrow$$

$$\sqrt{\frac{\lambda}{1-\lambda}} = \frac{1+\beta-\left(\frac{\bar{q}(t-1)}{\tilde{q}(\lambda)}\right)^{1-\beta}}{1-\beta}\frac{\tilde{q}(\lambda)}{\bar{q}(t-1)}h'\left(\frac{\tilde{q}(\lambda)}{\bar{q}(t-1)}\right)\frac{2}{\sigma}\ ,$$

i.e. such that for $q < \tilde{q}(\lambda)$ a marginal decrease in λ shifts up (2.31) more than (2.30), and vice versa for $q > \tilde{q}(\lambda)$. Note that $\tilde{q}(\cdot)$ is monotonously increasing. Then, by continuity, as λ decreases, (2.30) and (2.31) initially intersect at higher q^H and p^H, implying that equilibrium growth is increasing as we decrease λ. Growth will reach a peak when (2.30) and (2.31) intersect at $\tilde{q}(\lambda)$ and then decrease as we decrease λ further. This is illustrated in figure I.5 where we plot equations (2.30) and (2.31) in a q^H, p^H diagram for varying values of λ. For the parameter values chosen, $\lambda = 0.13$ (green dash-dotted lines) is the value for which (2.30) and (2.31) intersect at $\tilde{q}(\lambda)$. For smaller values of λ, q^H decreases as we lower λ until q^H converges to $\bar{q}(t-1)$ as $\lambda \to 0$.[66]

[66]To see that q^H converges to $\bar{q}(t-1)$ as $\lambda \to 0$, multiply equations (2.30) and (2.31) by λ,

— Figure I.5 about here —

$\sigma \uparrow$ with $\frac{1}{a_q(1-\beta)} < 1$ For $\sigma = 0$, the unique equilibrium is a pooling equilibrium with positive growth. As σ increases, and hence I^L decreases, the growth rate in the pooling equilibrium declines. To see this, observe that as I^L decreases, both equilibrium conditions for the pooling equilibrium shift downwards in the q^P, p^P diagram, but that (2.29) shifts more, implying that both q^P, and p^P decline. This, in turn, implies that higher-σ pooling equilibria are associated with a higher θ^H. Hence, for some σ large enough, (2.26) will hold with equality.[67]

As we increase σ further, we will switch from a pooling equilibrium to a separating equilibrium. In the separating equilibrium, an increase in σ will have two different effects: (i) The associated increase in I^H will have a strictly positive effect on growth.[68] (ii) The associated decrease in I^L will have an indirect effect on growth as its effect on q^L and p^L impacts p^H and, hence, θ^H which, in turn, pins down q^H via (2.26). This effect may initially be negative but will eventually be positive as well for σ large enough such that θ^L and q^L sufficiently small.[69] We show numerically that for a broad range of parameter specifications the direct effect via an increase of I^H always dominates. In particular, we numerically solve

and note that the right-hand-side of (2.30) converges to 0 while the right-hand-side of equation (2.31) converges to $-\frac{q^H}{\bar{q}(t-1)} h'\left(\frac{q^H}{\bar{q}(t-1)}\right) \frac{\beta}{(1-\beta)}$ which converges to 0 only if $q^H \to \bar{q}(t-1)$.

[67] Note that (2.26) and (2.29) together imply that (2.25) will also hold with equality and that for $q^H = q^L$ and therefore $p^H = p^L$ (2.24) trivially holds.

[68] To show (i), we proceed by contradiction. In particular, note that (2.26) defines an increasing relationship between θ^H and q^H, i.e. for growth to decline it must be that θ^H declines as well. (2.23) and (2.25) then imply that q^L must increase while θ^L decreases. But then equations (2.23) and (2.24) imply that p^H must decrease as well, a contradiction to θ^H being decreasing given that I^H increases and q^H decreases.

[69] A decrease in I^L will have a negative (positive) effect on growth if for the previously given q^H the price p^H increases (decreases). A decrease in I^L will, ceteris paribus, lower θ^L and, hence, lower p^L at a given q^L to satisfy individual rationality of the low types. Firms will, however, respond to the decrease in I^L by lowering quality for the low types, q^L, according to optimality condition (2.25). Now, equations (2.23) and (2.24) define marginal changes in θ^L and q^L such that—given the new equilibrium values for q^L and p^L and the previous equilibrium values for q^H and p^H—incentive compatibility for high types is just satisfied. In particular, totally differentiating (2.23), we get

$$dp^L = d\theta^L \left[v(q^L) - v(\bar{q}(t-1))\right] + \theta^L v'(q^L) dq^L ,$$

while totally differentiating (2.23) and using that q^H, p^H, and θ^H are constant, we get

$$dp^L = \theta^H v'(q^L) dq^L .$$

for q^H as a function of σ assuming $h'(x) = c(x-1)^\alpha$ for all possible parameter specifications from the following set:

λ :	$\{0.05, 0.15, ..., 0.95\}$
β :	$\{0.05, 0.15, ..., 0.95\}$
a_q :	$\{2, 4, ..., 20\}$
c :	$\{1, 2, 4, 8, 12\}$
α :	$\{0.05, 0.2, 1, 10, 20\}$

For each possible combination of these parameter specifications, q^H is increasing as a function of σ in a separating equilibrium.[70]

Combining the previous two equations and rearranging terms, we get

$$\frac{dq^L}{d\theta^L} = \frac{v(q^L) - v(\bar{q}(t-1))}{(\theta^H - \theta^L)v'(q^L)} \ . \tag{2.32}$$

Equation (2.32) characterizes how q^L has to change in response to a marginal change in θ^L for (IR^L) and (IC^H) still to be satisfied given q^H, p^H, and θ^H. On the other hand, noting that in a separating equilibrium equation (2.25) holds with equality and totally differentiating using again that θ^H stays constant by assumption, we get

$$\frac{dq^L}{d\theta^L} = \frac{v'(q^L)}{v''(q^L)} \frac{1}{\lambda\theta^H - \theta^L} \ . \tag{2.33}$$

Equation (2.33) characterizes the optimal change of q^L in response to a marginal change of θ^L for a given θ^H. Now, if the right-hand-side of (2.33) is larger than the right-hand-side of (2.32), then the optimal response of q^L to a marginal decrease of θ^L is larger in absolute terms than the one needed to have (IC^H) satisfied at the old levels of q^H and p^H. As the high types value quality more, this decreases the attractiveness of contract (q^L, p^L) to high types which, in turn, allows firms to increase p^H. As a consequence, growth will be lower via the negative general equilibrium effect of a higher p^H on θ^H. In other words, a decrease of I^L will lower growth if

$$\frac{v'(q^L)}{v''(q^L)} \frac{1}{\lambda\theta^H - \theta^L} > \frac{v(q^L) - v(\bar{q}(t-1))}{(\theta^H - \theta^L)v'(q^L)} \ .$$

Using the definition of $v(\cdot)$ and rearranging terms, this is equivalent to

$$\frac{\theta^H - \theta^L}{\theta^L - \lambda\theta^H} < \frac{\beta}{1-\beta}\left[1 - \left(\frac{\bar{q}(t-1)}{q^L}\right)^{1-\beta}\right] \ .$$

Now, the right-hand-side of the above condition approaches zero as $q^L \to \bar{q}(t-1)$ while the left-hand-side is strictly positive, which shows that, indeed a decrease in I^L will eventually have a positive effect on growth.

[70]If σ is large enough such that the economy reaches the point where innovating firms find it optimal to no longer serve the low types—i.e. if the solution to the system of equations in proposition 1(iii)(B) involves $q^L \leq \bar{q}(t-1)$—this is trivially the case and an increase in σ will always have a positive effect on growth as already noted above.

$\boldsymbol{\lambda \downarrow}$ with $\boldsymbol{\frac{1}{a_q(1-\beta)} < 1}$ For λ small enough, there will be a pooling equilibrium. In the pooling equilibrium, λ impacts the equilibrium only via its effect on I^L, which is inversely related to λ. As growth in the pooling equilibrium is increasing in I^L (cf. above), for λ small enough growth is therefore inversely related to λ.[71]

For λ large enough such that the equilibrium is a separating equilibrium and firms stopped serving the poor, we are in the case considered above and we know that growth follows a hump-shape as we vary λ.[72]

For intermediate λ, we are in a separating equilibrium where innovating firms still find it optimal to also serve the poor. In such case, the direct effect of a change in λ on the share and the income of the rich is, again, combined with an indirect general equilibrium effect of a change in the share and income of the poor on q^L and p^L. This, in turn, will affect p^H and hence θ^H for a given I^H and q^H. We again show by means of numerical simulations that the direct effect always dominates for a broad range of parameter specifications, i.e. in a separating equilibrium where innovating firms still serve the poor, growth also follows a hump-shape as we vary λ. For the vast majority of parameter specifications, as we increase λ, firms stop serving the poor before we reach the peak of the hump. For very convex functions $h(\cdot)$, however, it may be that we reach the peak first. In such case, when firms eventually stop to serve the poor growth may continue to be inversely related to λ or it may initially be increasing again such that in the separating equilibrium growth follows two humps as a function of λ. Figure I.6 provides an example for each of the two cases.

— Figure I.6 about here —

[71] To see that there must be a pooling equilibrium for λ sufficiently small, note that λI^H converges to 0 as $\lambda \to 0$. Equation (2.26) then implies that in a candidate separating equilibrium we must have $q^H \to \bar{q}(t-1)$. At the same time, $(1-\lambda)I^L$ converges to 1 as $\lambda \to 0$. With $\hat{I} < \overline{w}$, it would therefore be optimal for firms to choose $q^L > \bar{q}(t-1)$ even when just serving the poor, i.e. a separating equilibrium cannot be optimal.

[72] In the case considered above, we know that growth eventually has to decrease because growth will eventually be zero for values of λ large enough such that $\omega^H \leq \hat{I}$. In the case considered here we will always have $\omega^H > \hat{I}$. Still, growth eventually has to decrease for λ large enough. This follows from the fact that $\tilde{q}(\lambda)$ increases arbitrarily as $\lambda \to 1$, i.e. in a left neighborhood of $\lambda = 1$ we must have that $q^H < \tilde{q}(\lambda)$ and growth is inversely related to λ.

Proof of lemma 3

We show that constraint (IRf) cannot be binding for the low types. With $I^L \leq \hat{I}$ this is trivially the case. We thus consider the case of $I^L > \hat{I}$ and show that low types prefer quality $\bar{q}(t-1)$ over any imported quality.

As argued in the main body of the text, it is never optimal to import quality $q \leq \bar{q}(t-1)$. Hence, constraint (IRf) can only be binding if the preferred importing quality satisfies $q > \bar{q}(t-1)$. Combined with the fact that the marginal utility of quality is increasing in θ, this implies that low types will prefer quality $\bar{q}(t-1)$ over their best importing option if this is the case for some $\hat{\theta} \geq \theta^L$.

Now, the income of low types is bound from above by 1. Moreover, θ^L is decreasing in both, q^L and p^L. We conclude that θ^L is bound from above by

$$\bar{\theta}^L := \frac{1-\frac{1}{a_q}}{\beta\bar{q}(t-1)^{1-\beta}} \ .$$

A household of type $\bar{\theta}^L$ will prefer quality $\bar{q}(t-1)$ over its best importing option if

$$\bar{\theta}^L v(\bar{q}(t-1)) - \frac{1}{a_q} \geq \left[\bar{\theta}^L\right]^{\frac{1}{\beta}} \left[\bar{q}(t-1)\right]^{\frac{1-\beta}{\beta}} \chi(\tau) \ .$$

Using the definitions of $\bar{\theta}^L$, $v(\cdot)$, and $\chi(\tau)$, this can be rewritten as

$$\frac{1-\frac{1}{a_q}}{\beta\bar{q}(t-1)^{1-\beta}}\bar{q}(t-1)^{1-\beta} - \frac{1}{a_q} \geq \left[\frac{1-\frac{1}{a_q}}{\beta\bar{q}(t-1)^{1-\beta}}\right]^{\frac{1}{\beta}} \left[\bar{q}(t-1)\right]^{\frac{1-\beta}{\beta}} \left[\frac{a_q(1-\beta)}{\tau^2}\right]^{\frac{1-\beta}{\beta}} \beta \ .$$

Solving for τ and simplifying terms yields the expression given in assumption 1. □

Proof of proposition 3

Most parts of proposition 3 follow from the discussions in the main text. To show that rich households start importing higher quality than what would be provided by domestic firms, we consider the limiting case where it is just optimal to stop serving the rich and proceed by contradiction. In particular, we show that

$q^{H,f} \leq q^H$ contradicts that it is optimal for domestic firms not to serve the rich households.

Suppose that $q^{H,f} \leq q^H$, where $q^{H,f}$ denotes the imported quality and q^H denotes the optimal domestically-provided quality. The best importing quality satisfies the first-order condition for utility maximization of the rich

$$\theta^H v'(q^{H,f}) = \frac{\tau^2}{a_q A} ,$$

implying that

$$p^{H,f} = \frac{\tau^2}{a_q A} q^{H,f} = \theta^H v'(q^{H,f}) q^{H,f} , \tag{2.34}$$

where $p^{H,f}$ denotes the price of imported quality $q^{H,f}$. The fact that rich households prefer the importing option implies

$$\theta^H v(q^{H,f}) - p^{H,f} \geq \theta^H v(q^H) - p^H$$

and therefore

$$\begin{aligned} p^H &\geq \theta^H \left[v(q^H) - v(q^{H,f}) + p^{H,f} \right] \\ &= \theta^H \int_{q^{H,f}}^{q^H} v'(x) dx + \theta^H v'(q^{H,f}) q^{H,f} \\ &\geq \theta^H v'(q^H) q^H \ . \end{aligned}$$

The equality follows from using the fundamental theorem of calculus and equation (2.34). The second inequality follows from the fact that $v(\cdot)$ is concave and that $q^{H,f} \leq q^H$, by assumption, and from simplifying terms. The above inequalities are strict whenever $q^{H,f} < q^H$.

Now, there are two possibilities for when domestic firms find it optimal not to serve rich households: Either they stop innovating altogether or they keep on innovating—at a lower rate—to serve the poor. The first order condition for q^H implies

$$\lambda \theta^H v'(q^H) - \lambda \frac{1}{a_q A} - \frac{1}{\bar{q}(t-1)} h' \left(\frac{q^H}{\bar{q}(t-1)} \right) = 0 \ . \tag{2.35}$$

Clearly, the fact that $p^H \geq \theta^H v'(q^H)q^H$ and the convexity of $h(\cdot)$ imply that firms are making positive profits from just serving the rich households, i.e. a solution with no innovation cannot be optimal.

The fact that firms cannot make higher profits from just serving the poor households instead of both types of households follows from a revealed preference argument. In particular, in the separating equilibrium, it must be that $(\mathrm{IR}^{\mathrm{L}})$ is binding.[73] Moreover, firms could opt to offer poor households contract $(\tilde{q}^L, \tilde{p}^L)$, where we use this to denote the contract that firms would offer the low types in the hypothetical scenario where they just serve these types. This contract also satisfies $(\mathrm{IR}^{\mathrm{L}})$ with equality, i.e. low types are indifferent between contracts $(\tilde{q}^L, \tilde{p}^L)$ and (q^L, p^L). We now show that offering $(\tilde{q}^L, \tilde{p}^L)$ and $(\tilde{q}^H, \tilde{p}^H)$ would yield strictly higher profits than when just offering $(\tilde{q}^L, \tilde{p}^L)$, where $\tilde{q}^H = q^H$ and $\tilde{p}^H$ is as defined below. In turn, this implies that the optimal contracts in the separating equilibrium yield strictly higher profits than when just offering $(\tilde{q}^L, \tilde{p}^L)$.

If $\tilde{q}^L \leq q^L$, this follows immediately because the change in the contract of the poor will not affect the contract for the rich and because firms make positive profits from serving the rich.

If $\tilde{q}^L > q^L$ and $(\mathrm{IC}^{\mathrm{H}})$ is not binding, the same reasoning from before applies. If $(\mathrm{IC}^{\mathrm{H}})$ is binding, then the price of q^H changes to

$$\tilde{p}^H = \tilde{p}^L + \int_{\tilde{q}^L}^{q^H} \theta^H v'(x)dx$$

[73] $(\mathrm{IRf}^{\mathrm{L}})$ is never binding. Hence, the only possibility where $(\mathrm{IR}^{\mathrm{L}})$ is not binding is a hypothetical case where $(\mathrm{IC}^{\mathrm{L}})$ is binding, for otherwise firms could increase profits by increasing p^L which would only relax $(\mathrm{IC}^{\mathrm{H}})$. $(\mathrm{IC}^{\mathrm{L}})$, however, cannot be binding because, by assumption, the rich are indifferent between consuming the domestically produced quality q^H or importing a weakly lower quality. As richer households have a stronger taste for quality, poor households must then weakly prefer the best import choice of the rich households over (q^H, p^H) and, therefore, strictly prefer their own best import choice, i.e. $(\mathrm{IRf}^{\mathrm{L}})$ would have to be strictly binding in such case, a contradiction.

and we have

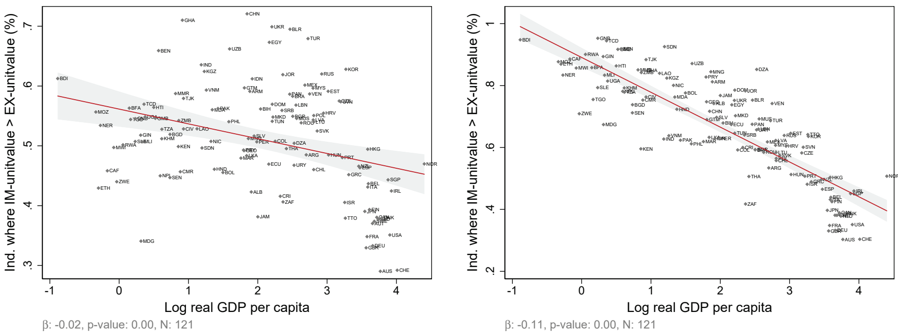
$$
\begin{aligned}
&(1-\lambda)\left(\tilde{p}^L - \frac{1}{a_q A}\tilde{q}^L\right) - h\left(\frac{\tilde{q}^L}{\bar{q}(t-1)}\right) \\
&< \left(\tilde{p}^L - \frac{1}{a_q A}\tilde{q}^L\right) - h\left(\frac{\tilde{q}^L}{\bar{q}(t-1)}\right) \\
&< \left(\tilde{p}^L - \frac{1}{a_q A}\tilde{q}^L\right) - h\left(\frac{\tilde{q}^L}{\bar{q}(t-1)}\right) + \\
&\int_{\tilde{q}^L}^{q^H} \lambda\theta^H v'(x) - \lambda\frac{1}{a_q A} - \frac{1}{\bar{q}(t-1)}h'\left(\frac{x}{\bar{q}(t-1)}\right) dx \\
&= \left(\tilde{p}^L - \frac{1}{a_q A}\tilde{q}^L\right) + \lambda\left(\tilde{p}^H - \tilde{p}^L\right) - \lambda\frac{1}{a_q A}\left(q^H - \tilde{q}^L\right) - h\left(\frac{q^H}{\bar{q}(t-1)}\right) \quad . \qquad (2.36)
\end{aligned}
$$

The first inequality follows from $\tilde{p}^L - \frac{1}{a_q A}\tilde{q}^L > 0$ and $\lambda > 0$. The second inequality follows from using (2.35) and the fact that $v(\cdot)$ is concave and $h(\cdot)$ is convex. The equality follows from solving the integral. The result then follows from noting that the expression in the last row is equal to total profits with this alternative separating contract. □

Appendix I: Appendix Figures and Tables

Figure I.1: Relative import unit prices and income, trade weighted

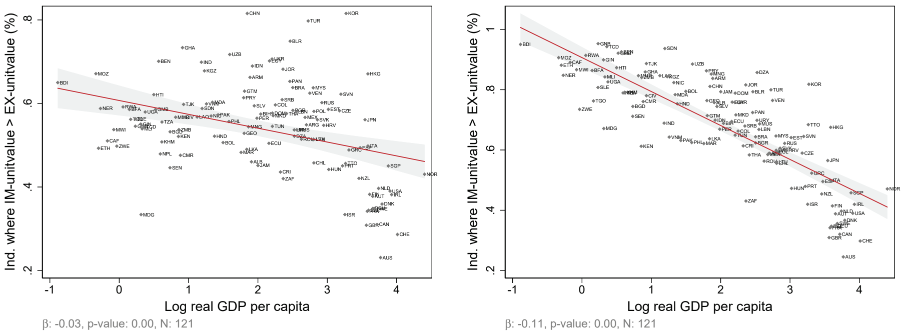
(a) Complete observations **(b) All observations**



Note: Share of industries by country, for the year 2005, where the unit price of imports exceeds the unit price of exports. The unit value for each industry is computed by summing the export (or import) values for the trade flows, starting with the highest quality, until 50% of the trade flows are covered, and then dividing this sum by the corresponding sum of quantities. Industries that produce homogeneous goods as well as resource-rich countries and micro states are excluded. The left panel includes industry observations for which we have data for both import and export unit prices, while in the right panel we set the unit price of exports (or imports) to zero if the country in this industry is not exporting (or importing).

Figure I.2: Relative import unit prices and income, not weighted

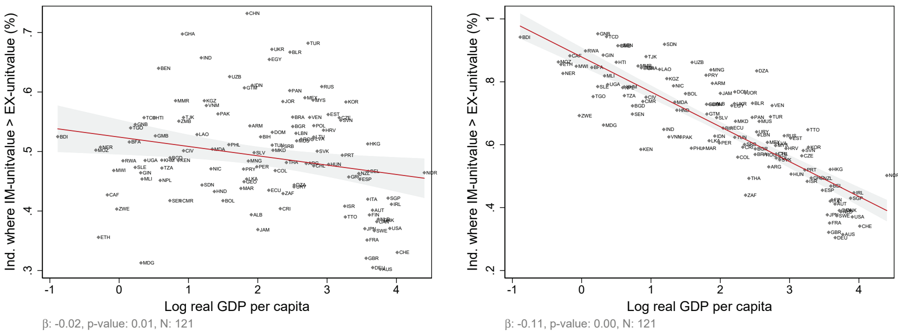
(a) Complete observations **(b)** All observations



Note: Share of industries by country, for the year 2005, where the unit price of imports exceeds the unit price of exports. The unit value for each industry is computed by summing the export (or import) values for the trade flows with above-median unit prices and then dividing this sum by the corresponding sum of quantities. Industries that produce homogeneous goods as well as resource-rich countries and micro states are excluded. The left panel includes industry observations for which we have data for both import and export unit prices, while in the right panel we set the unit price of exports (or imports) to zero if the country in this industry is not exporting (or importing).

Figure I.3: Relative import unit prices and income, trade weighted

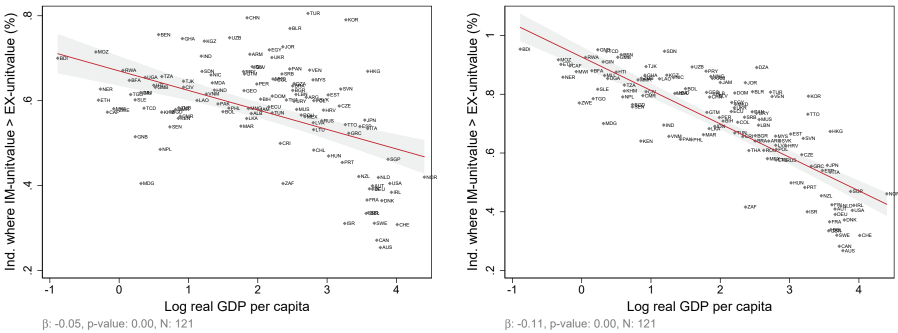
(a) Complete observations **(b) All observations**



Note: Share of industries by country, for the year 2005, where the unit price of imports exceeds the unit price of exports. The unit value for each industry is computed by summing the export (or import) values for the trade flows, starting with the highest quality, until 25% of the trade flows are covered, and then dividing this sum by the corresponding sum of quantities. Industries that produce homogeneous goods as well as resource-rich countries and micro states are excluded. The left panel includes industry observations for which we have data for both import and export unit prices, while in the right panel we set the unit price of exports (or imports) to zero if the country in this industry is not exporting (or importing).

Figure I.4: Relative import unit prices and income, not weighted

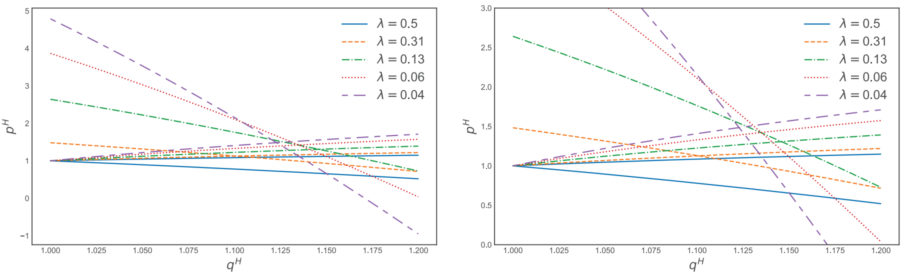
(a) Complete observations **(b) All observations**



Note: Share of industries by country, for the year 2005, where the unit price of imports exceeds the unit price of exports. The unit value for each industry is computed by summing the export (or import) values for the trade flows with unit prices in the top quartile and then dividing this sum by the corresponding sum of quantities. Industries that produce homogeneous goods as well as resource-rich countries and micro states are excluded. The left panel includes industry observations for which we have data for both import and export unit prices, while in the right panel we set the unit price of exports (or imports) to zero if the country in this industry is not exporting (or importing).

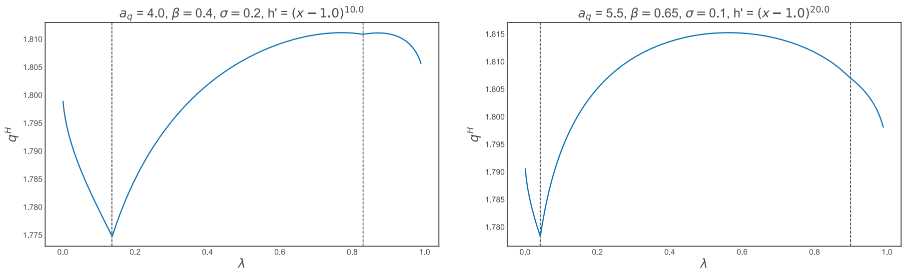
Figure I.5: p^H as a function of q^H for different values of λ

(a) Whole picture **(b) Zoomed in**



Note: The figure shows p^H as a function of q^H for equations (2.30) and (2.31) for different values of λ. The remaining parameters are set as follows: $a_q = 1.0$, $\beta = 0.5$, and $\sigma = 1.0$.

Figure I.6: q^H as a function λ



Note: The figure shows the equilibrium values of q^H for $\hat{I} < \bar{\omega}$ in proposition 1. The dashed lines indicate the changes to a different case. The specification of the parameters is indicated in the figures.

Table I.1: Robustness results: Distance

Dependent variable in t:	Growth t to $t+1$ in export quality				Growth t to $t+1$ in GDP per capita			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log export quality	-0.76***	-0.77***	-0.56***	-0.60***				
	(0.01)	(0.01)	(0.01)	(0.01)				
Log GDP per capita					-0.11***	-0.49***	-0.08***	-0.45***
					(0.02)	(0.05)	(0.01)	(0.04)
Openness	-0.01	-0.01**	0.01	0.01	-0.05	0.09	0.01	-0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.09)	(0.15)	(0.30)
Inequality	-0.26*	0.90***	-0.90***	0.21	0.26	0.02	-0.00	-0.40
	(0.14)	(0.16)	(0.23)	(0.17)	(0.17)	(0.62)	(0.28)	(1.06)
Distance	-0.27***		-0.11		0.21		0.40**	
	(0.07)		(0.09)		(0.23)		(0.18)	
Openness × Inequality	0.03	0.07***	-0.02	0.01	0.14	-0.32	0.04	-0.28
	(0.02)	(0.02)	(0.04)	(0.02)	(0.12)	(0.22)	(0.41)	(0.81)
Openness × Distance	0.04***	0.06***	0.03**	0.03***	0.09	0.34**	0.12	0.36
	(0.01)	(0.00)	(0.01)	(0.00)	(0.11)	(0.16)	(0.17)	(0.31)
Inequality × Distance	-0.23	-0.90***	0.07	-0.28***	-0.61	0.00	-0.89*	0.28
	(0.17)	(0.05)	(0.24)	(0.05)	(0.54)	(1.27)	(0.46)	(1.31)
Openness × Inequality × Distance	-0.10***	-0.17***	-0.07*	-0.09***	-0.22	-0.49	-0.33	-0.38
	(0.03)	(0.01)	(0.04)	(0.01)	(0.27)	(0.40)	(0.45)	(0.85)
Control variables	Yes	No	Yes	No	Yes	No	Yes	No
Industry × Year FE	Yes	Yes	Yes	Yes	No	No	No	No
Year FE	No	No	No	No	Yes	Yes	Yes	Yes
Country FE	No	Yes	No	Yes	No	Yes	No	Yes
Key coefficient	-0.07	-0.10	-0.09	-0.08	-0.08	-0.81	-0.29	-0.67
Wald test	0.00	0.00	0.00	0.00	0.76	0.02	0.14	0.01
Observations	95211	121769	59690	80615	379	486	334	425

Note: The specifications are the same as in table 2.2, except for the measure of Distance. The first two columns use a dummy variable indicating whether the export quality of an industry was amongst the lower 50% in the year 2000. Columns (3) and (4) again use 75% as the threshold but use 1985 as the reference year. Columns (5) to (8) repeat the exercise using GDP per capita and the country level data. Note that the industry level results are robust to defining the distance measure at the country level as well.

Table I.2: Robustness results: Openness

Dependent variable in t:	Growth t to $t+1$ in export quality				Growth t to $t+1$ in GDP per capita			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log export quality	-0.73***	-0.74***	-0.73***	-0.74***				
	(0.01)	(0.01)	(0.01)	(0.01)				
Log GDP per capita					-0.08***	-0.49***	-0.09***	-0.49***
					(0.01)	(0.05)	(0.01)	(0.05)
Openness	0.02	0.28***	-0.00	-0.02***	0.36**	-0.10	-0.03	
	(0.04)	(0.03)	(0.01)	(0.01)	(0.14)	(0.16)	(0.29)	
Inequality	-0.43***	1.37***	-0.41*	1.27***	1.17***	-0.99	0.09	-1.64
	(0.11)	(0.12)	(0.22)	(0.17)	(0.35)	(0.70)	(0.49)	(1.03)
Distance	-0.52***		-0.24***		0.53***		0.09	
	(0.05)		(0.08)		(0.14)		(0.19)	
Openness × Inequality	-0.02	-0.66***	0.01	0.08***	-0.92**	0.54	0.20	2.82
	(0.12)	(0.07)	(0.04)	(0.02)	(0.40)	(0.43)	(0.79)	(2.04)
Openness × Distance	0.11**	-0.26***	0.03**	0.05***	-0.29*	0.28	0.37	
	(0.05)	(0.02)	(0.01)	(0.00)	(0.17)	(0.18)	(0.51)	
Inequality × Distance	0.44***	-0.83***	-0.25	-0.89***	-1.33***	3.03***	-0.15	4.46***
	(0.12)	(0.03)	(0.24)	(0.07)	(0.37)	(0.81)	(0.52)	(1.20)
Openness × Inequality × Distance	-0.28**	0.65***	-0.08**	-0.12***	0.76*	-0.96**	-0.97	-8.71**
	(0.13)	(0.06)	(0.04)	(0.01)	(0.46)	(0.46)	(1.22)	(3.96)
Control variables	Yes	No	Yes	No	Yes	No	Yes	No
Industry × Year FE	Yes	Yes	Yes	Yes	No	No	No	No
Year FE	No	No	No	No	Yes	Yes	Yes	Yes
Country FE	No	Yes	No	Yes	No	Yes	No	Yes
Key coefficient	-0.30	-0.01	-0.08	-0.04	-0.16	-0.41	-0.77	-5.89
Wald test	0.00	0.92	0.00	0.02	0.47	0.06	0.44	0.09
Observations	95211	121769	96136	124441	379	486	379	486

Note: The specifications are the same as in table 2.2, except for the measure of Openness. Instead of using the continuous measure of the import share, we use a binary variable indicating whether the industry openness is amongst the higher 75% (columns (1) and (2)). In columns (3) and (4), we take the industry's import share in the year 2000 instead of the yearly import share. Columns (5) to (8) repeat the exercise using the country level data. Columns (5) and (6) show the results using a binary variable indicating whether the country's import share is amongst the highest 50%. We use the 50% threshold in order to avoid multicollinearity of the interaction terms. Using the 75% threshold and omitting openness does not substantially change the results. The last two columns use the country's import share in the year 2000. Note that for all specifications using the the year 2000 as the reference year we could use 1985 (the first year in our dataset) instead and the results remain robust and become even more clear.

Table I.3: Robustness results: Inequality

Dependent variable in t:	Growth t to $t+1$ in export quality				Growth t to $t+1$ in GDP per capita			
Inequality measure in t:	Top 20%		Top 10%		Top 20%		Top 10%	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log export quality	-0.75***	-0.77***	-0.75***	-0.77***				
	(0.01)	(0.01)	(0.01)	(0.01)				
Log GDP per capita					-0.09***	-0.48***	-0.09***	-0.47***
					(0.02)	(0.10)	(0.02)	(0.10)
Openness	0.04	-0.01	0.03	-0.02*	-0.09	0.35	-0.06	0.18
	(0.02)	(0.01)	(0.02)	(0.01)	(0.14)	(0.81)	(0.11)	(0.54)
Inequality	-0.58*	0.71***	-0.57	1.08***	0.64	-2.17	0.65	-1.79
	(0.33)	(0.21)	(0.36)	(0.22)	(0.76)	(2.00)	(0.96)	(2.30)
Distance	-0.47***		-0.45***		0.41		0.29	
	(0.16)		(0.12)		(0.32)		(0.25)	
Openness ×	-0.06	0.06**	-0.06	0.11***	0.15	-0.88	0.12	-0.75
Inequality	(0.05)	(0.03)	(0.06)	(0.03)	(0.37)	(2.11)	(0.46)	(2.24)
Openness ×	-0.01	0.03***	-0.01	0.03***	0.13	-0.01	0.09	0.03
Distance	(0.03)	(0.01)	(0.02)	(0.00)	(0.17)	(0.82)	(0.13)	(0.55)
Inequality ×	0.04	-0.89***	0.00	-1.29***	-0.79	0.70	-0.79	0.45
Distance	(0.34)	(0.07)	(0.38)	(0.11)	(0.82)	(2.04)	(1.02)	(2.36)
Openness ×	-0.01	-0.09***	-0.01	-0.15***	-0.25	0.25	-0.21	0.20
Inequality × Distance	(0.06)	(0.02)	(0.06)	(0.02)	(0.41)	(2.14)	(0.50)	(2.28)
Control variables	Yes	No	Yes	No	Yes	No	Yes	No
Industry × Year FE	Yes	Yes	Yes	Yes	No	No	No	No
Year FE	No	No	No	No	Yes	Yes	Yes	Yes
Country FE	No	Yes	No	Yes	No	Yes	No	Yes
Key coefficient	-0.07	-0.03	-0.07	-0.04	-0.10	-0.63	-0.09	-0.56
Wald test	0.00	0.22	0.01	0.14	0.53	0.02	0.58	0.06
Observations	53301	60115	53301	60115	222	234	222	234

Note: The specifications are the same as in table 2.2, except for the measure of Inequality. Instead of the Gini index, we use the income share earned by the top 10% or the top 20%, respectively.

Chapter 3

Dyadic Value Distance: Determinants and Consequences

Joint with Stefan Legge and Lukas Schmid

3.1 Introduction

The recent literature in economics has provided mounting evidence that culture matters for economic outcomes (Alesina and Giuliano, 2015; Guiso, Sapienza and Zingales, 2006). While earlier research emphasized the role of cultural variables for economic outcomes within a country (Alesina and Giuliano, 2010; Eugster et al., 2011), a more recent literature has put forward the impact of *bilateral* cultural differences between countries as a determinant of several economic outcomes, including technology diffusion (Spolaore and Wacziarg, 2009), fertility choice (Spolaore and Wacziarg, 2016*b*), conflict (Spolaore and Wacziarg, 2016*c*), and trade (Fensore, Legge and Schmid, 2017). An important channel through which cultural differences affect economic and social relationships is the degree to which values differ between two populations.

This paper intents to examine this effect by using the World Values Survey (WVS) to establish the dyadic value distance (DVD) as a measure of bilateral differences in values.[74] We demonstrate that DVD is closely associated with geographic distance as well as with genetic distance, a commonly used measure for the historical relatedness of populations across the globe. In addition, we apply our measure of value distance to a specific research question and test how much of the variation in current income levels can be accounted for by differences in values. The estimates document a close association between cross-country differences in value distance and differences in income.

Our work is related to prior studies finding evidence that differences in values can have direct and indirect effects on economic development (Harutyunyan and Özak, 2017). For the direct effects, Dohmen et al. (2016) find that patience matters for the accumulation of physical and human capital. The indirect (or barrier) effect is supported by Spolaore and Wacziarg (2009) who argue that genetic distance — which captures differences in values, norms, and habits — has affected the historical spread of technology. We complement this evidence by documenting that various dimensions of value differences help explain the variation in GDP per capita across countries, most prominently a society's openness to new ideas and immigration, the attitude towards freedom versus equality, as well as work ethics. This contributes to Becker, Enke and Falk (2018) who show that specific values, such as risk aversion, altruism, reciprocity, and trust, are related to a population's ancestry. More broadly, our work adds to the literature on the importance of values and norms for a variety of social and economic outcomes, including smoking behavior, educational choices, and political preferences (Alesina and Giuliano, 2014; Galor and Özak, 2016).

3.2 Data

The data set that we use in this study is based on three sources: the World Values Survey (WVS), information on bilateral genetic distance, and numerous

[74] The data set on dyadic value distance is available from the authors.

country-specific and bilateral variables. The latter two sources are relevant for the analysis of determinants and consequences of value differences. To measure differences in values, we use the longitudinal data set of the nationally representative World Values Survey. This data set includes answers from all six waves that were conducted between 1981 and 2014. It covers 95 countries, although not all countries were included in each wave. Our analysis is based on a total of 857 questions. In addition, we provide value differences in 19 categories that we will describe later.[75]

We complement our dataset with data on genetic distances from Spolaore and Wacziarg (2018) who argue that genetic distance is a measure of ancestral distance that captures a multitude of characteristics including differences in habits, customs, beliefs, norms, and conventions. One can consider genetic distance as a summary statistic for intergenerationally transmitted traits across populations. The study by Spolaore and Wacziarg (2016*a*) confirms this intuition by showing that although measures of cultural distance are poorly correlated to another, genetic distance is positively correlated to all of them. The data on genetic distance provided by Spolaore and Wacziarg (2018) is based on 267 populations defined by Pemberton, DeGiorgio and Rosenberg (2013) as well as ethnic compositions compiled by Alesina et al. (2003). While all people in the world share the same gene variants (alleles), the frequencies differ across populations. When populations split apart, genes start to change due to random drift or natural selection. Assuming drifts are constant, measured genetic distance can be thought of as a molecular clock. In other words, genetic distance provides us with an approximate time since the populations of two countries were the same population.

Finally, we enrich our data set with detailed economic and geographic information at the country-level. This includes data on GDP and population size for each country. As primary source, we use the Penn World Table 9.0 (PWT), for which we take into account the most recent update by Feenstra, Inklaar and Timmer (2015).[76] We also add geographic information to our data set from CEPII.

[75] In the appendix, we provide an overview of the country coverage for each wave in table J.1. Furthermore, table J.2 provides detailed information on which questions we use for each category. We also indicate the coverage of the survey for each question.

[76] Note that the PWT database does not cover Lybia. Thus, we use the World Development

This comprises both information for each country as well as bilateral variables. The former includes each country's location in terms of latitude and longitude, island status, as well as a dummy for being landlocked. The bilateral variables provide information on contiguity as well as access to the same sea. Overall, we have 90 countries in our data set. Hence, there are $(90 \times 89)/2 = 4{,}005$ bilateral observations.[77]

3.3 Dyadic Value Distance

Drawing on answers to the World Values Survey (WVS), we develop a measure of bilateral value distance. We build upon Desmet et al. (2011) as well as Spolaore and Wacziarg (2016*a*) and compute the average Manhattan distance in answers of the World Value Survey between countries.[78] Hence, we measure the distance for two countries i and j for a given question x by

$$w_{i,j,x} = \sum_{s=1}^{q} |x_i^s - x_j^s| \tag{3.1}$$

where x^s is the share of people choosing answer option s to question x, such that $\sum_{s=1}^{q} x_i^s = 1$ when q denotes the number of possible answers. Using this metric, we take into account the structure of each question. To obtain a dyadic measure of differences in values, we aggregate the measure in equation (3.1) over all N questions in the WVS to get

$$w_{i,j} = \frac{1}{N} \sum_{x=1}^{N} w_{i,j,x} \tag{3.2}$$

Indicators as secondary data source to predict the missing GDP. This procedure insures that the GDP (per capita) values are comparable even if they stem from different sources.

[77] We provide descriptive statistics on the data set as well as raw correlations between measures of genetic and value distance in table J.3 in the appendix. Note that data on genetic distance is missing for Andorra, Puerto Rico, Tanzania, Yemen, as well as former Yugoslavia.

[78] The measure by Desmet et al. (2011) is similar in its calculation but limited to 430 questions from four WVS waves. The value differences computed by Spolaore and Wacziarg (2016*a*) are based on 74 countries and 98 questions from both the WVS and the European Values Study. Comparing their variables with ours, we find a correlation of 0.67 to 0.89 for the relative and simple value distance, respectively.

as the average absolute distance in values. When exploring the effect of ancestry on technology diffusion, Spolaore and Wacziarg (2018) argue that the *relative* genetic distance to the technological frontier, the United States, rather than the bilateral distance affects technological differences. Therefore, we compute the relative distance in values to the United States between two countries as

$$r_{i,j,x} = |w_{i,US,x} - w_{j,US,x}| \tag{3.3}$$

for each question x. Again, we can aggregate to have an overall measure of value distance for each country pair to obtain

$$r_{i,j} = \frac{1}{N} \sum_{x=1}^{N} r_{i,j,x} \tag{3.4}$$

which denotes the relative value distance to the United States between countries i and j. The proposed measure avoids that the direct bilateral and the relative distances coincide, except for some special cases such as for questions with binary answer options and where x^1_{US} is larger or smaller than both x^1_i and x^1_j. In this case, $w_{i,j,x}$ and $r_{i,j,x}$ are the same.

— Figure 3.1 about here —

The simple dyadic value distances, $w_{i,j}$, appear to follow closely a normal distribution as documented in figure 3.1. The largest distance is between El Salvador and Sweden with a value of 0.210, the smallest is between Belarus and Ukraine with a value of 0.038. To illustrate dyadic value distances for a single country, let us consider the United States for which we depict the bilateral distance to each country in figure J.1 in the appendix. The data shows that in terms of values, the United States is closest to Canada (distance of 0.054) and Australia (0.060), while Morocco (0.149) and Egypt (0.151) are most distant. The map in figure J.1 in the appendix hints at two hypotheses on the determinants of value differences. First, countries that are geographically close have, on average, smaller differences in values. Second, the historical relatedness of populations matters for how different values are between current nations. We explore both hypotheses in the next section in the context of our full data set.

3.4 Determinants of Dyadic Value Distance

The literature in economics has defined culture as a set of beliefs and values that ethnic, religious, and social groups transmit from generation to generation (Guiso, Sapienza and Zingales, 2006). We understand dyadic value distances as a measure of cultural differences. Hence, we want to understand the origins of these differences by exploring two important determinants, namely geography and ancestral distance. The geographic distance between two countries is likely to affect value differences in at least two ways. First, migration between geographically close countries is very likely and thus changes a population's composition. This compositional change directly reduces value differences between countries with high migration flows. Second, geographically close countries are more likely to socially and economically interact with each other. These interactions in turn might translate into a convergence of values between countries. Panel (a) in figure 3.2 lends support to the conjecture that geographic and dyadic value distance are positively related.

— Figure 3.2 about here —

A second potential determinant of value differences is ancestral distance, a measure that captures the relatedness of populations. As values are transmitted from generation to generation, we expect that countries that share more recent common ancestors are more likely to have smaller differences in values. Panel (b) of figure 3.2 provides evidence for this hypothesis by depicting that countries with a larger ancestral distance also have a larger discrepancy in answers to the WVS. This relationship is robust to including fixed effects for countries in the regression equation.

— Table 3.1 about here —

To further explore the factors that explain differences in values, table 3.1 shows the result of six regressions. We find that genetic distance is positively and highly significantly correlated with our measure of dyadic value distance, even when controlling for a large set of geographic variables. Following column (6), a one standard deviation increase in genetic distance raises differences in values by 11% of a standard deviation. The strong correlation between genetic distance and our measure of value differences is in line with Harutyunyan and Özak (2016) who find that some of the cultural dimensions of Hofstede, Hofstede and Minkov (2010) such as individualism and long-term orientation correlate with genetic distance.

3.5 Consequences of Dyadic Value Distance

The previous section has documented that values are closely related to geographic and ancestral distance. Yet, what are the consequences of value differences between countries? In what follows, we provide evidence of a statistical association between dyadic value distance and economic development. Previous research suggests two potential channels for this effect. First, cultural differences can operate as a barrier to the adoption of new technologies. Spolaore and Wacziarg (2009) show that the diffusion of economic development has been shaped by the relatedness of populations in terms of norms, habits, and values.[79] A second channel is based on the idea that certain cultural traits, such as patience, directly affect economic development (Dohmen et al., 2016; Galor and Özak, 2016). To explore whether value differences help explain differences in current income levels, we introduce our measure of value distance into a gravity model:

$$\Delta Y_{i,j} = \beta_1 DVD_{i,j} + \beta_2 GD_{i,j} + \mathbf{X}_{i,j}\boldsymbol{\beta} + \varepsilon_{i,j} \qquad (3.5)$$

where the left-hand side, $\Delta Y_{i,j} = |Y_i - Y_j|$, denotes the absolute difference in log GDP per capita between country i and j in the year 2010. Our focus is on the estimated parameters $\hat{\beta}_1$ and $\hat{\beta}_2$ which indicate the effect of dyadic value distance

[79] Spolaore and Wacziarg note that studying the specific microeconomic mechanisms through which the effects operate is left for future research: "What traits are captured by genetic distance? We argue that, by its very definition, genetic distance is an excellent *summary statistic* capturing divergence in the whole set of implicit beliefs, customs, habits, biases, conventions, etc. that are transmitted across generations–biologically and/or culturally–with high persistence." (Spolaore and Wacziarg, 2009, p.471).

and genetic distance, respectively. Note that we can use either the simple distance between i and j or the relative distance to the United States. Furthermore, we add a vector of control variables denoted by $\mathbf{X}_{i,j}$ which includes geographic distance, common border, differences in latitude and longitude, access to the same sea, as well as dummy variables for island and landlocked status. We follow Cameron, Gelbach and Miller (2011) as well as Egger and Tarlea (2015) and cluster the standard error ($\varepsilon_{i,j}$) at the country-pair level.

— Table 3.2 about here —

The results of table 3.2 show that both genetic distance and our measure of value distance are significantly correlated with bilateral income differences. Column (1) documents that increasing the relative value distance raises the gap in current income levels. The estimate in column (2) suggests that genetic distance relative to the United States affects current levels of GDP per capita as suggested by Spolaore and Wacziarg (2009). When including both measures of value as well as genetic distance in column (3), we find that our measure for dyadic value distance reduces the effect of genetic distance by 2.9%. We obtain similar results when using the simple value and genetic distance. In column (6), the effect of genetic distance is reduced by 7.0% once we include our measure of value differences. Furthermore, the R^2 increases from 0.167 to 0.226 (or from 0.195 to 0.281 for the simple distances). The estimates of table 3.2 support both channels through which value differences affect economic development. In line with Harutyunyan and Özak (2016, 2017), the point estimates suggest that value differences across countries can (i) directly affect income levels and (ii) work as a barrier to the adoption of new technology. To illustrate the magnitude of the coefficients, we report the standardized beta coefficients. These are defined as the effect of a one-standard-deviation change in the regressor, expressed as a percentage of one standard deviation of the dependent variable. For the relative value distance, we obtain a standardized beta of about 23.2%. In comparison, we find a similar standardized beta of 22.4% for the relative genetic distance. These estimates are comparable in magnitude to the impact of linguistic and religious distance for which Spolaore and Wacziarg (2009) find a standardized beta of 15.1% and

20.2%, respectively.

A potential concern for the validity of these estimates is that our measure of dyadic value distance makes use of all 857 questions asked in the World Values Survey. This could bias the results if some questions are only asked in selected regions. To probe the robustness of our results to the set of questions included, we restrict our analysis to those questions that are asked in all 90 countries. Table J.4 in the appendix reveals that we obtain very similar results using a reduced set of questions.

— Figure 3.3 about here —

To explore which specific values affect the diffusion of technology, we use our bilateral measures on specific value distances. Figure 3.3 shows that differences in values such as openness to new ideas and migration are key determinants of economic development. It is important to bear in mind that such differences in values may have a direct effect on economic development but also work as a barrier to the adoption of knowledge (Harutyunyan and Özak, 2017). For instance, if openness to migration positively affects economic prosperity, ceteris paribus, two countries with a similar attitude towards immigration would have a similar income level. The results are reported in Panel (a) of figure 3.3 that depicts the impact of the relative dyadic value distance, namely how similar two countries' values are relative to the United States. We find that mainly openness to new ideas, the attitudes towards fate versus control, immigration openness, as well as attitudes towards freedom versus equality lower the distance in terms of economic development between countries. As for the the simple value differences, the results of Panel (b) suggest that hedonism, immigration openness, and work ethics are decisive values.

3.6 Conclusion

In this paper, we develop a measure of dyadic value distance for a large set of countries. We explore the determinants of bilateral value distances by linking it to geography as well as the historic relatedness of populations across the world. Our analysis reveals that geographically closer countries have, on average, a smaller value distance. Furthermore, the results provide evidence that countries which are historically more closely related – measured by genetic distance – exhibit smaller differences in values. These findings shed light on the spread of values across generations and space. In addition, we document the consequences of value differences for economic outcomes. The inclusion of value distance in a regression of economic development on ancestral distance improves our understanding of current differences in income levels across countries. In line with Spolaore and Wacziarg (2009), our estimation results suggest that value differences are associated with the global diffusion of economic development. Following Harutyunyan and Özak (2017), we also provide evidence that differences in values can have both direct and indirect effects on current income levels.

Our work complements recent efforts exploring cultural determinants of economic outcomes. Thus far, researchers have primarily focused on the consequences of culture at the individual level due to a lack of aggregate data on cultural differences. This paper adds to the literature by providing a comprehensive measure of cultural differences from nationally representative surveys. Future research may shed further light on the mechanisms through which culture affects economic outcomes. This work will benefit from the availability of data on bilateral differences in values and preferences. In addition to our measure of dyadic value distance, the work by Falk et al. (2018) on the Global Preference Survey will enable researchers to better understand how culture, values, and preferences shape economic development.

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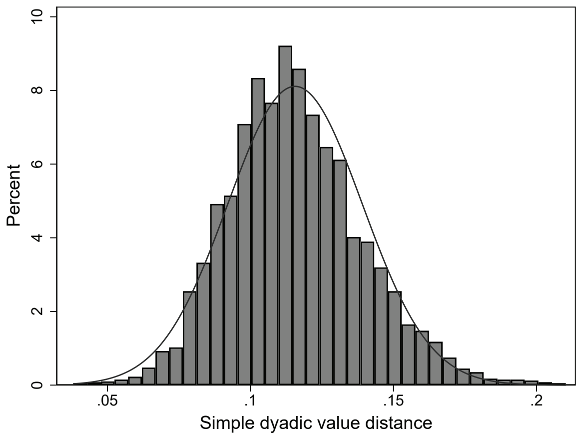
Figures and Tables

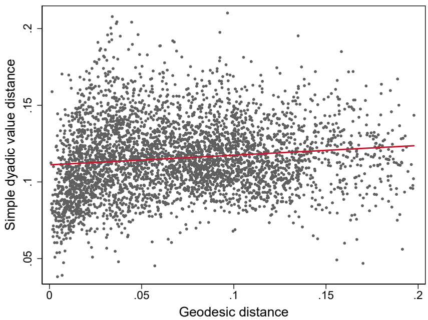
Figure 3.1: Distribution of simple dyadic value distance



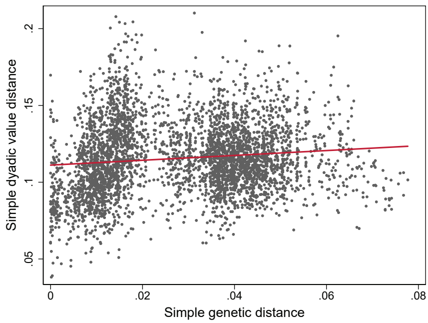
Note: The figure plots the distribution of the mean simple bilateral distances in answers to the World Value Surveys. A normal distribution is added to the figure.

Figure 3.2: Dyadic values distance and geographic as well as genetic distance

(a) Geographic distance



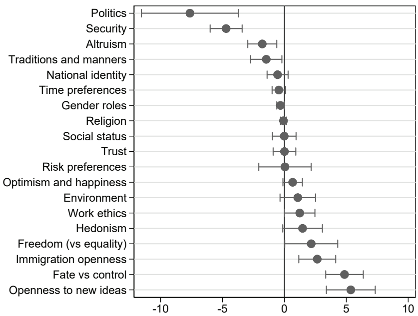
(b) Ancestral distance



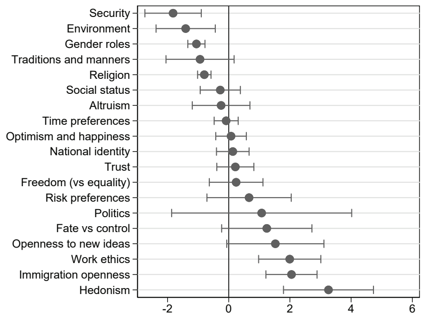
Note: The figure in part (a) plots the relationship between differences in values and geographic distance. Part (b) shows the relationship between differences in values and ancestral distance. Each dot reflects one country pair and a linear fit is added. Both relationships are highly statistically significant.

Figure 3.3: Differences in GDP p.c. and components of dyadic value distance

(a) Relative dyadic value distance



(b) Simple dyadic value distance



Note: The figure plots the estimated coefficients and their 95% confidence interval for the constructed variables listed in table J.2, derived from re-estimating models (2) and (4) of table 3.2 including these variables as additional regressors. The figure shows which WVS differences components can explain differences in GDP per capita, given genetic distance and the mean in WVS differences over all components. The components are further described in table J.2. Panel (a) shows results for the relative differences in WVS, while panel (b) shows the results for the simple differences in WVS.

Table 3.1: Determinants of dyadic value distance

Dependent variable:	Dyadic value distance					
	Relative distance			Simple distance		
	(1)	(2)	(3)	(4)	(5)	(6)
Relative genetic distance	0.06***		0.04*			
	(0.02)		(0.02)			
Simple genetic distance				0.16***		0.11***
				(0.02)		(0.03)
Geodesic distance		-0.13***	-0.13***		-0.03	-0.07***
		(0.02)	(0.02)		(0.02)	(0.02)
Common border		-0.01***	-0.01***		-0.03***	-0.03***
		(0.00)	(0.00)		(0.00)	(0.00)
Add. geographic controls	No	Yes	Yes	No	Yes	Yes
Observations	4005	4005	4005	4005	4005	4005
R^2	0.002	0.105	0.106	0.013	0.071	0.075

Note: The table shows the result of six separate regressions using dependent variables as indicated in the top row. The sample includes all 90 countries. Geodesic distance is re-scaled, measured in 100'000 km to improve readability. The additional controls include differences in latitude and longitude, as well as dummies for being an island, landlocked and having access to the same sea. Standard errors are clustered at the country pair level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***.

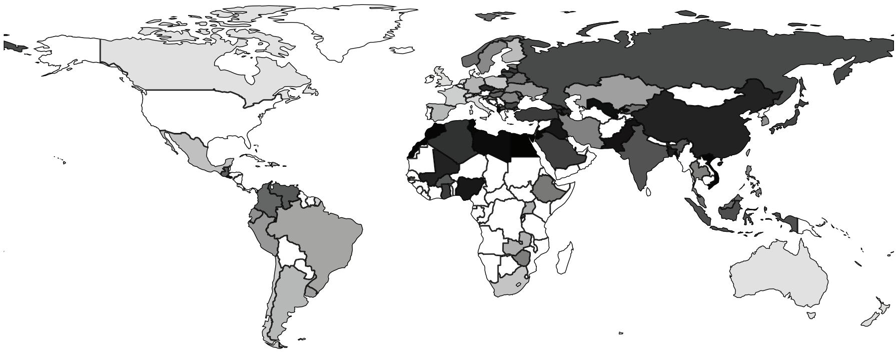
Table 3.2: Regression results

Dependent variable:	Difference in per capita GDP					
	(1)	(2)	(3)	(4)	(5)	(6)
Relative dyadic value distance	16.68***		16.25***			
	(0.88)		(0.84)			
Relative genetic distance		20.36***	19.76***			
		(1.30)	(1.23)			
Simple dyadic value distance				12.06***		11.35***
				(0.52)		(0.50)
Simple genetic distance					18.12***	16.86***
					(0.87)	(0.81)
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4005	4005	4005	4005	4005	4005
R^2	0.174	0.167	0.226	0.209	0.195	0.281

Note: The table shows the result of six separate regressions using the absolute value of the difference in log GDP per capita between two countries as dependent variable. The sample includes all 90 countries for which we have data on genetic distance. Control variables include differences in latitude and longitude, geodesic distance as well as dummies for being an island, landlocked, sharing a common border and having access to the same sea. Standard errors are clustered at the country pair level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***.

Appendix J: Additional Figures and Tables

Figure J.1: Dyadic value distance for the United States



Note: The figure shows the dyadic value distance of the United States to 89 other nations. Countries for which there is no data available are left white. Brighter (darker) colors indicate smaller (higher) distances in values.

Table J.1: Countries in the sample and coverage in WVS

Country	WVS waves	Country	WVS waves	Country	WVS waves
Albania	3, 4	Algeria	4, 6	Argentina	1, 2, 3, 4, 5, 6
Armenia	3, 6	Australia	1, 3, 5, 6	Azerbaijan	3, 6
Bahrain	6	Bangladesh	3, 4	Belarus	2, 3, 6
Brazil	2, 5, 6	Bulgaria	3, 5	Burkina Faso	5
Canada	4, 5	Chile	2, 3, 4, 5, 6	China	2, 3, 4, 5, 6
Colombia	3, 5, 6	Croatia	3	Cyprus	5, 6
Czech Republic	2, 3	Dominican Republic	3	Ecuador	6
Egypt	4, 5, 6	El Salvador	3	Estonia	3, 6
Ethiopia	5	Finland	1, 3, 5	France	5
Georgia	3, 5, 6	Germany	3, 5, 6	Ghana	5, 6
Guatemala	5	Hong Kong	5, 6	Hungary	1, 3, 5
India	2, 3, 4, 5, 6	Indonesia	4, 5	Iran	4, 5
Iraq	4, 5, 6	Israel	4, 6	Italy	5
Japan	1, 2, 3, 4, 5, 6	Jordan	4, 5, 6	Kazakhstan	6
Korea	1, 2, 3, 4, 5, 6	Kuwait	6	Kyrgyzstan	4, 6
Latvia	3	Lebanon	6	Libya	6
Lithuania	3	Macedonia	3, 4	Malaysia	5, 6
Mali	5	Mexico	1, 2, 3, 4, 5, 6	Moldova	3, 4, 5
Morocco	4, 5, 6	Netherlands	5, 6	New Zealand	3, 5, 6
Nigeria	2, 3, 4, 6	Norway	3, 5	Pakistan	3, 4, 6
Peru	3, 4, 5, 6	Philippines	3, 4, 6	Poland	2, 3, 5, 6
Qatar	6	Romania	3, 5, 6	Russian Federation	2, 3, 5, 6
Rwanda	5, 6	Saudi Arabia	4	Singapore	4, 6
Slovakia	2, 3	Slovenia	3, 5, 6	South Africa	1, 2, 3, 4, 5, 6
Spain	2, 3, 4, 5, 6	Sweden	3, 5, 6	Switzerland	2, 3, 5
Taiwan	3, 5, 6	Thailand	5, 6	Trinidad and Tobago	5, 6
Tunisia	6	Turkey	2, 3, 4, 5, 6	U.S.A	3, 4, 5, 6
Uganda	4	Ukraine	3, 5, 6	United Kingdom	3, 5
Uruguay	3, 5, 6	Uzbekistan	6	Venezuela	3, 4
Vietnam	4, 5	Zambia	5	Zimbabwe	4, 6

Note: The table shows the set of 90 countries which participated in at least one wave of the World Values Survey (WVS). We indicate in which waves each country participated. There were a total of six waves between 1981 and 2014.

Table J.2: Categories of WVS questions

Category	Questions	Waves	# Countries
Trust	A165, D001, D001_B	1,2,3,4,5,6	90
Time preferences	A038	1,2,3,4,5,6	90
Work ethics	A005, A030, C038, C039, C040, E040	1,2,3,4,5,6	90
Traditions and manners	A196, A198, B016	3,5,6	86
Immigration openness	C002, E143, G032	2,3,4,5,6	85
Openness to new ideas	A189	5,6	75
Social status	A190, A194, C011, C014	1,2,3,4,5,6	87
Altruism	A193, A199, E129, E129C	4,5,6	81
Risk preferences	A195	5,6	75
Freedom (vs equality)	E010, E032, E035	2,3,4,5,6	90
Security	A191, H001	5,6	75
Hedonism	A003, A192	2,3,4,5,6	90
Optimism and happiness	A170, B017	1,2,3,4,5,6	90
Politics	E039	2,3,4,5,6	89
National identity	E012, G006	1,2,3,4,5,6	90
Religion	F050	1,2,3,4,6	77
Fate vs control	F198	5	47
Gender roles	C001	2,3,4,5,6	90
Environment	A197, B008	3,4,5,6	90

Note: The table shows the 19 categories of questions based on the World Values Survey (WVS). Columns 3 and 4 indicate in which waves and in how many countries each question was included in the survey.

Table J.3: Descriptive statistics

PANEL A: SUMMARY OF THE VARIABLES

Variable	Mean	Std. dev.	Min.	Max.	N
Part I: Cultural distance variables:					
Simple dyadic value distance	0.12	0.02	0.04	0.21	4,005
Relative dyadic value distance	0.07	0.01	0.03	0.15	4,005
Simple genetic distance	0.03	0.02	0.00	0.08	4,005
Relative genetic distance	0.01	0.01	0.00	0.04	4,005
Part II: Country-level variables:					
GDP (billion USD)	950.98	2,221.65	14.18	15,273.33	90
Population (milions)	67.59	193.09	0.83	1,340.97	90
GDP per capita (thousand USD)	21.73	21.27	1.09	148.52	90
Part III: Bilateral variables:					
Geodesic distance (in 1000 km)	7.04	4.54	0.08	19.77	4,005
Common border	0.03	0.16	0.00	1.00	4,005
Landlocked (none, one, both)	0.42	0.57	0.00	2.00	4,005
Access to same sea	0.14	0.35	0.00	1.00	4,005
Island (none, one, both)	0.24	0.46	0.00	2.00	4,005
Difference in latitude	28.04	22.16	0.01	106.29	4,005
Difference in longitude	65.86	53.35	0.02	284.46	4,005

PANEL B: CORRELATION OF MAIN VARIABLES

	Simple DVD	Relative DVD	Simple GenDist	Relative GenDist
Simple DVD	1.00			
Relative DVD	0.79	1.00		
Simple GenDist	0.11	0.03	1.00	
Relative GenDist	0.13	0.05	0.70	1.00

Note: There are 90 countries in our sample, and therefore we have $(90 \times 89)/2 = 4{,}005$ bilateral observations. GDP is measured as real GDP at constant 2011 national prices in 2011 US Dollars. GDP and population are both for the year 2010 and stem from the Penn World Tables 9.0. Data on Libya are not available in the PWT, and therefore we impute these values using the World Bank World Development Indicators.

Table J.4: Regression results with questions from all countries

Dependent variable:	Difference in per capita GDP					
	(1)	(2)	(3)	(4)	(5)	(6)
Relative dyadic value distance	17.29***		16.14***			
	(0.84)		(0.82)			
Relative genetic distance		20.36***	18.29***			
		(1.30)	(1.24)			
Simple dyadic value distance				10.69***		9.60***
				(0.43)		(0.41)
Simple genetic distance					18.12***	15.43***
					(0.87)	(0.80)
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4005	4005	4005	4005	4005	4005
R^2	0.193	0.167	0.237	0.226	0.195	0.285

Note: The table shows the result of six separate regressions using the absolute value of the difference in log GDP per capita between two countries as dependent variable. As in table 3.2, the sample includes all 90 countries for which we have data on genetic distance. However, dyadic value distances are computed using only those 50 questions that are asked in all countries. Control variables include differences in latitude and longitude, geodesic distance as well as dummies for being an island, landlocked, sharing a common border and having access to the same sea. Standard errors are clustered at the country pair level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***.

Table J.5: Correlations between specific value differences

PANEL A: SIMPLE VALUE DISTANCES

	Total	Alt	Env	Fac	Fre	Gen	Hed	Ide	Imm	Nat	Opt	Pol	Rel	Ris	Sec	Sta	Tim	Tra	Tru	Wor
Total	1.00																			
Alt	0.15	1.00																		
Env	0.18	0.19	1.00																	
Fac	0.36	-0.02	-0.06	1.00																
Fre	0.26	0.06	0.07	0.11	1.00															
Gen	0.49	-0.00	0.14	0.27	0.03	1.00														
Hed	0.37	0.09	0.18	0.30	0.11	0.15	1.00													
Ide	0.22	0.41	0.14	0.07	0.06	-0.00	0.22	1.00												
Imm	0.35	-0.06	0.05	0.13	0.04	0.34	0.03	-0.06	1.00											
Nat	0.36	0.24	0.00	-0.07	0.15	0.07	0.16	0.18	0.16	1.00										
Opt	0.13	0.06	0.00	0.05	0.09	0.03	0.10	0.02	-0.03	0.03	1.00									
Pol	0.51	0.12	0.08	0.40	0.30	0.20	0.20	0.11	0.28	0.35	-0.05	1.00								
Rel	0.41	0.17	-0.05	-0.03	0.10	0.03	0.10	0.15	0.14	0.32	0.02	0.25	1.00							
Ris	0.30	0.19	0.15	0.12	0.12	0.06	0.27	0.44	-0.04	0.23	0.06	0.23	0.14	1.00						
Sec	0.30	0.39	0.12	0.23	0.15	0.17	0.15	0.30	-0.00	0.23	0.03	0.29	0.14	0.23	1.00					
Sta	0.52	0.18	0.09	0.17	0.11	0.22	0.18	0.18	0.08	0.12	0.22	0.13	0.12	0.28	0.18	1.00				
Tim	0.16	0.11	0.07	-0.02	0.12	-0.01	0.08	0.21	-0.02	0.07	0.05	0.08	0.14	0.11	0.05	0.06	1.00			
Tra	0.34	0.36	0.09	0.23	0.16	0.16	0.19	0.31	0.05	0.16	0.31	0.21	0.11	0.30	0.48	0.33	0.06	1.00		
Tru	0.37	0.07	0.03	0.05	0.08	0.11	0.16	0.02	0.22	0.10	-0.01	0.29	0.27	0.10	0.07	0.27	0.03	0.15	1.00	
Wor	0.43	0.03	0.04	0.20	0.19	0.13	0.22	0.10	0.18	0.19	0.11	0.29	0.15	0.11	0.11	0.23	0.03	0.16	0.25	1.00

PANEL B: RELATIVE VALUE DISTANCES

	Total	Alt	Env	Fac	Fre	Gen	Hed	Ide	Imm	Nat	Opt	Pol	Rel	Ris	Sec	Sta	Tim	Tra	Tru	Wor
Total	1.00																			
Alt	0.13	1.00																		
Env	0.17	0.21	1.00																	
Fac	0.38	-0.05	-0.05	1.00																
Fre	0.27	0.12	0.14	0.19	1.00															
Gen	0.48	0.01	0.09	0.30	0.05	1.00														
Hed	0.38	0.01	0.03	0.25	0.09	0.15	1.00													
Ide	0.20	0.26	0.04	0.12	0.10	0.08	0.13	1.00												
Imm	0.26	0.04	0.13	0.14	0.10	0.22	0.03	-0.02	1.00											
Nat	0.23	0.14	0.03	-0.06	0.05	0.01	0.07	0.06	-0.02	1.00										
Opt	0.21	0.02	-0.02	0.03	0.16	-0.00	0.10	-0.02	0.03	0.01	1.00									
Pol	0.25	0.10	0.06	0.20	0.19	0.05	0.16	0.07	0.13	0.19	-0.04	1.00								
Rel	0.26	0.01	-0.02	-0.07	-0.07	-0.06	0.03	-0.05	0.00	0.28	0.02	0.05	1.00							
Ris	0.30	0.12	0.01	0.24	0.16	0.20	0.24	0.49	0.07	0.05	0.09	0.12	-0.02	1.00						
Sec	0.23	0.31	0.12	0.24	0.19	0.23	0.15	0.21	0.15	0.00	-0.01	0.14	-0.12	0.13	1.00					
Sta	0.43	0.09	0.07	0.20	0.10	0.23	0.15	0.28	0.05	0.08	0.13	0.02	-0.06	0.37	0.16	1.00				
Tim	0.14	0.03	0.03	-0.06	0.03	-0.02	0.12	0.02	0.02	0.10	0.05	-0.01	0.18	-0.04	0.00	0.02	1.00			
Tra	0.36	0.23	0.18	0.31	0.21	0.18	0.11	0.19	0.09	0.11	0.20	0.11	0.02	0.24	0.42	0.30	0.08	1.00		
Tru	0.19	0.09	0.08	0.09	0.09	-0.01	0.04	0.06	0.03	0.03	-0.02	0.11	0.02	0.03	0.04	0.02	0.01	0.05	1.00	
Wor	0.38	0.08	0.08	0.22	0.16	0.17	0.18	0.15	0.13	0.07	0.07	0.12	0.02	0.19	0.15	0.24	0.01	0.12	0.16	1.00

Note: The table shows the correlation between 19 specific value differences (and the value distance over all questions). The specific value differences are the categories outlined in table J.2. Abbreviations are as follows: Total: Value Distance; Alt: Altruism; Env: Environment; Fac: Fate vs Control; Fre: Freedom (vs Equality); Gen: Gender roles; Hed: Hedonism; Ide: Openness to new ideas; Imm: Immigration openness; Nat: National identity; Opt: Optimism and happiness; Pol: Politics; Rel: Religion; Ris: Risk preferences; Sec: Security; Sta: Social status; Tim: Time preferences; Tra: Tradition and manners; Tru: Trust; Wor: Work ethics.

Chapter 4

Loss Aversion at the Aggregate Level Across Countries and its Relation to Economic Fundamentals

Joint with Reto Föllmi and Rina Rosenblatt-Wisch

4.1 Introduction

Preferences are important features in macroeconomic modelling. Differences in preferences might correlate with aggregate economic fundamentals. In recent years, differences in preferences across countries and cultures have been studied more frequently. Several papers found differences in preferences across cultures and/ or countries using evidence generated at the micro level, in the form of surveys or experiments (see e.g. Herrmann, Thöni and Gächter, 2008; Rieger, Wang and Hens, 2015; Vieider et al., 2015).

To gain progress in determining whether differences in preferences matter for aggregate outcomes, our paper approaches this from the opposite direction: We start from a purely macroeconomic perspective and test whether preferences, namely, reference point dependence and loss aversion, two key elements of Kahneman and Tversky's prospect theory, vary across countries by only using a macroeconomic time series. To do so, we follow Rosenblatt-Wisch (2008), in which she introduced prospect theory in a stochastic version of the Cass-Koopmans-Ramsey optimal growth model. The preferences of the representative agent in that model are given by the experimentally validated prospect utility function of Kahneman and Tversky (1979) and Tversky and Kahneman (1992). She then tested the model with US data and found evidence of loss aversion in a US macroeconomic time series, in line with the values found by Kahneman and Tversky (1979) and Tversky and Kahneman (1992).

Our contribution is two-fold. First, we test empirically for loss aversion across countries for the aggregate economy. We find that loss aversion prevails at the aggregate level in all countries and that the average degree of loss aversion clearly differs across countries. To check whether these degrees of loss aversion could be explained by micro data, we apply the cultural dimensions constructed by Hofstede, Hofstede and Minkov (2010) and data from the World Values Survey. Because of the large heterogeneity of the data, we find little statistical evidence that either the Hofstede dimensions or the World Values Survey data can explain the cross-country variations in the estimated loss aversion.

Second, we analyse whether the different degrees of loss aversion correlate with economic fundamentals such as GDP and consumption per capita. We find that indeed, according to our analysis, loss aversion is negatively correlated with GDP and consumption per capita and is positively correlated with consumption smoothing. These empirical results are in line with the theoretical ones found by Foellmi, Rosenblatt-Wisch and Schenk-Hoppé (2011).

We concentrate on two key elements of Kahneman and Tversky's experimentally validated prospect theory, namely, reference point dependence and loss aversion. In a recent survey on thirty years of prospect theory, Barberis (2013) notes that the concept of loss aversion relative to a reference point could be promising when thinking about macroeconomics. Focusing on these two aspects of prospect theory, namely, reference point dependence and loss aversion, is common for analysing the aggregate level. Barberis, Huang and Santos (2001) apply these aspects in order to assess the aggregate stock market behaviour, and Benartzi and Thaler (1995) study the equity premium under loss aversion. The paper by Berkelaar, Kouwenberg and Post (2004) uses GMM to estimate loss aversion in the aggregate U.S. stock market. They find an implied loss aversion coefficient of the same size as the one found by Tversky and Kahneman (1992). Kahneman and Tversky (1979) formulated their theory on individual choice under uncertainty. The above-cited papers find loss aversion even in aggregate market data. Brooks and Zank (2005), Kőszegi and Rabin (2006) and Abdellaoui, Bleichrodt and Paraschiv (2007) found experimental evidence of loss aversion at the aggregate level. In addition, loss aversion and thinking in differences have also been found in purely deterministic models (see e.g. Kahneman, Knetsch and Thaler, 1990; Thaler, 1980; Tversky and Kahneman, 1991). Chen, Lakshminarayanan and Santos (2006) find, in an experiment with Capuchin monkeys, that these two behavioural biases even extend beyond species and may be innate, rather than learned.

The rest of the paper is structured as follows. Section 4.2 reviews the model. Section 4.3 discusses the data. Section 4.4 estimates loss aversion across countries, presents the results and tries to explain differences by applying cultural dimensions constructed by Hofstede, Hofstede and Minkov (2010) and/ or data from the World Values Survey. Section 4.5 analyses whether and in what manner differences in loss aversion correlate with economic fundamentals. Section 4.6 then concludes the paper.

4.2 The Model

In the macroeconomic model, we assume a non-time-separable utility function, as inspired by Kahneman and Tversky's prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992). The subsequent empirical section then tests whether loss aversion can be found in macroeconomic time series. For this aim, we will estimate the Euler equation predicted by the non-standard prospect utility function. To apply GMM when estimating the stochastic Euler equation, we assume a parametric form of loss aversion.

In Kahneman and Tversky's prospect theory, agents value their prospects in terms of gains and losses relative to a reference point. They are loss averse, which means that they are more averse to losses than gain seeking on the other hand. Furthermore, they perform subjective, non-linear probability transformations whereby they allot higher weights to small probabilities and lower weights to high probabilities. Kahneman and Tversky originally propose a value function that is concave in the region of gains and convex for losses. The basic idea on how to capture loss aversion is the fact that the value function must be steeper in the loss region.

The setup of our model follows Rosenblatt-Wisch (2008). While this model is influenced by some long-standing ideas derived from the field of psychology, it does not attempt to implement all aspects of prospect theory. The focus lies on loss aversion and on thinking in differences. The value function is linear for losses and gains, with a kink at the reference point. The agent generates utility out of negative or positive changes in consumption. This piecewise-linear approximation and the replacement of subjective probability weighting by objective probabilities is a widely accepted approach, particularly in regard to analysing markets on an aggregate level (see e.g. Aït-Sahalia and Brandt, 2001; Barberis, Huang and Santos, 2001; Berkelaar, Kouwenberg and Post, 2004). Berkelaar, Kouwenberg and Post (2004) deliberately abstract from the power function, since it is difficult to disentangle the effects of loss aversion and risk aversion. For the same reason, they do not apply subjective decision weights.

Taking these thoughts into account, one can define a piecewise-linear prospect utility function:

$$u(\Delta c_t) = \begin{cases} \Delta c_t & \text{if } \Delta c_t \geq 0, \\ \lambda \Delta c_t & \text{if } \Delta c_t < 0, \end{cases} \tag{4.1}$$

where $\Delta c_t = c_t - c_{t-1}$. The individual cares about consumption differences but weighs losses more heavily, with the parameter $\lambda > 1$ capturing loss aversion. Formally, marginal utility is positive everywhere but larger in the loss region:

$0 < \frac{\partial u(\Delta c_t)}{\partial \Delta c_t} < \frac{\partial u(-\Delta c_t)}{\partial(-\Delta c_t)}$ for $\Delta c_t \neq 0$.

In every period, the individual realizes a certain level of consumption and correspondingly a level of the capital stock. This consumption level then becomes the new reference point. Hence, the reference point is dynamically updated: The level realized in every period serves as the new reference point. This choice of the reference point is also in line with the dynamic updating scheme of, e.g., Barberis, Huang and Santos (2001).[80] Benartzi and Thaler (1995) show that the equity premium puzzle with loss averse agents can be explained if these agents monitor the performance of their portfolios every eight months (given a piecewise-linear value function and a loss aversion coefficient of 2.25) or every year (given Tversky and Kahneman's (1992) cumulative prospect theory).

In our analysis, we account for possible sources of psychological influence in the GMM estimations in section 4.4 and run our estimations for different reference-updating horizons, namely, a quarterly, half-yearly and annual updating scheme.

How the reference point is updated exactly is an on-going debate (see e.g. Barberis, 2013). Kőszegi and Rabin (2006, 2007, 2009) developed expectations-based reference-dependent preferences. In their works, agents' expectations form the reference point. In addition, utility is generated not only out of gains and losses but also through levels in consumption. Pagel (2017) recently applied these ideas to a life-cycle consumption model. Gneezy et al. (2017), on the contrary, provide some evidence on the limitation of expectations-based reference dependence. The application of expectations-based reference dependence to a macroeconomic framework like ours would significantly increase the degrees of freedom, particularly when estimating the parameters across countries. For simplicity and tractability, we focus on two main aspects of prospect theory: loss aversion and thinking in differences. Foellmi, Rosenblatt-Wisch and Schenk-Hoppé (2011) show that a utility function defined over these two aspects generates transitional dynamics different from the standard Cass-Koopmans-Ramsey model. Namely, it leads to excess consumption smoothing and can cause the economy to stay in a steady state of low consumption and low capital.[81] In addition, the length of our macroeconomic

[80] In Barberis, Huang and Santos (2001), the reference point is also influenced by history, but the idea of a dynamic status quo is incorporated in their approach.

[81] Foellmi, Rosenblatt-Wisch and Schenk-Hoppé (2011) also include utility out of levels in

times series limits the simultaneous estimation of several parameters. We will come back to this issue in section 4.4.

Thus, given this prospect utility function, the social planner[82] solves

$$\max_{\Delta c_t, k_{t+1}} E \sum_{t=0}^{\infty} \beta^t u(\Delta c_t) \tag{4.2}$$

subject to the constraint

$$f(k_t) + (1-\delta)k_t = c_t + k_{t+1}, \tag{4.3}$$

where the production function $f(k_t)$ is strictly increasing and concave, and the production shocks A_t (introduced later) are assumed to enter into the production function in a multiplicative manner. β is the discount factor, and $0 < \beta < 1$.

Δc_t can be expressed as

$$\Delta c_t = f(k_t) + (1-\delta)k_t - k_{t+1} - f(k_{t-1}) - (1-\delta)k_{t-1} + k_t. \tag{4.4}$$

Substituting the constraint into the objective function, the social planner's problem becomes

$$\max_{k_{t+1}} E \sum_{t=0}^{\infty} \beta^t u(f(k_t) + (1-\delta)k_t - k_{t+1} - f(k_{t-1}) - (1-\delta)k_{t-1} + k_t). \tag{4.5}$$

This can be solved under the condition that there is an interior solution to the above problem. Having linear utility, corner solutions could be an issue. However, the social planner approach unites maximization of households and firms. Even though utility is linear with $\lambda > 1$, the production function is concave and, hence, the social planner chooses an interior solution.

consumption, but they show that the different dynamics compared to the standard case only stem from the prospect utility part, namely, loss aversion and thinking in differences.

[82] Markets are complete, and agents behave competitively, so the First Fundamental Theorem of Welfare Economics holds.

The stochastic Euler equation has the following form

$$\frac{\partial u(\Delta c_t)}{\partial \Delta c_t} = E_t \left\{ \begin{array}{c} \beta \frac{\partial u(\Delta c_{t+1})}{\partial \Delta c_{t+1}} \left(\frac{\partial f(k_{t+1})}{\partial k_{t+1}} + (1-\delta) + 1 \right) \\ -\beta^2 \frac{\partial u(\Delta c_{t+2})}{\partial \Delta c_{t+2}} \left(\frac{\partial f(k_{t+1})}{\partial k_{t+1}} + (1-\delta) \right) \end{array} \right\}. \tag{4.6}$$

Equation (4.6) deviates from the standard Euler equation in a stochastic Cass-Koopmans-Ramsey model. Consumption is no longer time-separable since the objective function is now dependent not only on c_t and c_{t+1} but also on c_{t+2}. Previous decisions about consumption and capital move the reference point, and this influences current and future expected utility. Thus, current marginal utility is compared not only to marginal utility in the next period but also to marginal utility thereafter.

We will estimate the stochastic Euler equation using the Generalized Method of Moments. GMM goes back to Hansen and Singleton (1982), who introduced the concept of testing the implications of stochastic Euler equations directly using that method. One advantage of GMM is that it does not require full specification of the underlying economy. It is an econometric estimation procedure in which it is possible to estimate parameters in dynamic objective functions without explicitly having to solve for the stochastic equilibrium. GMM estimation allows us to derive parameter estimation of the stochastic Euler equation and to test for overidentification. Similarly, Aït-Sahalia and Brandt (2001) derive an asset pricing Euler equation for loss averse investors, which is then used for GMM estimation and Berkelaar, Kouwenberg and Post (2004) use GMM to estimate loss aversion in the aggregate U.S. stock market.

To apply GMM, the function to be estimated must be continuously differentiable. However, as noted above, the utility function in equation (4.1) is not differentiable at the reference point. To perform GMM, Rosenblatt-Wisch (2008) therefore assumes a smooth parametric auxiliary function such that the utility function is also differentiable at the kink. This can be done by setting up the loss aversion coefficient as a switching function. Under the assumption of loss aversion, λ in equation (4.1) should be greater than 1 in the loss area and exactly 1 in the gains area. Its value should switch as close as possible to the reference point. Such a switching function $g(\cdot)$ for the loss aversion coefficient λ can be represented by

$$g(\Delta c) = 1 + \frac{\lambda - 1}{1 + e^{\mu \Delta c}}, \tag{4.7}$$

where μ represents the speed of switching.

— Figure 4.1 about here —

The higher μ is, the faster the switching around zero (see figure 4.1). As required by the assumption of loss aversion, the function $g(\Delta c)$ approaches 1 for $\Delta c > 0$ and λ for $\Delta c < 0$. Thus, expression (4.7) yields a smooth function to express the loss aversion coefficient λ in the model. Inserting (4.7) for λ in the piecewise-linear utility function (4.1) and denoting the parameterized marginal utility by $\hat{u}'(\cdot)$ gives

$$\hat{u}'(\Delta c) = 1 + \frac{\lambda - 1}{1 + e^{\mu(\Delta c)}} - \frac{(\lambda - 1)\, \mu \Delta c_t e^{\mu \Delta c_t}}{(1 + e^{\mu \Delta c_t})^2}. \tag{4.8}$$

Plugging equation (4.8) into the Euler equation yields

$$1 + \frac{\lambda - 1}{1 + e^{\mu \Delta c_t}} - \frac{(\lambda - 1)\, \mu \Delta c_t e^{\mu \Delta c_t}}{(1 + e^{\mu \Delta c_t})^2} =$$
$$E_t \left\{ \begin{array}{l} \beta \left(1 + \frac{\lambda-1}{1+e^{\mu(\Delta c_{t+1})}} - \frac{(\lambda-1)\mu \Delta c_{t+1} e^{\mu \Delta c_{t+1}}}{(1+e^{\mu(\Delta c_{t+1})})^2}\right) \left(\frac{\partial f(k_{t+1})}{\partial k_{t+1}} + (1-\delta) + 1\right) \\ -\beta^2 \left(1 + \frac{\lambda-1}{1+e^{\mu \Delta c_{t+2}}} - \frac{(\lambda-1)\mu \Delta c_{t+2} e^{\mu \Delta c_{t+2}}}{(1+e^{\mu \Delta c_{t+2}})^2}\right) \left(\frac{\partial f(k_{t+1})}{\partial k_{t+1}} + (1-\delta)\right) \end{array} \right\}. \tag{4.9}$$

This is the form we need in order to apply GMM. It can be easily seen that we receive the standard Euler equation of the Cass-Koopmans-Ramsey model when we set $\lambda = 1$ in (4.9). This yields $1 = \beta E_t \left(\partial f(k_{t+1})/\partial k_{t+1} + 1 - \delta\right)$, which is the first order condition of the corresponding Cass-Koopmans-Ramsey model with linear utility.[83] Thus, testing for $\lambda = 1$ is also an implicit test against/ for the standard Ramsey model.

The production side of the model is specified as follows. The supply side is hit by technological shocks, specified as Solow residuals in the data, which creates

[83] See also Rosenblatt-Wisch (2005).

the uncertainty in the economy. Output is assumed to be produced with a Cobb-Douglas production function

$$F(A_t, K_t, L_t) = Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \tag{4.10}$$

and in intensive form, dividing by L_t, this gives

$$f(k_t) = y_t = A_t k_t^{\alpha}, \tag{4.11}$$

where $y_t = Y_t/L_t$ and $k_t = K_t/L_t$. Taking logs and first differences, the Solow residual can then be expressed as

$$\Delta \ln (A_t) = \Delta \ln (y_t) - \alpha \Delta \ln (k_t), \tag{4.12}$$

where α represents the capital share in the production function.

The depreciation rate is set to $\delta = 1$.[84] Introducing the Cobb-Douglas type production function into the Euler equation and setting the depreciation rate $\delta = 1$ yields:

$$1 + \frac{\lambda - 1}{1 + e^{\mu \Delta c_t}} - \frac{(\lambda - 1)\, \mu \Delta c_t e^{\mu \Delta c_t}}{(1 + e^{\mu \Delta c_t})^2} = E_t \left\{ \begin{array}{c} \beta \left(1 + \frac{\lambda-1}{1+e^{\mu(\Delta c_{t+1})}} - \frac{(\lambda-1)\mu \Delta c_{t+1} e^{\mu \Delta c_{t+1}}}{(1+e^{\mu(\Delta c_{t+1})})^2} \right) \left(\alpha A_{t+1} k_{t+1}^{\alpha-1} + 1 \right) \\ -\beta^2 \left(1 + \frac{\lambda-1}{1+e^{\mu \Delta c_{t+2}}} - \frac{(\lambda-1)\mu \Delta c_{t+2} e^{\mu \Delta c_{t+2}}}{(1+e^{\mu \Delta c_{t+2}})^2} \right) \alpha A_{t+1} k_{t+1}^{\alpha-1} \end{array} \right\}. \tag{4.13}$$

Our estimations will be built on this Euler equation.

4.3 Data

The following countries are included in our analysis: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, EU, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg,

[84] The depreciation rate enters the calculations of the capital formation stock data (OECD basis) and is as such a part of our physical capital available in the production process.

Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and the United States. We use quarterly data from 1950 (or the year when they first became available) to 2015, obtained from Datastream. Due to data availability, the sample sizes might differ considerably across countries. However, to make results comparable across countries, we prefer using the same data source, if possible, for all countries, which comes at the price of having fewer data points for some countries. Table K.1 in the appendix lists the countries we included and their abbreviations used in the figures, along with the information regarding which years are covered in the sample. The data for GDP, consumption and capital stock originate from the OECD, while data for labour are mostly provided by the respective national statistical offices. GDP is measured at constant prices and is seasonally adjusted, as are consumption and the measure for capital stock. Consumption measures private final consumption expenditures, whereas we use gross fixed capital formation to proxy for the capital stock. Labour is measured by total employment, and the exact definitions might differ from country to country. The data for labour are seasonally adjusted as well. GDP and its components are reported in the currency of their respective country, and labour is measured in volumes. We transform GDP, consumption and capital into their intensive form by dividing by labour. The Solow residual is then calculated from a Cobb-Douglas form production function. For each country, data for the capital share α are taken from the Penn World Table, version 9.0 (see Feenstra, Inklaar and Timmer, 2015). To calculate the Solow residual, we use the average capital share over time for each country.

4.4 Loss Aversion Across Countries

4.4.1 Estimation: Loss aversion coefficients across countries

We estimate equation (4.13) using GMM. An advantage of GMM estimation is that we do not have to know, or to specify, the full economic setting of the underlying economy.

It would be desirable to jointly estimate loss aversion λ and the discount factor β in equation (4.13), since these parameters might vary across countries. However, the data at hand are not sufficient to estimate these two parameters jointly. GMM does no longer converge in most specifications when estimating more than one parameter.

For the discount factor β, we use four different values: 0.90, 0.95, 0.97 and 0.99. We hold the discount factor constant across countries, which is the common approach in current DSGE modelling across countries (see e.g. Justiniano and Preston, 2010).[85]

We take α from the data, as outlined in the previous section. We average α over time for each country and use this value throughout. For the EU, no data for the capital share are available. Therefore, we set α equal to 0.33, a standard value in the literature.[86] For computational efficiency, we set μ equal to 0.1.

We only report results if we have at least 15 observations, which is true for all countries if we use the full sample. As a special case, we are also investigating whether the loss aversion coefficients across countries have converged over time, with a particular interest in the Euro Area countries after the introduction of the Euro as a single currency. We, therefore, also estimate equation (4.13) for two sub-samples (pre-2000 and post-2000). However, for the pre-2000 sub-sample, we do not have enough observations for Poland, Czech Republic, Romania, Bulgaria, Malta, Croatia, Cyprus, Lithuania and Greece.

For the specifications of the estimation, we follow the strategy used in Rosenblatt-Wisch (2008). In the baseline specification, we estimate equation (4.13) without additional moment conditions. As a robustness check, we also introduce additional moment conditions in which we use lagged values as instruments: Assuming individuals form expectations rationally, they use information from period t to form

[85] Our data only covers well-developed OECD countries with well-integrated financial markets. The discount factor in stochastic models represents a long-run average real return on risky and riskless assets. One could think of a broad portfolio, or from a finance point of view of the market portfolio. With global financial integration this market portfolio can be assessed by each country and should therefore be similar across countries.

[86] See, for example, Abel and Bernanke (2001) or Hall and Taylor (1997). We also performed some robustness checks regarding the capital share. Setting $\alpha = 0.33$ for each country does not change our results qualitatively. This finding is robust when using other values for α such as α equal to 0.2 and 0.5 or when using a time-varying α for each country.

expectations about period $t + 1$ but no information from earlier periods. Hence, lagged variables are not correlated with the error terms. In total, we consider seven different specifications concerning the moment conditions. As mentioned, the baseline version is the one without instruments. The other six specifications include lagged values of consumption differences, capital and combinations of it, to formulate additional moment restrictions.

In macroeconomic time series, it is common for the error terms to be correlated over time. Therefore, to allow for heteroscedasticity and autocorrelation in the residuals, we use a heteroscedasticity-and autocorrelation-consistent (HAC) weighing matrix (in case we use instrumental variables) as well as HAC standard errors, using the Bartlett kernel with 4 lags. We use an iterative GMM estimator since it might be more efficient in finite samples (Hall, 2005, p. 88–94), and, as is often the case with macroeconomic time series, our empirical investigation is performed in small samples, which makes this strategy particularly appealing (Hansen, Heaton and Yaron, 1996).

Furthermore, we verify that all input series are stationary, since GMM relies on the stationarity of the components. The null hypothesis of a unit root (tested by the augmented Dickey-Fuller test) can be rejected for all input series for all countries considered. The consumption series are first-difference stationary. We define the Solow residual in terms of growth rates for technological progress together with the growth rate of capital productivity. Using the exponential of the Solow residual generates a stationary time series for the production part of our Euler equation.

4.4.2 Results: Loss aversion coefficients across countries

First, we confirm the results found in Rosenblatt-Wisch (2008) for a large set of OECD countries. In general, it seems to hold true that we can track loss aversion in an aggregate time series for different countries and across various specifications of the estimated model. Second, and as expected, we find that larger values of β lead to lower estimates of the loss aversion parameter. As documented in Rosenblatt-Wisch (2008), a higher value for β as well as a higher degree of loss aversion imply that the individual is hurt more by future losses. Hence, β and

λ work in the same direction, which implies that when fixing a data point, the higher β is, the lower λ has to be and vice versa. This result is confirmed in the data, across specifications as well as across countries.

Table 4.1 presents the results in detail for one country, namely, the United States. We estimate various specifications with and without instrumental variables. To keep the exposition tractable, some further results are included in the appendix. The estimates are very similar to those found in Rosenblatt-Wisch (2008). Overall, the results reveal highly significant estimates of the loss aversion coefficient.

— Table 4.1 about here —

Tables K.3 and K.4 in the appendix show the results for the United States when using lagged consumption (table K.3) and lagged capital stock (table K.4) as an instrument. The results documented in table 4.1 can be confirmed. For the specification with $\beta = 0.97$, the loss aversion coefficient is estimated to be 1.3 for the semi-annual updating scheme and 2.2 for the annual update scheme, when using lagged consumption as the instrument. These numbers change slightly to 1.6 and 2.3, respectively, when using lagged capital stock as the instrument. All estimates are highly significant. These estimates are close to Tversky and Kahneman's experimentally supported value of 2.25 for the loss aversion coefficient.

These findings carry over to a broad set of OECD countries: Basically, all estimates are above 1, indicating loss aversion and are statistically significant. Figure 4.2 summarizes the results for the estimates resulting from the specifications without instruments for a discount factor of $\beta = 0.97$ and from semi-annual as well as annual reference point updating (for tractability we will use these two specifications as our baseline results for the rest of the paper). We find loss aversion in all countries. The results are somewhat stronger for the semi-annual reference point updating scheme compared to the annual updating scheme.

Furthermore, not only do we find loss aversion in all countries, but we also find cross-country differences in the degree of loss aversion. This holds particularly true for larger updating horizons. Even though the order of the countries when ranked according to their estimated loss aversion coefficient is subject to changes across different specifications, we observe that some country groups are often clustered together at similar loss aversion coefficients.

— Figure 4.2 about here —

Finally, we test for convergence of loss aversion across countries, comparing the pre-2000 and post-2000 samples. We do not find robust evidence for differences in loss aversion when comparing the pre-2000 sample with the post-2000 sample. Our data do not suggest that we see cross-country convergence in loss aversion. Figure K.1 in the appendix shows the estimated loss aversion coefficients for the pre-2000 and the post-2000 sample, using $\beta = 0.97$ and a semi-annual as well as an annual reference-point updating scheme. Visual inspection does not suggest that the variation in the estimates along the post-2000 axis is smaller than along the pre-2000 axis. To underpin this finding, we report the results from a variance comparison test in table K.5 in the appendix. There, we test whether the standard deviations of the cross-country estimates are significantly different for the two samples. As the last column reveals, we can reject the null-hypothesis that the standard deviations are the same for only three specifications with an updating horizon of one quarter–the specifications in which the standard deviations across countries are very small. For all other specifications, we do not find any evidence that loss aversion has converged.

Conceivably, institutional settings and loss aversion are closely inter-linked. In table K.6 in the appendix, we repeat the variance comparison test for the sample of countries within the Euro Area only, accounting for the fact that Euro Area countries' preferences could have become more identical after the year 2000, i.e., after having formed a monetary union, or differently said, after having changed the institutional settings. Table K.6, however, shows that convergence in preferences has not taken place to date. We cannot reject the null-hypothesis that the standard deviations of the estimates in the two sub-samples are the same for most specifications.

To sum up, the results found in Rosenblatt-Wisch (2008) for the United States basically carry over to other countries: We consistently find loss aversion coefficients that exceed one (indicating individuals are loss averse), and interestingly, we also find pronounced variation in the size of the loss aversion coefficients across countries.

Can these differences in loss aversion at the aggregate level across countries be explained by micro evidence? We investigate this question in the next section. Specifically, we check how our estimated loss aversion coefficients are related to the cultural dimensions reported by Hofstede, Hofstede and Minkov (2010), as well as how they relate to some key questions from the World Values Survey (WVS).

4.4.3 Possible reasons for different loss aversion across countries

This section analyses how the variation in loss aversion coefficients at the aggregate level is matched with micro evidence.

As our first source of micro evidence, we consider the six cultural dimensions reported by Hofstede, Hofstede and Minkov (2010) and investigate whether they correlate with our estimated values. This approach follows Wang, Rieger and Hens (2016), who, using data based on surveys, show that loss aversion and the Hofstede dimensions are related.[87]

As our second source of micro evidence, we use data from the World Values Survey to see whether they have any explanatory power for our estimated loss aversion coefficients.

To uncover the statistical link between our estimated loss aversion and either the Hofstede cultural dimensions or the values from the WVS, we estimate

$$LA_j = cons + \gamma \times culture_j + \epsilon_j \tag{4.14}$$

applying OLS. LA_j is the estimated loss aversion coefficient for country j, while $culture_j$ is a culture variable from the Hofstede or WVS data.

Data: Hofstede et al. (2010) and World Values Survey — The Hofstede,

[87] Another reason for differences in loss aversion across countries could be climate, as Galor and Savitskiy (2018) argue.

Hofstede and Minkov (2010) dimensions consist of six variables: *Power distance index (PDI)*, *Individualism versus collectivism (IDV)*, *Masculinity versus femininity (MAS)*, *Uncertainty avoidance index (UAI)*, *Long term orientation versus short term normative orientation (LTO)* and *Indulgence versus restraint (IND)*. The data result from surveys conducted in several years. However, the data do not have any time dimension; it is a cross-section rather than a panel. Table 4.2 briefly introduces and describes these variables; more information about the variables can be obtained from Geert Hofstede's website (see source of table 4.2).

— Table 4.2 about here —

Descriptive statistics for the Hofstede variables used here are provided in part I of table K.2 in the appendix. Wang, Rieger and Hens (2016) use only the first four of these dimensions to establish a link between them and loss aversion, mostly on the individual level. They find that individuals with a higher value for PDI and IDV are more loss averse and that individuals living in countries with a higher value for MAS are more loss averse. However, they do not include LTO and IND in their paper.

Our second source, the World Values Survey[88], includes more than 800 individual questions. Hence, we are required to select some key variables that we consider to have an impact on our estimate of loss aversion. Table 4.3 lists our selected variables, while we provide descriptive statistics in part II of table K.2 in the appendix. *Variable* is how we name them, and *Code* is the code for the question asked in the WVS data. *Description* is a short description of the content of the variable. The variables are selected partly because we think they are important for economic outcomes and partly because they were used in earlier economic studies. For example, the question we selected to measure time preferences, A038, was used in Galor and Özak (2016) to proxy for long-term orientation or patience.

— Table 4.3 about here —

For these variables, we compute the average for each country, i.e., for each country and question pair, we take the simple mean to reduce individual observations to one observation per country, similar to Hofstede, Hofstede and Minkov

[88] The WVS data can be obtained from `http://www.worldvaluessurvey.org/wvs.jsp`

(2010)'s calculations of country averages for individual questions that constitute one dimension (see, for example, Hofstede, Hofstede and Minkov (2010, p. 55)). This procedure yields, for each country, an estimated loss aversion parameter, six Hofstede dimension values and 19 values from the World Values Survey. We then normalize the data on the Hofstede dimensions, as well as the World Values Survey data, by subtracting the minimum of each variable and then dividing by the difference of the maximum and the minimum. Therefore, all values lie between zero and one.

Relation between loss aversion and culture & values — Comparing the six Hofstede dimensions with our estimates of loss aversion, we find that our estimates of loss aversion do not significantly correlate with the four dimensions shown in Wang, Rieger and Hens (2016). Interestingly, however, for our main specifications with $\beta = 0.97$, indulgence, one of the dimensions not used by Wang, Rieger and Hens (2016) seems to be significantly negatively correlated with our estimate of loss aversion. Figure 4.3 shows this relationship.

— Figure 4.3 about here —

The left panel in figure 4.3 uses the estimated loss aversion coefficient with a semi-annual updating scheme, whereas the right panel uses the results from the specification with an annual scheme. Indulgence measures how individuals are able to control their impulses. A lower score implies that individuals are more restrained (i.e., more able to control their impulses and desires), which is related to a higher degree of loss aversion. Furthermore, we find that long-term orientation, the last remaining dimension and not shown in Wang, Rieger and Hens (2016), is positively correlated with loss aversion. However, the link is not statistically significant. The results for indulgence and long-term orientation seem to be in line with the status quo bias that loss aversion induces (see Samuelson and Zeckhauser, 1988). The more loss averse an agent is, the higher is his status quo bias. The status quo bias can be interpreted as a long-term orientation and as not being tempted by short-sighted impulses and desires.

For the selected indicators from the World Values Survey, a similar picture emerges: Most of the variables do not seem to be statistically significantly correlated with our estimates of loss aversion. One indicator that seems to have some explanatory power for loss aversion is optimism: Pessimistic people show higher loss aversion. This relationship is shown in figure 4.4.

— Figure 4.4 about here —

Again, the result seems intuitively plausible. Taking risks and moving away from the status quo could generate gains but might also generate losses. Pessimistic people would expect a higher likelihood for losses in general, and these losses loom large because of loss aversion. Therefore, pessimistic people would prefer the status quo, and a high status quo bias goes hand in hand with high loss aversion.

However, overall, we find little statistical evidence that either the Hofstede dimensions or the World Values Survey data can explain the cross-country variance in the estimated loss aversion coefficients, at the aggregate level. This could be because the power of our statistical tests is limited because we only have a small number of observations. Alternatively, due to large heterogeneity and as noted by, e.g., Falk et al. (2018) or Frey and Gallus (2014), simple aggregation of micro evidence might not be able to successfully gauge preferences, at the aggregate level.

4.5 Loss Aversion and its Relation to Economic Fundamentals

Previous studies investigating individual preferences suggest that these might influence a country's growth trajectory (Falk et al., 2018). For example, a lower level of patience might reduce a country's savings rate, which in turn will lower its accumulated capital. Foellmi, Rosenblatt-Wisch and Schenk-Hoppé (2011) find that an economy with loss averse agents might be stuck in a steady state with low consumption and low capital because loss averse individuals are reluctant to reduce consumption today in order to achieve a higher steady state tomorrow. Furthermore, they show that the presence of loss aversion leads to stronger consumption smoothing.

Hence, we investigate whether our estimated loss aversion coefficients (again with the specification of $\beta = 0.97$) are correlated with a series of economic fundamentals series, such as GDP per capita, consumption, savings rates, inflation, investment shares, monetary aggregates and long-term interest rates. Furthermore, we also look at correlations between unemployment benefits and financial openness with loss aversion. Since the estimated loss aversion coefficients are constant over time, we select the economic fundamentals from the year 2010 as well as the year 2000 to exclude potential effects of the crisis. Furthermore, we look at averages over the years as well as fluctuations of these variables over the years, in order to capture long-term trends as well as business cycle fluctuations of these variables.

As we only have 32 observations, we look at bivariate relationships. Obviously, many other factors affect a country's growth trajectory or other economic fundamentals, while driving loss aversion at the same time. However, due to data limitations, this section focuses on correlations only. By doing so, we shed some light on potential links between loss aversion and economic fundamentals, without claiming any causal relationship.

4.5.1 Data

We retrieve data for the economic fundamentals from standard macroeconomic data sources. For the long-term interest rates, we use 10-year government bond yields from the OECD database. For the monetary aggregates, we use the broad money (M3) index taken from the OECD database as well. From the same database, we include data on the replacement ratio (for a single individual having worked full time) and an index of financial services restrictions to proxy financial openness. Real GDP and consumption are taken from the Penn World Table (version 9.0) and adjusted to per-capita terms, using population data from the same database.[89] Additionally, from the Penn World Table, we take shares of

[89] We use GDP and consumption data from the Penn World Table here as a standard source for macroeconomic data. Note, that they are only available at annual frequency, which is sufficient

household consumption and government consumption. Finally, we use annual inflation (of consumer prices), broad money (M3) as a % of GDP and savings rates reported in the World Development Indicators (WDI), provided by the World Bank. Summary statistics for these variables can be found in part III of table K.2 in the appendix. For the loss aversion coefficients, we use our point estimates, using the baseline specifications without additional moment restriction, a discount factor of $\beta = 0.97$ and semi-annual and annual reference point adjustments.

4.5.2 Results

We investigate the statistical link between the economic fundamentals introduced above and the estimated loss aversion, applying OLS. Hence,

$$Y_j = cons + \theta \times LA_j + v_j, \tag{4.15}$$

where Y_j is any economic fundamental in country j, either at a given point in time (i.e., in either the year 2000 or 2010), or the average over time, or (in the case of consumption smoothing) the standard deviation over time. LA_j again is the estimated loss aversion in country j.

Among the economic fundamentals investigated, we find a consistent and significant effect for GDP per capita and consumption: Less loss aversion is significantly correlated with higher consumption levels as well as GDP per capita. Figures 4.5 and 4.6 summarize this result. Here, we use the average of GDP per capita over the same sample for which we have data to estimate the loss aversion coefficient. For Switzerland, for example, we have data from 1970 onward to estimate the Euler equation (see table K.1 in the appendix), and, hence, we calculate, in this case, the average GDP per capita since 1970. Again, the left panel uses semi-annual reference point updating, whereas the right panel uses annual updating.

— Figure 4.5 about here —

— Figure 4.6 about here —

for the exercise in this section. For the estimations of the loss aversion parameters, we used quarterly data from the OECD database.

These results do not change qualitatively when using data of the year 2000 or data of the year 2010, instead of taking the average over time. We find empirical evidence for the theoretical predictions that higher loss aversion relates to lower income and consumption.

Concerning the savings rate, we find a negative correlation between loss aversion and the savings rate, in line with what theory would predict. However, the correlation is statistically insignificant in most specifications.

For inflation, the relationship with loss aversion is positive in all specifications, but the correlation is not significant. The results are similar for the long-term interest rate and the measure of financial regulation (i.e., financial openness is related to lower levels of loss aversion). For the broad money stock M3 and the replacement rate, no patterns can be observed.

What about consumption smoothing? Theory predicts that a higher degree of loss aversion goes hand in hand with more consumption smoothing. Therefore, we calculate the standard deviation of the share of household consumption in output over the years for each country in our sample. This gives a simple measure of the fluctuations in consumption shares. We expect a negative correlation between this measure and loss aversion.[90] Figure 4.7 illustrates this finding.

— Figure 4.7 about here —

Looking at the raw correlation, the two measures seem to be negatively correlated, but the relationship is not significant. However, it is likely that a high level of GDP is both negatively correlated with loss aversion and negatively correlated with fluctuations in consumption. Indeed, if we include average GDP over the years in our estimation (by adding average GDP as an additional regressor to equation 4.15), the link between the standard deviation of consumption over time and estimated loss aversion becomes statistically stronger. Note that the statistical link found is stronger than suggested by figure 4.7 because we need to control for GDP. As indicated at the bottom of the figures, using semi-annual reference point updating, the p-value is 0.06, whereas with annual reference point

[90] We exclude Malta here, since its standard deviation of consumption is very large and therefore this data point is a huge outlier.

updating, it is 0.09. Hence, we find some indicative evidence for a link between loss aversion and consumption smoothing, as theory would suggest.

4.6 Conclusion

Preferences of agents matter when thinking about macroeconomic modelling and economic developments. In this paper, we find evidence for loss aversion for a broad set of OECD countries, at the aggregate level. The average degree of loss aversion clearly differs across these countries. To understand these differences, we explore the correlation between loss aversion and macroeconomic fundamentals. We find that GDP per capita and consumption levels are significantly and negatively related to our estimates of loss aversion, in line with what theory would predict. Furthermore, we find a higher degree of consumption smoothing in countries with a higher loss aversion.

To gain more insights on the link between institutions and preferences, we also checked whether loss aversion has converged over time, and, in particular, among Euro Area countries after the introduction of the Euro as the single currency. This seems not to have taken place to date.

To understand the underlying reasons of how reference points are formed, it would be interesting to incorporate expectations-based reference dependence. However, such an approach would increase the degrees of freedom substantially, in particular, when estimating the parameters across countries. The data at hand is not sufficient to perform this exercise. However, as time goes by, the length of the macro time series extends. We, therefore, leave this exercise to future research.

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Figures and Tables

Figure 4.1: Switching function

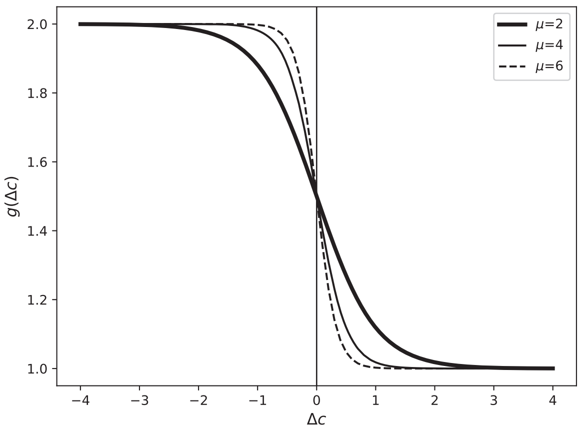
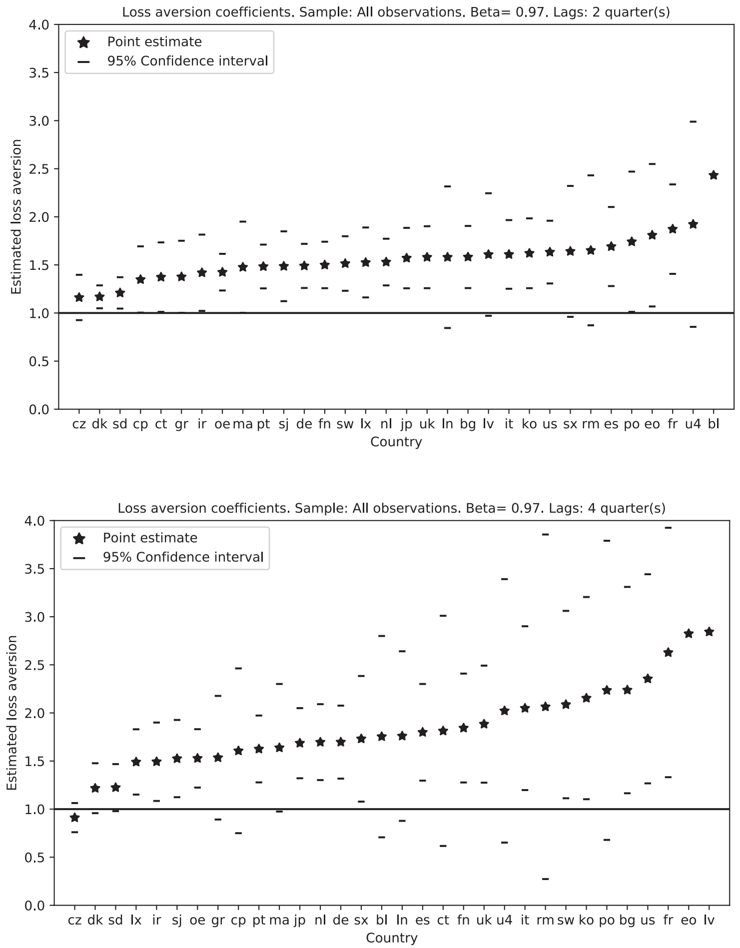
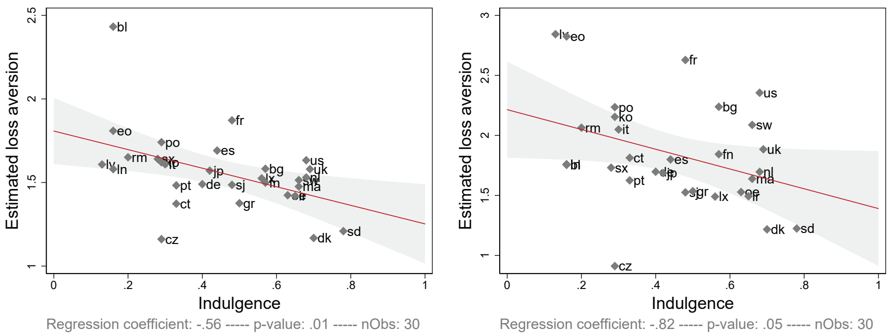


Figure 4.2: Estimated loss aversion across countries



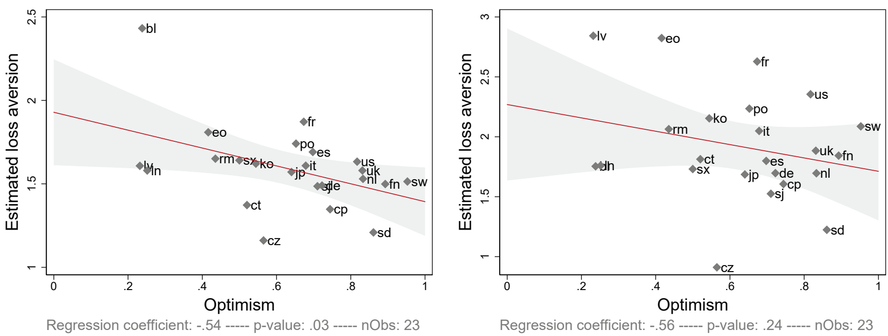
Note: Figure in the top (bottom) panel shows results for semi-annual (annual) reference point updating.

Figure 4.3: Estimated loss aversion and indulgence



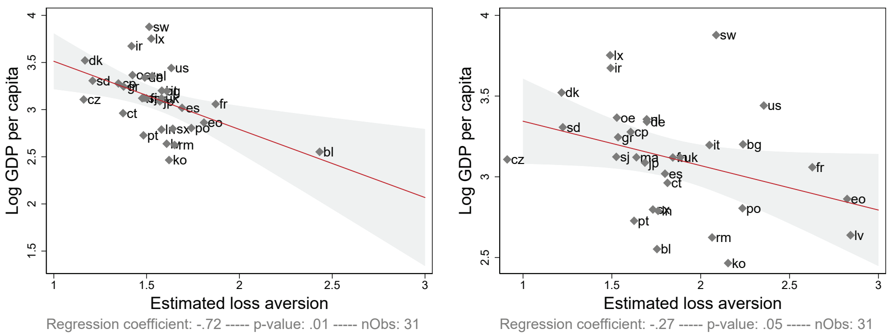
Note: Figure in the left (right) panel shows results for semi-annual (annual) reference point updating.

Figure 4.4: Estimated loss aversion and optimism



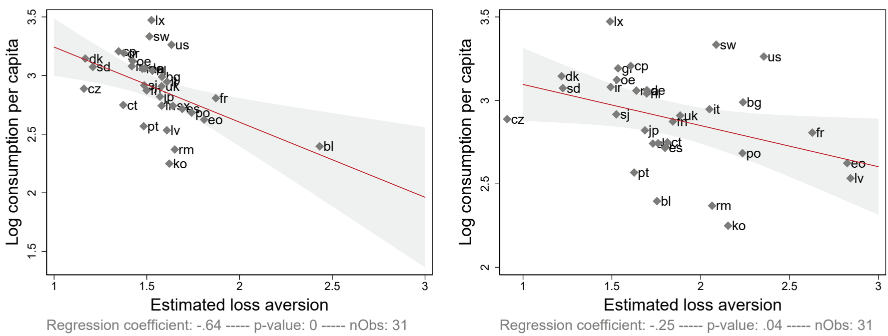
Note: Figure in the left (right) panel shows results for semi-annual (annual) reference point updating.

Figure 4.5: Estimated loss aversion and average GDP per capita



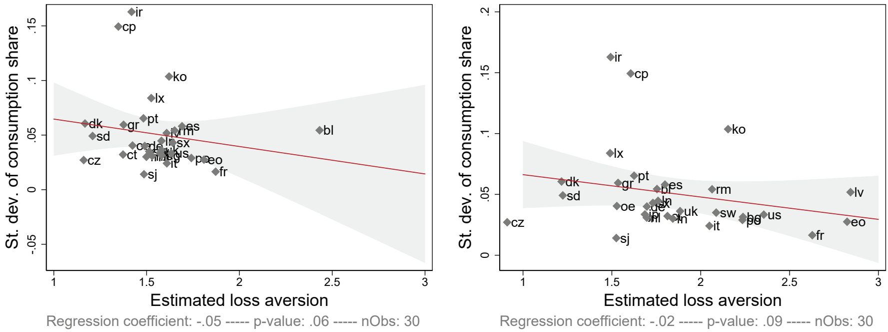
Note: Figure in the left (right) panel shows results for semi-annual (annual) reference point updating.

Figure 4.6: Estimated loss aversion and average consumption per capita



Note: Figure in the left (right) panel shows results for semi-annual (annual) reference point updating.

Figure 4.7: Estimated loss aversion and fluctuations in consumption



Note: Figure in the left (right) panel shows results for semi-annual (annual) reference point updating.

Table 4.1: Results for the US without additional moment restrictions

Reference point adj.	1 quarter	2 quarters	4 quarters
$\beta = 0.90$			
λ	1.915***	2.464***	4.346***
stv. dev.	0.128	0.302	1.138
p-value	0.000	0.000	0.003
$\beta = 0.95$			
λ	1.569***	1.884***	2.960***
stv. dev.	0.096	0.205	0.738
p-value	0.000	0.000	0.008
$\beta = 0.97$			
λ	1.414***	1.633***	2.355**
stv. dev.	0.084	0.166	0.555
p-value	0.000	0.000	0.015
$\beta = 0.99$			
λ	0.825***	1.330***	1.656*
stv. dev.	0.043	0.125	0.351
p-value	0.000	0.008	0.062
Nobs	243	243	243

Note: The table shows the estimates for the loss aversion parameter λ in equation (4.13) using data from the United States. *,**,*** denote statistical significance at the 1%, 5% and 10% level.

Table 4.2: Summary description of the Hofstede variables

Variable	Description
Power distance index	Measures the degree to which less powerful individuals accept that power is distributed unequally. People living in societies with a high Power Distance accept a hierarchical order in which everyone has his or her place.
Individualism vs. collectivism	Measures the degree of individualism, i.e., to what degree members of a society are only expected to take care of themselves and their family. People living in societies with a high degree of individualism define their self-image as "I", whereas people in collectivist societies define themselves as "We".
Masculinity vs. femininity	Measures the importance of achievement and material success in society. Masculine societies tend to be competitive, while feminine societies are more consensus-oriented.
Uncertainty avoidance index	Measures the degree to which the members of society feel uncomfortable with uncertainty or ambiguity. Societies with a higher score want to try to control the future, while societies with a low score just let the future happen.
Long term orientation	Measures how societies value the future in terms of the present and past. Societies that score low view social change with suspicion, while societies with a high score encourage thrift and education to prepare for the future.
Indulgence vs. restraint	Measures to what degree human drives are regulated by social norms. Indulgent societies allow free gratification of drives related to enjoying life and having fun. In restraint societies, gratification is regulated to a stronger degree by strict social norms.

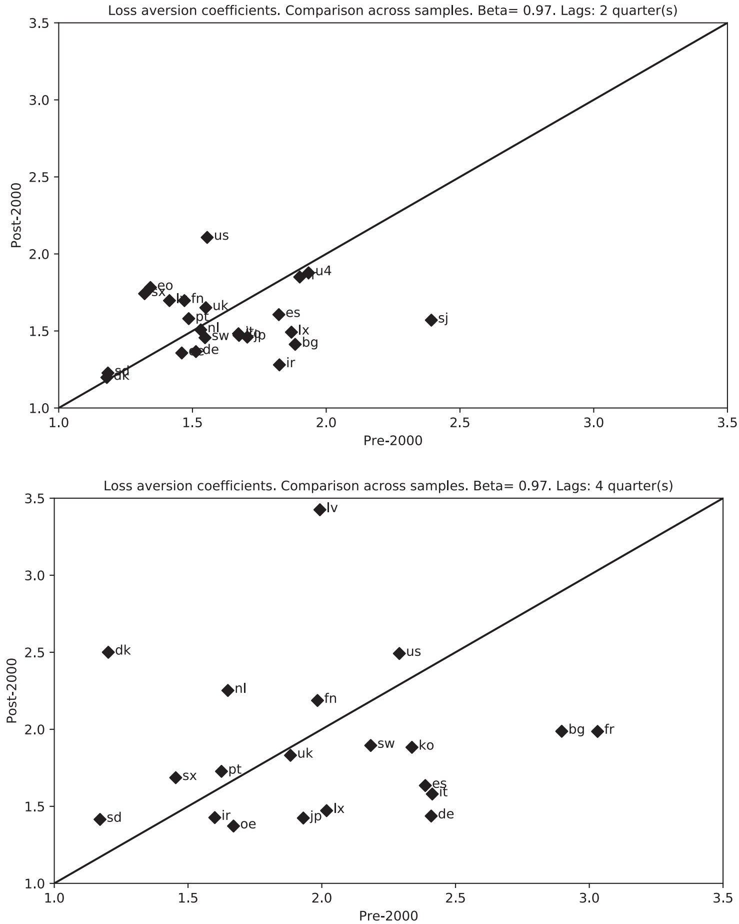
Source: Hofstede, Hofstede and Minkov (2010); Geert Hofstede's website: `https://geert-hofstede.com/national-culture.html`. More detailed information about the six variables, as well as the measurement of the variables, can be found there.

Table 4.3: Selected variables from the World Values Survey

Variable	Code	Description
Work	A030	Important child qualities: Hard work
Timepref	A038	Important child qualities: Thrift, saving money and things
Trust	A165	Most people can be trusted
Optimism	A170	Satisfaction with your life
Ideas	A189	Schwartz: Important to think up new ideas and be creative
Status	A190	Schwartz: Important to be rich
Security	A191	Schwartz: Important to live in secure surroundings
Altruism	A193	Schwartz: Important to help the people nearby
Risk	A195	Schwartz: Important to be adventurous and to take risks
Environment	A197	Schwartz: Important to look after the environment
Tradition	A198	Schwartz: Important to value tradition
Genderroles	C001	Jobs scarce: Men should have more right to a job than women
Freedom	E010	National goals: Free speech
Equality	E035	Income equality
Politics	E039	Competition: Good or harmful
Immigration	E143	Immigration policy
Religion	F050	Belief in god
Fatecontrol	F198	Fate versus control
National	G006	Pride in nationality

Appendix K: Additional Figures and Tables

Figure K.1: Estimated loss aversion before and after 2000



Note: The figure in the top (bottom) panel shows results for semi-annual (annual) reference point updating.

Table K.1: Countries and sample composition

Code	Country	First year
bg	Belgium	1960
bl	Bulgaria	2000
cp	Cyprus	1999
ct	Croatia	2002
cz	Czech Republic	1994
de	Germany	1962
dk	Denmark	1969
es	Spain	1961
eo	Estonia	1995
fn	Finland	1960
fr	France	1950
gr	Greece	2000
ir	Ireland	1990
it	Italy	1960
jp	Japan	1960
ko	Korea	1970
ln	Lithuania	1998
lv	Latvia	1995
lx	Luxembourg	1985
ma	Malta	2000
nl	Netherlands	1960
oe	Austria	1969
po	Poland	1995
pt	Portugal	1960
rm	Romania	1997
sd	Sweden	1960
sj	Slovenia	1995
sw	Switzerland	1970
sx	Slovakia	1993
u4	EU28	1995
uk	United Kingdom	1959
us	United States	1955

Table K.2: Descriptive statistics

Variable	Mean	Std. dev.	Min.	Max.	N
Part I: Hofstede variables:					
Power distance	51.03	20.14	11.00	100.00	30
Individualism	57.53	19.23	18.00	91.00	30
Masculinity	47.33	24.33	5.00	100.00	30
Uncertainty avoidance	70.17	21.86	23.00	100.00	30
Long term orientation	59.43	19.57	24.00	100.00	30
Indulgence	44.90	19.64	13.00	78.00	30
Part II: World Values Survey variables:					
Trust	1.68	0.14	1.36	1.89	23
Work	0.53	0.26	0.10	0.90	23
Tradition	2.96	0.59	2.12	4.15	17
Immigration	2.48	0.16	2.23	2.82	20
Ideas	2.87	0.37	2.09	3.63	17
Status	4.48	0.31	4.07	4.98	17
Security	2.73	0.41	1.96	3.51	17
Altruism	2.47	0.45	1.67	3.41	16
Risk	4.05	0.37	3.41	4.84	17
Environment	2.58	0.36	2.00	3.29	17
Optimism	6.66	0.93	4.90	8.11	23
Politics	3.79	0.55	2.91	5.03	23
Freedom	1.71	0.24	1.35	2.05	9
Equality	5.40	0.81	4.21	7.06	23
National	1.80	0.25	1.37	2.22	23
Religion	0.72	0.18	0.42	0.97	20
Fatecontrol	6.61	0.49	5.59	7.44	14
Genderroles	1.93	0.09	1.76	2.18	23
Timepref	0.41	0.10	0.23	0.60	23
Part III: Economic fundamentals variables:					
Log GDP per capita	3.42	0.37	2.69	4.07	31
Log consumption per capita	3.18	0.29	2.53	3.73	31
CPI inflation in %	1.77	1.40	-1.07	6.09	32
Share of government consumption	0.21	0.05	0.08	0.28	31
Share of household consumption	0.57	0.08	0.40	0.75	31
10y interest rate in %	4.08	2.03	1.15	10.34	25
Savings rate in %	21.34	6.64	5.58	39.35	32
Broad money (M3) / GDP	161.45	231.17	37.98	911.21	13
Replacement rate in %	58.91	14.07	29.40	86.40	29
Financial regulation index * 100	1.37	1.83	0.00	6.70	27

Note: Descriptive statistics include only those countries that are in our sample to estimate the loss aversion coefficient. The Hofstede variables measure a country's score for each of the six dimensions on a scale from 0 to 100. As an example, consider the power distance. Societies with a high degree of power distance accept that there is a hierarchical order in which everyone has his or her place. In our sample, the lowest score for power distance is 11 for Austria, indicating that Austrians have strong demands for equalization of power. The World Value Survey variables we use here are country averages. The values for the variables start at 1 (indicating "disagreement" with the question asked) and go up to a maximum of 10, depending on the question. As an example, consider the trust variable. The statement given to the individuals is "Most people can be trusted", with possible answers "1: Most people can be trusted" and "2: Cannot be too careful". The economic fundamentals variables reflect some conditions in the countries examined in our sample. For tractability and to keep interpretation simple, we here report the data for the year 2010.

Table K.3: Results for the US, using lagged consumption as an instrument

Reference point adj.	1 quarter	2 quarters	4 quarters
$\beta = 0.90$			
λ	1.872***	2.013***	5.324**
stv. dev.	0.305	0.390	1.878
p-value	0.004	0.009	0.021
$\beta = 0.95$			
λ	1.518**	1.464***	3.119**
stv. dev.	0.231	0.179	1.080
p-value	0.025	0.009	0.050
$\beta = 0.97$			
λ	1.362*	1.268***	2.207*
stv. dev.	0.196	0.103	0.638
p-value	0.065	0.009	0.058
$\beta = 0.99$			
λ	0.762	1.086***	1.357*
stv. dev.	0.159	0.033	0.183
p-value	0.134	0.009	0.052
Nobs	243	243	243

Note: The table shows robustness results for table 4.1, using lagged consumption as an instrument when estimating equation (4.13). *,**,*** denote statistical significance at the 1%, 5% and 10% level.

Table K.4: Results for the US, using lagged capital as an instrument

Reference point adj.	1 quarter	2 quarters	4 quarters
$\beta = 0.90$			
λ	1.943***	2.459***	4.294***
stv. dev.	0.131	0.302	1.125
p-value	0.000	0.000	0.003
$\beta = 0.95$			
λ	1.591***	1.877***	2.917***
stv. dev.	0.100	0.203	0.724
p-value	0.000	0.000	0.008
$\beta = 0.97$			
λ	1.434***	1.626***	2.319**
stv. dev.	0.087	0.164	0.541
p-value	0.000	0.000	0.015
$\beta = 0.99$			
λ	0.835***	1.324***	1.629*
stv. dev.	0.042	0.122	0.336
p-value	0.000	0.008	0.061
Nobs	241	241	241

Note: The table shows robustness results for table 4.1, using lagged capital as an instrument when estimating equation (4.13). *,**,*** denote statistical significance at the 1%, 5% and 10% level.

Table K.5: Estimated loss aversion for different sub-samples

			Mean		St. dev.		
β	Lag	Nobs	Pre-2000	Post-2000	Pre-2000	Post-2000	p-value
0.90	1	23	1.95	1.80	0.26	0.17	0.05
0.90	2	23	2.47	2.26	0.59	0.49	0.41
0.90	4	20	3.49	3.05	1.31	1.40	0.77
0.95	1	23	1.58	1.50	0.16	0.11	0.05
0.95	2	23	1.88	1.77	0.37	0.30	0.35
0.95	4	20	2.45	2.23	0.74	0.75	0.93
0.97	1	23	1.42	1.37	0.12	0.08	0.05
0.97	2	23	1.62	1.56	0.28	0.22	0.30
0.97	4	20	2.01	1.88	0.50	0.51	0.96
0.99	1	23	1.10	1.06	0.21	0.18	0.48
0.99	2	23	1.32	1.26	0.17	0.19	0.71
0.99	4	20	1.50	1.44	0.24	0.34	0.14

Note: The table reports an overview of the point-estimates for the different countries. For example, in the column Mean Pre-2000, the cross-country mean of the estimated loss aversion coefficient for the years prior to 2000 is reported, while St. dev. reports the standard deviation across the cross-country estimates. p-value reports the p-value from a variance comparison test in which the tested hypothesis is that the standard deviations are not the same.
Extreme outliers have been removed from the sample.

Table K.6: Estimated loss aversion for different sub-samples: Euro Area countries

			Mean		St. dev.		
β	Lag	Nobs	Pre-2000	Post-2000	Pre-2000	Post-2000	p-value
0.90	1	17	1.94	1.74	0.26	0.12	0.00
0.90	2	17	2.44	2.17	0.63	0.42	0.10
0.90	4	15	3.41	2.99	1.49	1.53	0.93
0.95	1	17	1.57	1.47	0.16	0.08	0.01
0.95	2	17	1.85	1.72	0.41	0.26	0.08
0.95	4	15	2.40	2.21	0.84	0.82	0.94
0.97	1	17	1.42	1.34	0.13	0.07	0.01
0.97	2	17	1.60	1.52	0.31	0.20	0.07
0.97	4	15	1.97	1.87	0.57	0.55	0.93
0.99	1	17	1.11	1.07	0.21	0.16	0.32
0.99	2	17	1.31	1.23	0.20	0.20	0.90
0.99	4	15	1.48	1.43	0.27	0.38	0.21

Note: The table reports an overview of the point-estimates for the different countries. For example, in the column Mean Pre-2000, the cross-country mean of the estimated loss aversion coefficient for the years prior to 2000 is reported, while St. dev. reports the standard deviation across the cross-country estimates. p-value reports the p-value from a variance comparison test in which the tested hypothesis is that the standard deviations are not the same.
Extreme outliers have been removed from the sample.

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