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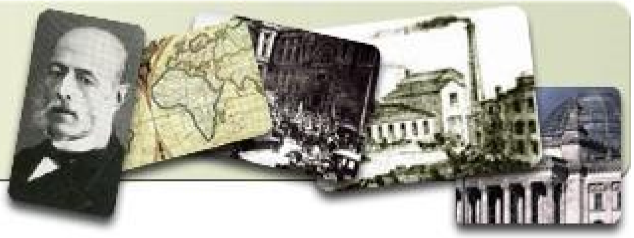

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Technical change and the postwar slowdown in Soviet economic growth

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Abstract

The existing studies usually find that technical change was very important in constraining the economic growth of the Soviet Union. While these studies have been successful in quantifying the extent of technical change, they have been less successful in quantifying its nature. This paper probes the essence of technical change by analysing its direction and bias. I find that the Soviet Union achieved strong increases in labour efficiency until the 1960s. Although the labour efficiency growth subsequently slowed down, it is capital efficiency that drove the postwar slowdown in economic growth. I argue that labour shortages, combined with an inadequate investment policy, retarded the Soviet capital efficiency.

Keywords: Soviet Union; Economic Growth; Technical Change; Economic History

JEL Classification Numbers: O47: O33; N14; P27

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1 Introduction

The rapid industrialisation of the Soviet Union under central planning is one of the most important state-led development strategies ever attempted. Until the 1950s, the Soviet Union seemed capable of achieving rapid industrialisation through a massive mobilisation of resources. It seemed capable of achieving this without the increase in inequality that is often associated with development under capitalism (Kuznets, 1955). It is thus unsurprising that many developing countries at the time, like China or India, sought to emulate the Soviet growth experience (Cheremukhin et al., 2017). Since the 1960s, however, the Soviet growth rates started gradually slowing down. Success turned into failure after 1970, when the growth rate dropped substantially. Eventually, the economic growth reached a standstill, and the country disintegrated in 1991.

Many researchers have analysed the sources of the Soviet growth slowdown. They frequently find that technical change played an important role in retarding the Soviet economic growth.[1] While these studies have been effective in quantifying the extent of technical change, they have been less successful, however, in quantifying its nature. This paper probes the essence of Soviet technical change by analysing its direction and bias.[2]

The vast majority of papers that analyse the socialist economies assume that technical change is *factor neutral* (Allen, 2003; Vonyó, 2017; Vonyó and Klein, 2019; Kukić, 2018, 2020). Factor neutrality implies that technical change affects all factors of production equally. This means, for example, that a one per cent decrease in aggregate efficiency implies that the efficiency of both capital and labour has decreased by exactly one per cent. This approach to technical change is self-limiting, and potentially masks a richer set of dynamics at a more granular level.

This paper allows technical change to be *non-neutral*. By that, I allow the efficiency of capital and labour to grow at different rates. This allows me to move closer towards the direction of fundamental explanations underpinning the economic slowdown of the Soviet Union. For instance, if capital efficiency was the primary reason for the slowdown in economic growth, researchers should focus on analysing factors that distorted capital efficiency, like the inadequate investment policy (Cohn, 1979, 1982; Allen, 2003). If labour efficiency was the main contributor to the growth slowdown, researchers should focus instead on factors that distorted labour efficiency, like the poor structure of material incentives (Kornai, 1992; Hanson, 2003).

Using revised data and the constant elasticity of substitution (CES) production function of Caselli and Coleman (2006) and Caselli (2017), I focus the analysis on factors related to efficiency that caused the postwar slowdown in economic growth.[3] To provide a longer historical perspective, I include in the analysis the interwar period, as well as a period of the Russian Empire (turn of the twentieth century). For comparative reasons, I also include in the analysis the United States - the global technological frontier.

This paper presents three novel findings. First, capital efficiency is the principal determinant

[1] See Ofer (1987) for a literature survey.

[2] If the efficiency of one input increases over time, the existing literature refers to this as *factor-augmenting* or *directed* technical change. If the relative input efficiency changes over time, the existing literature refers to this as *biased* technical change. These definitions of technical change date back to Hicks (1939).

[3] There are other papers, however, that also apply the CES production function to the Soviet Union (Weitzman, 1970; Desai, 1976; Easterly and Fischer, 1995; Nakamura, 2015). The novelty of the present paper lies in using the CES framework to analyse non-neutral technical change, which yields new analytical insights.

of the Soviet economic growth retardation. Capital efficiency decreased from the beginning of central planning in 1928, and continued decreasing until 1989, driving the postwar slowdown in economic growth. This decrease in capital efficiency was presumably caused by an increase in labour shortages, combined with an inadequate investment policy.

A distinctive feature of the Soviet investment policy was the over-concentration of investment in new firms, compared with replacing equipment in the existing firms (Cohn, 1979, 1982; Hanson, 1981). One corollary of this policy is the increasing stock of incomplete projects. Such stocks held up production, delayed the introduction of new technologies, and decreased capital efficiency. Once these stocks were brought up to production, however, there were barely any workers to operate them, causing capital inefficiency. In the terminology of Abramovitz (1986), the investment policy of the Soviet Union was hence not 'technologically congruent' with the existing labour endowment.

The second key finding is that labour efficiency was an important source of growth, growing strongly during most of the postwar period. At the turn of the 1980s, however, labour efficiency stagnated. This stagnation was driven by a deterioration in population health (Brainerd, 2010), a sequence of harvest failures in agriculture (Hanson, 2003), and possibly by increased shortages of consumer goods that destimulated labour effort (Kim, 2002; Kim and Shida, 2017). Nevertheless, labour efficiency eventually rebounded, and was not of primary importance in causing the deterioration of economic growth over the long-run.

The CES framework also allows me to analyse the bias of technical change within the labour aggregate (composed of skilled and unskilled labour) and within the capital aggregate (composed of structures and equipment). As a third key finding, I show that technical change was biased toward skills in the labour aggregate, and biased toward equipment in the capital aggregate. This suggests that skilled labour boosted the overall labour efficiency growth, and that the decrease in capital efficiency was driven by structures, and mitigated by equipment. These final results, however, depend on some data shortcuts, which I elaborate later in the text.

The findings of this paper shed novel light on the Soviet economic performance. The existing literature uses two analytical models to explain the growth slowdown of the Soviet Union. Under a Cobb–Douglas production function, the growth slowdown is typically attributed to a slowdown in total factor productivity (TFP) growth (Cohn, 1976; Ofer, 1987; Allen, 2003; Hanson, 2003).[4] Under a CES production function with a low elasticity of factor substitution, the decline is instead attributed to a diminishing marginal product of capital (MPK) (Weitzman, 1970; Desai, 1976; Easterly and Fischer, 1995). By allowing technical change to be non-neutral, my paper largely reconciles the findings of these two strands of literature. The results of the paper imply that TFP was indeed the main cause of the Soviet growth slowdown, just like Markevich and Nafziger (2017) and Voskoboynikov (2021) find using revised data. My results, however, suggest that the fall in total efficiency was primarily caused by a fall in capital efficiency, which is consistent with the literature that focuses on the role of diminishing MPK.[5]

[4]Using revised data and new methodologies, recent research on the other socialist economies in Europe challenges this view. Vonyó and Klein (2019) find higher TFP growth rates in Czechoslovakia, Hungary and Poland compared with the existing studies. Kukić (2018) finds that the contribution of TFP to Yugoslav economic growth increased over time.

[5]As section 3 shows, a fall in MPK implies a fall in capital efficiency. The decrease in capital efficiency, in turn, drags down aggregate efficiency.

At a deeper level, the existing literature usually attributes the Soviet growth slowdown to changes in economic policy during the postwar period, like an increase in defense spending, or a shift in investment priority (Allen, 2003).[6] This paper demonstrates that capital efficiency constrained economic growth since the beginning of central planning in 1928. This suggests that the postwar slowdown in growth can be traced and instead at least partially attributed to the factors that were fundamental to the operation of the central planning system.

At a fundamental level, there are many inefficiencies that plagued central planning. Central planning and the absence of private property rendered rational economic calculation impossible (Mises, 1922/1981; Hayek, 1937, 1945). Furthermore, central planning stifled innovation (Berliner, 1976), and demoralised labour (Ofer, 1987, pp. 1815-1816). Moreover, it ensured the survival of inefficient firms (Kornai, 1992), and it was unable to adapt to the requirements of flexible production technology (Broadberry and Klein, 2011).

All these explanations suggest that the Soviet Union was intrinsically plagued by inefficiency. Krugman (1994) thus concludes that the Soviet Union was bound to fail. The factor-neutrality approach taken by most empirical research, however, implies that the socialist economies failed because of the fundamental factors that caused both capital and labour inefficiency. This paper decisively rejects that idea. The Soviet Union failed due to the investment policy that, combined with increasing labour shortages, distorted capital efficiency. This is not to imply that other factors, like those that influenced labour efficiency (e.g., weak material incentives), were irrelevant. They were rather of second-order importance in constraining Soviet growth.

This paper is also related to the wider literature on development under biased technical change (Acemoglu, 1998; Kumar and Russell, 2002; Allen, 2009, 2012). Biased technical change contains important implications for our understanding of comparative economic development patterns. It suggests that technology developed at the global frontier might be unsuitable to the relative factor endowments of the developing economies (Basu and Weil, 1998; Acemoglu and Zilibotti, 2001). The Soviet Union appears to be a salient example of such a developing country. It adopted an input-intensive process of mass production (Davies et al., 1994), which became less suitable over time due to the increasing scarcity of (unskilled) labour.[7] This is consistent with the argument of Broadberry and Klein (2011). They argue that socialist economies should have transitioned to flexible production technology (skilled-labour using) to sustain growth.

The remainder of the paper is organised as follows. Section 2 provides an overview of the Soviet economic institutions and policies. Section 3 provides a description of the methodology I use in the paper, while section 4 provides an extensive description of the required data. Section 5 presents the results of this paper, and section 6 interprets those results. The final section 7 concludes.

[6] Concerning the other socialist economies in Europe, Vonyó (2017) and Vonyó and Klein (2019) attribute the growth standstill of the 1980s to the balance of payments crisis that these countries entered after the oil shocks of the 1970s.

[7] More precisely, the mass production technology that the Soviet Union adopted was intensive in the usage of capital and unskilled labour, economising on the usage of skilled labour (Davies et al., 1994, pp. 182-197).

2 Historical background

This section describes the evolution of economic institutions and policies in the Soviet Union. For the economic history of the Russian Empire, see important recent works like Nafziger (2010); Markevich and Zhuravskaya (2018), and Gregg (2020).

In 1914, Russia entered World War I, which was followed by the Bolshevik Revolution in 1917, and the Civil War that lasted until 1921. Output fell catastrophically during this period (Markevich and Harrison, 2011). The Bolsheviks thus faced a daunting task. They first had to reconstruct the economy, before setting it on a higher growth trajectory.

Soon after the start of the civil war, the communists began their task by establishing a system called "War Communism". The central feature of the system was the compulsory acquisition of agricultural goods from the peasants. The peasants received little or nothing in return. Industrial goods and the services were also brought under tight central control: industrial firms were nationalised, and private trade banned.

Under the strains of the civil war and the radical institutional changes, the economy imploded (Nove, 1992, pp. 57-68). Faced with the threat of a rebellion, the communist leadership under Lenin changed direction (Nove, 1992, pp. 68-77). The New Economic Policy, or NEP, was introduced in 1921. The central feature of the NEP was the retreat into a market economy. In agriculture, peasants could produce and sell their goods freely. Private trade was reintroduced, and most of retail trade was transferred back to market agents (Davies et al., 1994, p. 8). The communists kept the heavy industry in state hands, but privatised most of small-scale firms. The institutional changes brought about by NEP instigated rapid economic growth. By 1928, per capita income recovered to its pre-war levels (Markevich and Harrison, 2011). The pressing question became what to do now that recovery was achieved.

Stalin's answer was to reverse the NEP. In the mid-1920s, Stalin presented himself as an economic moderate who favoured strengthening the NEP. He was opposed to those who favoured greater state involvement (Nove, 1992, pp. 115-132). Once he had achieved power, however, Stalin pursued an industrialisation strategy with much greater state involvement than any imagined. Beginning in 1928, Stalin rapidly put in place the institutions of central planning that defined the Soviet economic system - collectivised agriculture, output targets, soft budget constraints, and the five-year plans. These institutions launched an unprecedentedly rapid economic growth that lasted into the early postwar period.

In order to finance the Soviet industrial revolution, consumption was squeezed (Allen and Khaustova, 2019), and the agricultural surplus was expropriated (Nove, 1962). Peasants were forced to join the collective farms. These farms received compulsory quotas for grain procurement at below-market prices. A disproportionately higher burden fell on the richer peasants (*kulaks*). The collectivisation campaign caused massive distortions in agriculture, and a catastrophic fall in agricultural productivity (Cheremukhin et al., 2017). The mass famine of 1932-1933 ensured, claiming millions of lives (Davies et al., 1994, p. 77).

The drop in agricultural output and the widespread famine in 1932–33 forced Stalin to ease the brutal collectivisation campaign (Davies et al., 1994, pp. 126-127). Despite the easing of collectivisation, agricultural output recovered to the pre-1929 levels only towards the end of the 1930s (Davies et al., 1994, p. 113), while agricultural productivity remained retarded for decades

(Hanson, 2003, pp. 52-57).

Many scholars have examined whether Stalin's policies in agriculture were necessary for the economic development of the Soviet Union. Nove (1962) argues that, in an autarkic socialist state, they were. Collectivisation extracted the agricultural surplus that provided the necessary resources to increase the industrial investment. It also ensured a massive transfer of labour from farms to factories, which fuelled the industrialization drive.[8] Allen (2003) largely agrees with Nove (1962). Cheremukhin et al. (2017), however, do not. They find that collectivisation distorted the Soviet economy, and was not an effective tool of industrialisation.

Simultaneously with the collectivization of agriculture, Stalin nationalised trade, eliminated the remaining private industry, and introduced price controls. The prices no longer reflected opportunity costs, and firms had no rational criteria on which to base their investment choices. Central planning was designed to solve that issue.

Beginning with 1928, five-year plans were introduced. They were extremely ambitious. The aim was to stimulate industrial development and to catch-up with the advanced capitalist economies as soon as possible. Stalin clearly stated this aim in 1931: "We are fifty or a hundred years behind the advanced countries. We must make good this distance in ten years. Either we do so, or we shall go under" (Nove, 1992, p. 190).

In this environment of extreme haste, ministries were translating the plan into practice by setting compulsory annual output targets for the individual firms. Substituting output targets for profits as the governing objective of firms had a profound impact on efficiency. Among other things, it effectively resulted in the end of cost control. It led to a phenomenon that Kornai (1992) termed the "soft budget constraint." To assure the fulfilment of output targets, firms could use more resources than initially planned. Poorly performing firms were rarely allowed to fail. They were kept solvent through a liberal provision of credits, and could disregards costs in their quest to reach the output target. The soft budget constraint bred inefficiency, but also stimulated investment in a backward economy otherwise starved of capital.

Allen (2003) and Cheremukhin et al. (2017) argue that output targets and the soft budget constraints were an effective policy-mix that increased the Soviet industrial output in the short-run and in the medium-run. The most conservative Western estimates indicate that industrial production grew at about 7 per cent per annum during the 1930s (Davies et al., 1994, 138–141). This achievement is all the more impressive given that the rest of the world was mired in the Great Depression at that time.

The economy of the Soviet Union continued expanding rapidly until the late 1950s. The expansion was achieved by the central planning institutions that rapidly mobilised resources. This resulted in an "extensive" growth pattern based on factor accumulation. The extensive growth strategy, however, eventually reached its limits, and economic growth started gradually slowing down since the 1960s. The incentive framework became increasingly unsuitable to sustain growth. The Soviet Union needed to make a transition to an "intensive" growth model, based on innovation and efficiency improvements.

The incentive to innovate and to use the resources efficiently, however, was highly distorted

[8]The collectivisation campaign decreased the income of peasants below their marginal product. It effectively decreased the relative reward of staying in agriculture, stimulating migration to cities.

(Berliner, 1976; Amman and Cooper, 1982; Kornai, 1992; Hanson, 1981, pp. 49-80). Among other issues; the research and development sector was disjointed from the production enterprises, and the reward system was unsuitable at all relevant stages of the innovation process. The firms also faced no competitive pressures to innovate or to improve their efficiency. The emphasis on short-term output targets further discouraged the firms to innovate and to seek efficiency gains.

The Soviet leadership was acutely aware of these issues (Hanson, 2003, pp. 140-148). Nevertheless, the institutions of central planning during the postwar period remained largely the same. The institutional changes that occurred were typically piecemeal, frequently counterproductive, and usually backtracked from.[9] Only Gorbachev at the very end of the 1980s started making real changes to the system. He dismantled the central planning system, but without replacing it with a viable alternative (Nove, 1992, pp. 394-419). The Soviet Union disintegrated in 1991, and each successor state embarked on a transition process to a market economy.

3 Methodology

In this section, I use the framework developed by Caselli and Coleman (2006) and Caselli (2017). Their method allows me to identify separately the efficiency of capital and labour, as well as the relative efficiency of the capital (equipment and structures) and labour (skilled and unskilled labour) sub-inputs. This, in turn, allows me to move closer towards pinpointing the fundamental factors that may have shaped the Soviet growth process.

There is a large theoretical and empirical literature that examines the causes and consequences of technical change.[10] This literature typically uses the Cobb-Douglas production of the following form:

$$Y = AK^{\alpha}(hL)^{1-\alpha} \tag{1}$$

where Y, K, hL and α are, respectively, output, capital, labour (L) augmented by quality (h), and the elasticity of output with respect to its inputs. The TFP term, A, is the efficiency with which capital and labour are used to produce output. Equation 1 is characterised by constant returns to scale, so that α and $1 - \alpha$ must sum to unity.

The Cobb-Douglas production function is an immensely useful starting point in examining the role that TFP has in shaping economic growth. It provides, however, only a single quantitative measure of technical change. It is thus incapable of identifying the possible differences in capital and labour efficiency.

To examine how capital and labour efficiency may influence output, I generalise the Cobb-Douglas production function of equation 1 to the constant elasticity of substitution (CES) form:

$$Y = [(A_K K)^{\sigma} + (A_L hL)^{\sigma}]^{1/\sigma} \tag{2}$$

where σ determines the elasticity of substitution, $1/(1 - \sigma)$, with which capital and labour are combined to produce output. Capital and labor are weak substitutes, relative to a Cobb-Douglas case, if $\sigma < 0$. The inputs are good substitutes, relative to a Cobb-Douglas case, if $\sigma > 0$. The Cobb-Douglas production function is a special case of equation 2 when $\sigma = 0$. In that case,

[9] See Markevich and Zhuravskaya (2011), for example, for the case of Khrushchev's reforms during the 1950s.
[10] See Jones (2016) for a literature survey.

inputs can be exchanged at a rate of one-to-one while maintaining the same level of output (unit elasticity between capital and labour).

In the CES production function, A_K denotes the efficiency of capital, while A_L denotes the efficiency of labour. If A_K increases, this means that the efficiency of capital has increased. if A_L increases, this means that the efficiency of labour has improved. The growth rate of capital or labour efficiency can be influenced by many factors, including factor quality (Jorgenson and Griliches, 1967), managerial quality (Bloom and Van Reenen, 2007), the utilisation rate (Basu, 1996), and spillover effects (Aghion and Howitt, 1992).

There are many CES production functions that can be used. The advantage of that one in equation 2 is threefold. First, it allows me to identify the efficiency of each input. Second, it keeps the number of parameters to a minimum. Finally, it is consistent with a large literature that offers some guidance on the value of the elasticity of substitution parameter.

Moving further, first-order conditions of equation 2 yield:

$$mpl = (A_L)^{\sigma} \left(\frac{Y}{L}\right)^{1-\sigma} \tag{3}$$

$$mpk = (A_K)^{\sigma} \left(\frac{Y}{K}\right)^{1-\sigma} \tag{4}$$

where mpl is the marginal product of labour, and mpk is the marginal product of capital. In equations 3 and 4, the marginal product of an input depends on the productivity (second term of each equation) and efficiency (first term of each equation) of that input. The elasticity of substitution determines the strength of these relationships.

Equations 3 and 4 can be rearranged to back out the efficiency of each input:

$$A_L = \left(\frac{mplL}{Y}\right)^{\frac{1}{\sigma}} \frac{Y}{L} \tag{5}$$

$$A_K = \left(\frac{mpkK}{Y}\right)^{\frac{1}{\sigma}} \frac{Y}{K} \tag{6}$$

Equations 5 and 6 are synonymous. I focus on the interpretation of equation 5, which yields the intuitive result that a high level of labour productivity and mpl implies a high level of labour efficiency. Assuming perfectly competitive markets, where labour is paid its marginal product, the ratio within the parenthesis in equation 5 can be converted into the labour share of output - $(mplL)/Y = (wL)/Y$, where w is the wage rate of labour.[11] The relationship in equation 5 then implies that a high level of efficiency in labour labor increases the effective supply of labour. This will increase the labour share of output if labour and capital are good substitutes ($\sigma > 0$), and reduce it if they are poor substitutes ($\sigma < 0$).

In the Soviet Union, however, inputs did not get paid according to their marginal product and, consequently, the share of input compensation in output was distorted. The assumption of perfectly competitive markets is thus invalid for the Soviet Union. Nevertheless, this assumption

[11] This means that the wage rate of labour is equal to mpl. Synonymously, the rental rate of capital is equal to mpk.

provides a useful starting point in establishing a benchmark value of the ratios $(mplL)/Y$ and $(mpkK)/Y$. Following Easterly and Fischer (1995), I assume that the labour share in output is 0.6, and that the capital share is 0.4.[12] In appendix A.2.1, I experiment widely with these values, and the results are qualitatively identical to the baseline case.

Concerning the Soviet elasticity of substitution parameter, I assume that it is 0.55, based on Easterly and Fischer (1995).[13] The existing literature typically finds higher values of the Soviet substitution parameter (close to one) (Ofer, 1987). With a higher elasticity of factor substitution, I would increase the importance of capital efficiency in driving the Soviet growth deterioration, reinforcing the results of the paper (see appendix A.2.2). By using a lower elasticity value, my baseline results thus provide a lower bound estimate of the capital efficiency effect.

I now decompose the aggregate labour input into skilled and unskilled labour, and the aggregate capital input into equipment and structures. By that, I can analyse the relative efficiency of the sub-inputs that compose each aggregate input - capital and labour.

With that aim in sight, equation 2 can be rewritten as:

$$Y = [(A_{Kc}K_c)^{\sigma} + (A_{Lc}L_c)^{\sigma}]^{1/\sigma} \tag{7}$$

where L_c is labour composed of an unskilled component, U, and a skilled component, S, and K_c is capital composed of equipment, M, and structures, N:

$$L_c = [(A_U U)^{\rho} + (A_S S)^{\rho}]^{1/\rho} \tag{8}$$

$$K_c = [(A_N N)^{\eta} + (A_M M)^{\eta}]^{1/\eta} \tag{9}$$

In the above equations, A_U is the efficiency of unskilled labour, A_S is the efficiency of labour labor, A_N is the efficiency of structures, and A_M is the efficiency of equipment. The parameter ρ determines the elasticity of substitution, $1/(1-\rho)$, with which skilled and unskilled labour are combined into aggregate labour. Equipment and structures are combined into aggregate capital with the elasticity of substitution $1/(1-\eta)$.

Under the assumption of perfectly competitive markets, the first-order conditions of the system of equations 7-9 yield:

$$\frac{w_S}{w_U} = \left(\frac{A_S}{A_U}\right)^{\rho}\left(\frac{S}{U}\right)^{\rho-1} \tag{10}$$

$$\frac{r_M}{r_N} = \left(\frac{A_M}{A_N}\right)^{\eta}\left(\frac{M}{N}\right)^{\eta-1} \tag{11}$$

where w_S is the wage rate of skilled labour, w_U is the wage rate of unskilled labour, r_M is the rental rate of equipment, and r_N is the rental rate of structures. Equation 10 (11) yields the result that the wage (rent) premium is decreasing in the relative supply of skills (equipment), and increasing in the relative efficiency of skilled labour (equipment). In order to back out the

[12] For the United States, I make the standard assumption that the labour share is 0.67, and that the capital share is 0.33.

[13] For the United States, I assume that the elasticity of substitution is 0.7, following Oberfield and Raval (2014).

relative efficiency of skilled labour and equipment, equations 10 and 11 can be rearranged into:

$$\left(\frac{A_S}{A_U}\right)^{\rho} = \left(\frac{S}{U}\right)^{1-\rho} \frac{w_S}{w_U} \tag{12}$$

$$\left(\frac{A_M}{A_N}\right)^{\eta} = \left(\frac{M}{N}\right)^{1-\eta} \frac{r_M}{r_N} \tag{13}$$

In both equations, the relative efficiency of an input depends on its relative supply and its relative price. The strength of the relative supply effect depends on the elasticity of substitution parameter. If inputs are very similar and highly substitutable, it makes sense to boost the efficiency of the relatively abundant factor of production, as it is relatively cheap. If, instead, inputs are very different and highly complementary, it makes sense to boost the efficiency of the relatively scarce factor of production, as it is the one which is constraining growth.

In the setup of equations 7-9, it is impossible to establish the level of efficiency of each sub-input (there are more unknown variables than there are equations), like I previously did for aggregate capital and labour. Nevertheless, examining the bias of technical change, $(A_S/A_U)^{\rho}$ and $(A_M/A_N)^{\eta}$, is highly informative in itself. For instance, if the efficiency of equipment increased over time relative to the efficiency of structures, this implies that the total decrease in capital efficiency was driven by structures, and mitigated by equipment. If, for example, the relative efficiency of skilled labour increased over time, this implies that the total increase in labour efficiency was driven by skilled labor.

I now turn to establishing the remaining parameters of the model. The elasticity of substitution between skilled and unskilled labour has attracted much attention in labour economics.[14] Few if any estimates lie outside the interval [1,2], and a majority cluster around 1.5. I thus assume that the elasticity of substitution between skilled and unskilled labour in the Soviet Union and the US is 1.5. There is much less research on the elasticity of substitution between equipment and structures. I take the estimate of this parameter for both the Soviet Union and the US from Temple (1998). He estimates it at a global level, and finds a value of 0.8. Appendix A.2.3 shows that the results are not sensitive to these elasticity values. Even with elasticity values that lie far outside any reasonable bounds found in the literature, the results remain qualitatively identical to the baseline case.

4 Data

This section discusses the construction of the data. I first discuss the aggregate output and input data, and then discuss the sub-input data.

4.1 Aggregate output and input data

The main source of output, capital, investment and labour data for Russia in 1885–1913 is Gregory (1982). He compiled economic data on the Russian Empire using a variety of historical sources, most of them based on the official statistical publications. Appendix A.1 provides data

[14]See Caselli (2017) for a literature overview.

sources for the US.

The official data sources of the Soviet Union are highly problematic, and require much greater exposition. While the physical output indicators are considered reliable, aggregates expressed in values are distorted by numerous issues, including index number problems, centrally-set prices, hidden inflation, and other factors.[15] These issues lead to a substantial overestimation of the Soviet output growth. In response, Western researchers have invested an enormous effort into eliminating the statistical biases that plague the official output data.

Bergson (1953) was an early pioneer, estimating Soviet output during the interwar period. He aggregated output by industry and sector using factor-cost weights, creating independently established benchmarks of the GDP level. He subsequently used official data on physical output to project output over time based on these benchmarks. During the postwar period, the most substantial work was carried out by the CIA and the Joint Economic Committee of the US Congress, using the same methodology that Bergson (1953) proposed. The alternative estimates by Abram Bergson and the CIA are widely acknowledged as the best available, and are frequently used by economic historians (Harrison, 1998; Allen, 2003; Vonyó, 2017; Vonyó and Klein, 2019; Kukić, 2018).[16]

The alternative output estimates, however, are not uncontroversial. Khanin and Seliunin focused their attention on the CIA figures, claiming that they overestimate Soviet growth, mostly because they underestimate the extent of hidden inflation.[17] Some of the results of Khanin and Seliunin, however, are non-replicable, and they seem to have neglected serious index-number problems when estimating hidden inflation (Harrison, 1993, p. 159). I thus adhere to the CIA (1990, pp. 69-72) estimates for the 1950-1989 period, which were revised and refined after the work of Khanin and Seliunin was published. For the earlier period (1928-1949), I use the output data from Moorsteen and Powell (1966, pp. 361-362), who based their estimates upon Bergson (1953).

The problems that afflict the official output data also afflict the official investment data (Vonyó and Klein, 2019). As such, I take the investment data from the researchers that tried to correct these statistical distortions.[18] Concerning physical capital, it is composed from three asset categories: structures, equipment and livestock. For the 1928-1962 period, I take the net physical capital stock from Moorsteen and Powell (1966, p. 315). They based their work upon the official surveys of the capital stock volume, whose scope was wider and of higher quality than in the contemporaneous market-oriented economies (Goldsmith, 1985). The prices that socialist statisticians used to value capital goods, however, are highly problematic, as they do not reflect factor costs. Moorsteen and Powell (1966) addressed this issue by revaluing the capital stock in 1937 prices that reflect factor costs.

For the remaining period of analysis (1963-1989), I estimate the annual net capital stock

[15] See Ofer (1987, pp. 1770-1775) for an overview of the main issues.

[16] Vonyó (2017); Vonyó and Klein (2019) and Kukić (2018) use an extension of the CIA work that covers the other socialist countries in Central and East Europe.

[17] See Harrison (1993) for an overview of their work.

[18] For the 1928-1949 period, I take the investment data from Moorsteen and Powell (1966, p. 386). For the 1950-1989 period, I take the investment data from CIA (1990, pp. 69-72).

using the perpetual inventory method with geometric depreciation:

$$K_{i,t} = K_{i,t-1}(1 - \delta_i) + I_{i,t} \tag{14}$$

where K denotes capital stock in period t of type i, I denotes gross investment, and δ denotes the deprecation rate. To make the capital stock series internally consistent over the whole period of analysis, I take the depreciation rate for each asset from Moorsteen and Powell (1966) (I also took the capital stock from them for the earlier 1928-1962 period). This makes the depreciation rate for structures 4.6 per cent, and the depreciation rate for equipment 12.7 per cent.

These depreciation rates are similar to what is typically assumed in papers that analyse comparable, market-oriented, economies during the same period.[19] They are higher, however, than in Vonyó and Klein (2019), who analyse central European economies under socialism. Vonyó and Klein (2019) argue that socialist economies used capital for a long duration, and that capital under central planning depreciated at a lower rate than what is commonly assumed, like in the present paper. Assuming lower rates of depreciation, however, would reinforce my results. Capital stock would grow faster, and the fall in capital efficiency would be faster as well (see appendix A.2.4).

After constructing the time series for each asset type, I sum these into an unweighted aggregate. In the absence of a capital market, it is impossible to estimate the returns to capital by type, with which different assets could be weighted and adjusted for quality.

The official labour statistics of the Soviet Union are generally considered trustworthy (Lane, 1966). I thus use labour data from the researchers who based their estimates upon the official data.[20] I express the annul employment data in full-time equivalents, and adjust it for hours worked. This adjustment is important, because average hours worked have fallen significantly after Stalin's death in 1953. If unaccounted for, the fall in hours worked would inflate the growth in labour efficiency.

I adjust labour for quality using the Mincerian approach, following Hall and Jones (1999). Namely, I transform average years of schooling into Mincerian human capital by adjusting for the efficiency of labour with education, relative to the efficiency of labour without education.[21] I assume that the efficiency of labour is piecewise linear, and identical to the return to education. However, unlike Hall and Jones (1999), who assume diminishing returns to education, I assume that the return to education is constant - there is no evidence of diminishing returns to education in either the US or the Soviet Union during the 20th century.[22]

For the US, I make the standard assumption that the return to education is 10 per cent. For the Soviet Union, I assume that the return to education is 6.6 per cent, following Brainerd (1998). She estimated the return to education for the period of the early 1990s, when Russia embarked on a transition process to a market economy. The research that focuses on the central planning period, however, typically finds much lower returns to education than 6.6 per cent (Brainerd,

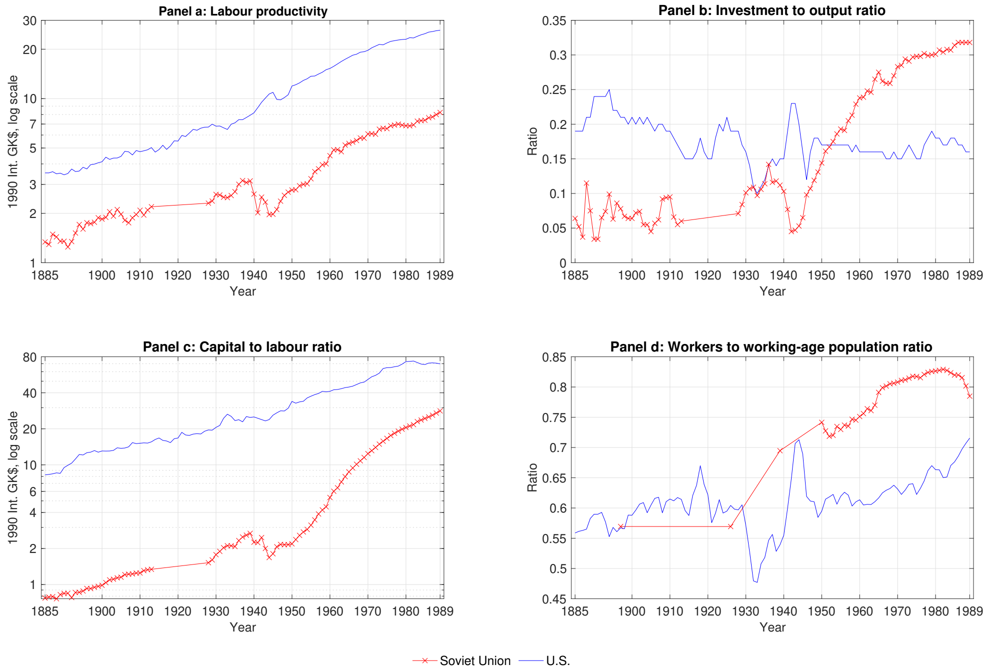
[19] For example, see Prados de la Escosura and Rosés (2009) for Spain.

[20] For the 1928-1940 period, as well as the 1945-1949 period, I take the labour data from Moorsteen and Powell (1966, p. 365). For the 1941-1944 period, I take the labour data from Powell (1968, p. 35). For the 1950-1985 period, I take it from Rapawy and Kingkade (1988, pp. 42-43, p. 63), and from Goskomstat (1991) for the 1986-1989 period.

[21] I take average years of schooling from Lee and Lee (2016).

[22] For the US, see Turner et al. (2007); for the Soviet Union, see Brainerd (1998).

Figure 1: Macroeconomic data of the Soviet Union (Russian Empire) and the US, 1885-1989



Sources: Own calculations. Working-age population (15-64) of the Soviet Union for the years 1897, 1926 and 1939 is based upon population censuses, and is taken from Institute of Demography, HSE (Online). Working-age population for the 1950-1989 period is taken from the United Nations (Online). I take the US working-age population from Lee and Lee (2016) For the rest of the data source, see section 4 for the Soviet Union, and appendix A.1 for the US.

1998). By assuming a lower return to education, I would attach a lower weight to human capital as a source of growth. As appendix A.2.5 shows, this would boost the contribution of labour efficiency to growth, and increase the relative importance of capital efficiency in constraining growth, reinforcing the results of the paper.

Nevertheless, the low return to education during the central planning period does not necessarily imply that socialist workers were inefficient. Egalitarian pressures compressed wage differentials in socialist countries, and workers were not paid according to their marginal product. Basing the return to education on the period of the early transition, when wages were liberalised, but the economic structure still resembled that of the Soviet Union, intends to capture the efficiency of Soviet workers as closely as possible.

Figure 1 reports some of the data I constructed for the period 1885-1989. At the turn of the 20th century, the Russian Empire experienced modest, but roughly consistent, labour productivity gains (panel a). In contrast, productivity gains in the Soviet Union were highly volatile between 1928 and the late 1940s. During this period, there were bursts of labour productivity growth (the start of central planning in 1920s, the consolidation of it during the mid-1930s, and the postwar recovery), interspersed by periods of adverse economic performance (the famine of 1932-1933, the Stalinist purges of the late 1930s, and WWII).

By the 1950s, the Soviet economy had entered calmer waters. During the 1950s, labour productivity gains averaged 4.1 per cent on an annual basis - the highest that the Soviet Union ever achieved. These growth rates, however, are mediocre when placed within a European postwar perspective (Crafts and Toniolo, 2010, table 12.9). Moreover, they soon started decreasing (see table 1 later in text).

Regarding factor accumulation, the Soviet Union experienced an extremely rapid growth in capital (panels b and c) and labour (panel d) until the late 1980s. This rapid expansion of inputs is well established in the existing literature (Ofer, 1987, pp. 1782-1785). As indicated in section 2, the massive mobilisation of resources, brought about by forced savings, stimulated investment into physical capital. Firms engaged in an investment spree because they could disregard cost considerations - the state bailed out the firms that ran into problems. The state also stimulated the expansion of the labour force, primarily through promoting the female labour-force participation rate.

Nevertheless, despite the rapid factor accumulation, the Soviet Union did not manage to converge significantly towards the labour productivity level of the US during the 20th century (figure 1.a). This suggests that efficiency is the principal factor that constrained the economic growth of the Soviet Union relative to that of the US.

Figure 2 situates the Soviet growth performance (GDP per capita) within a wider context. The Soviet Union during the 1928-1989 period grew faster than the majority of advanced, market-oriented, economies. The Soviet Union, however, sits below the fitted (convergence) line. This means that the country did not grow very fast in a comparative perspective, given its initial level of development (panel a).

The Soviet growth performance remains below the sample average in figure 2.b when controlling additionally for the investment rate and education (i.e. the expansion of physical and human capital). Figure 2.b implies that Soviet growth, given the included controls and the performance of other countries, should have been 0.6 percentage points higher on an average annual basis than what it actually was (2.3%). This further suggests that efficiency constrained the relative economic performance of the Soviet Union during the 1928-1989 period.

Focusing only on the later phase of development (1960-1989) paints an even bleaker picture of the Soviet economic performance (panels c and d). Figure 2.d implies that the Soviet growth rate should have been about twice as high as in the actual state during the 1960-1989 period, conditional on the included controls.[23] Within a comparative perspective, the economic growth of the Soviet Union thus became severely retarded since 1960.

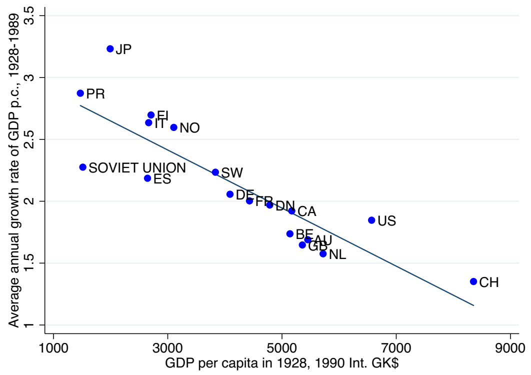
4.2 Sub-input data

I now describe the data I use to estimate the bias in technical change within the capital aggregate and within the labour aggregate. Estimating the bias of technical change within the capital aggregate requires data on the relative supply of equipment and the equipment premium (ratio of rental rates) (equation 13). It is impossible to obtain the data on rental rates, as the capital market in the Soviet Union did not exist. I thus assume that the ratio of rental rates is constant over time. The equipment bias in technical change is, therefore, driven solely by the movement in the relative supply of equipment.

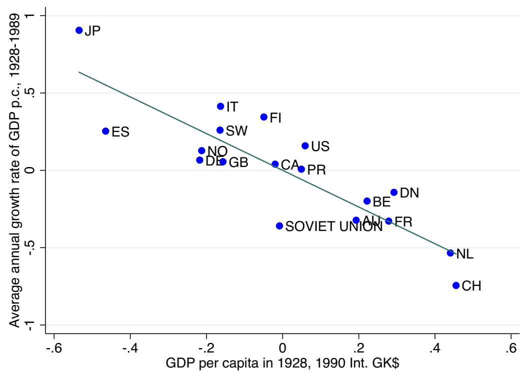
[23] The figure implies that, during the 1960-1989 period, the Soviet average annual growth rate should have been 4.1 per cent, instead of the actual 2 per cent.

Figure 2: Economic growth and convergence in the Soviet Union and advanced economies

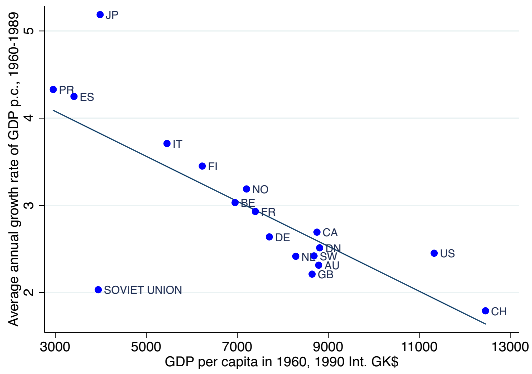
(a) Overall period (1928-1989), unconditional relationship



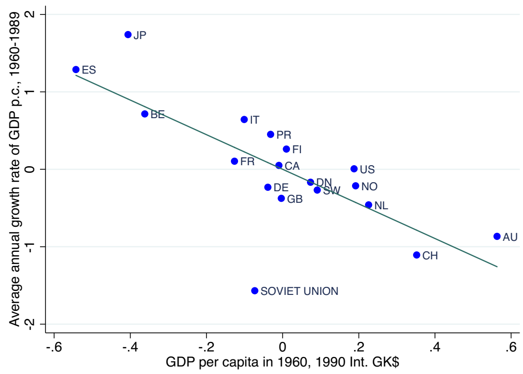
(b) Overall period (1928-1989), conditional relationship



(c) Growth slowdown period (1960-1989), unconditional relationship



(d) Growth slowdown period (1960-1989), conditional relationship



Notes: The relationship between economic growth and initial GDP p.c. in subfigures 2b and 2d is conditional on the average annual investment rate and the average annual growth rate in years of schooling during the periods 1928-1989 and 1960-1989, respectively. The period of WWII (1939-1945) is excluded from the analysis. The regression line is fitted to the actual values of the observations. AU=Australia; BE=Belgium; CA=CANADA; DN=Denmark; FI=Finland; FR=France; DE=Germany; IT=Italy; JP=Japan; NL=Netherlands; NO=Norway; PR= Portugal; ES=Spain; SW=Sweden; GB= United Kingdom; US= United States.

Sources: Own calculations. Data for the Soviet Union is described in section 4. Data for other countries is taken from Jorda et al. (2017) and Lee and Lee (2016)

In order to estimate the technical bias within the labour aggregate, it is necessary to obtain data on the wage premium and the relative supply of skills (equation 12). I first focus on creating unskilled and skilled labour aggregates, which involves choosing an education threshold that separates the skilled labour from the unskilled labour.[24] I take secondary school degree-holders as the lowest skilled group. I thus classify the individuals who did not finish secondary school as unskilled, and those who did as skilled. This is obviously an arbitrary choice, but one that is frequently made in the literature on human capital and development (Goldin and Katz, 2008; Jones, 2014; Caselli, 2017). Appendix A.2.6 shows that experimenting with different classifications does not affects the results.

Following Caselli (2017), the unskilled and skilled aggregates take the forms:

$$U = \sum_{j=1}^{4} e^{\beta_j} l_j \tag{15}$$

$$S = \sum_{j=5}^{7} e^{\beta_j} l_j \tag{16}$$

where l is the share of achievement-group j in the working-age population. Within the unskilled aggregate, β_j measures the efficiency of workers relative to workers with no schooling and, within the skilled aggregate, β_j measures the efficiency of workers relative to workers who completed high school.[25]

Figure 3.a shows that, within the labour aggregate, unskilled labour, relative to skilled labour, was the initially abundant factor of production in the Soviet Union. Over time, however, unskilled labour became the relatively scarce factor production, with the Soviet Union strongly converging towards the relative factor endowments of the US. More broadly, the labour aggregate, relative to the capital aggregate, eventually became the scarce factor of production in the Soviet Union, mirroring the relative scarcity of the labour aggregate in the US (figure 3.b).[26]

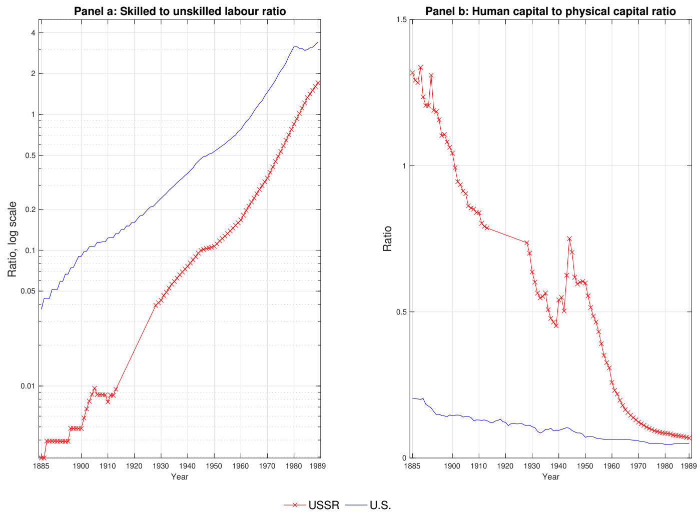
Concerning the skill premium, I would ideally estimate it from the annual individual-level

[24] I base this on the work of Lee and Lee (2016), who provide long-run data on human capital, including by educational threshold (1) no education; (2) some primary schooling; (3) primary schooling completed; (4) some secondary schooling; (5) secondary schooling completed; (6) some college; and (7) at least a college degree.

[25] The literature that examines returns to education when using continuous measures of education, like years of schooling, typically finds constant returns to education, just like I assumed before for the labour aggregate. The literature that focuses on educational threshold effects, however, typically finds non-linear returns to education (see Trostel (2005, pp. 191-192) for a literature overview). I take the educational threshold coefficients β_j from Caselli (2017), who also finds non-linear returns to education. His estimates are based on the US data - there are no such estimates for the Soviet Union. The difference between the Soviet (0.066) and US (0.1) Mincerian coefficient, however, implies that the relative efficiency of Soviet workers at each educational level was lower than in the US. I thus adjust the Soviet β_j coefficients by the ratio between the Soviet and US Mincerian coefficient ($6.6/10 = 0.66$). In the unskilled aggregate, this makes the relative efficiency of Soviet (US) workers 0.21 (0.32) with some primary schooling; 0.25 (0.38) with primary school completed; and 0.37 (0.56) with some secondary school. In the skilled aggregate, the relative efficiency of Soviet (US) workers is 0.09 (0.14) with some college; and 0.3 (0.46) with at least a college degree. I experiment widely with these values in appendix A.2.7, and the results remain robust.

[26] These findings imply that the technologies developed at the global frontier became gradually more suitable to the relative factor endowments of the Soviet Union. The Soviets, however, kept using the input-intensive (capital and low-skilled labour using) process of mass production, developed during the interwar period in the US (Davies et al., 1994; Broadberry and Klein, 2011). The problem was that this production process became less technologically congruent with the Soviet relative factor endowments due to the increasing scarcity of (unskilled) labour.

Figure 3: Factor endowments in the Soviet Union and the US, 1885-1989



Sources: Own calculations. See section 4 for the data sources.

data. Given that this is impossible, I take the shortcut method of Caselli (2017):

$$logW_S - logW_U = \frac{b\sum_j (s_j - u_s)^2 l_j - \sum_j \beta_j (s_j - u_s) l_j}{\sum_{j>4}(s_j - u_s) l_j} \quad (17)$$

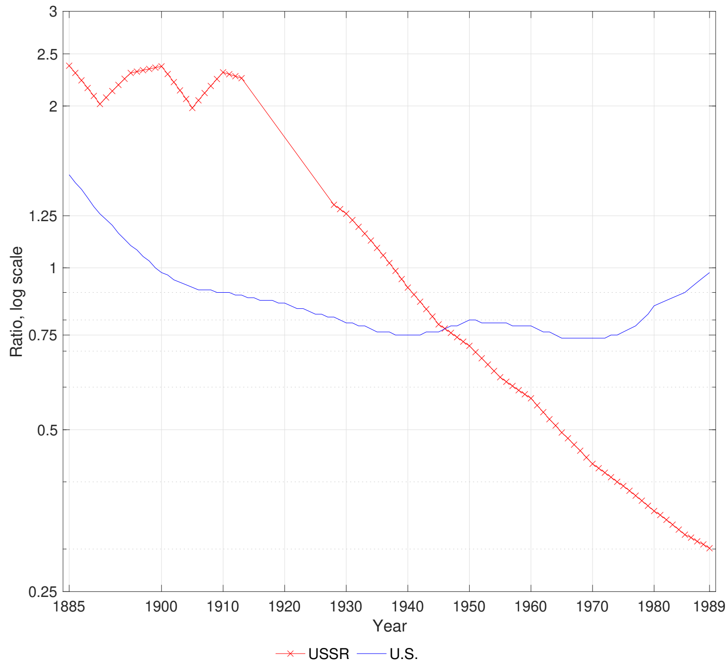
where b is the Mincerian coefficient, s is the years of schooling for each attainment group j, and u is the average years of schooling for the total population. The formula yields the intuitive result that the skill premium is increasing in the Mincerian coefficient, and decreasing in the supply of skills. Given that wages in the Soviet Union were compressed on egalitarian grounds, equation 17 is strongly biased *against* finding a skill premium. Nevertheless, the results may be biased *towards* finding a wage premium if the Soviet policy of wage compression loosened over time. The existing literature, however, demonstrates that this was not the case (Novokmet et al., 2018).

Figure 4 shows the wage premium in the Soviet Union and the US during the 1885-1989 period. The wage premium in Russia at the turn of the twentieth century was high. After the establishment of the Soviet Union, the wage premium decreased. This is aligned with the results of Novokmet et al. (2018), who find that inequality in the Soviet Union was much lower than in the Russian Empire. Concerning the US, the U-shaped evolution of the wage premium during the 20th century mirrors the results of Goldin and Katz (2008).

5 Results

This section presents the main results of the paper. Figure 5 depicts the evolution of labour efficiency. The Russian Empire at the turn of the 20th century experienced a strong growth in labour efficiency. This labour efficiency growth continued into the early Soviet period, although with the initial setbacks associated with the collectivisation of agriculture in 1930-1933 and the Second World War.

Figure 4: The wage premium in the Soviet Union and the US, 1885-1989



Sources: Own calculations. See section 4 for the data sources.

Since the end of WWII, labour efficiency grew at a rapid pace until the early 1960s. Although the labour efficiency growth rate subsequently slowed down, it remained high until the mid-1970s. During this period, the Soviet Union experienced faster labour efficiency gains than the US, converging towards the labour efficiency level of the technological frontier.[27] At the turn of the 1980s, however, the Soviet Union experienced a sharp reversal in trend - labour efficiency decreased, severally handicapping growth during that period.[28] Nevertheless, the decrease in labour efficiency was only temporary, rebounding during the mid-1980s.

Figure 5 also shows the evolution of capital efficiency. Since 1928, the Soviet Union experienced chronic declines in capital efficiency, which were particularly salient during the postwar period. In contrast, capital efficiency in the US remained roughly constant over the 20th century.[29] The evolution of capital efficiency in the Russian Empire at the turn of the twentieth century did not exhibit any strong trend as well. In comparative perspective, therefore, the decline in capital efficiency emerges as a salient fact of the Soviet growth performance.

Table 1 establishes the contribution of capital and labour efficiency to the labour productivity

[27] Between 1946 and 1975, labour efficiency in the Soviet Union increased by a factor of 2.46, while in the US it increased by a factor of 1.66.

[28] US experienced a similar reversal in trend during the 1970s, when labour efficiency stagnated. In the Soviet Union, however, labour efficiency outright declined.

[29] However, it fluctuated strongly. For example, the Great Depression of the 1930s seems to be associated with a major fall in capital efficiency, which was probably induced by a fall in the capital utilisation rate (Basu and Weil, 1998). In the run-up to the WWII, as the economic recovery picked up steam, capital efficiency strongly rebounded. The oil shocks of the 1970s seem to be associated with another strong fall in capital efficiency in the US. This makes intuitive sense to the extent that oil shocks are supply-side shocks. During the 1980s, however, capital efficiency has rebounded, which might be related to the taming of inflation and Ronald Reagan's deregulation push.

Figure 5: Evolution of capital and labour efficiency in the Soviet Union and the US, 1928-1989

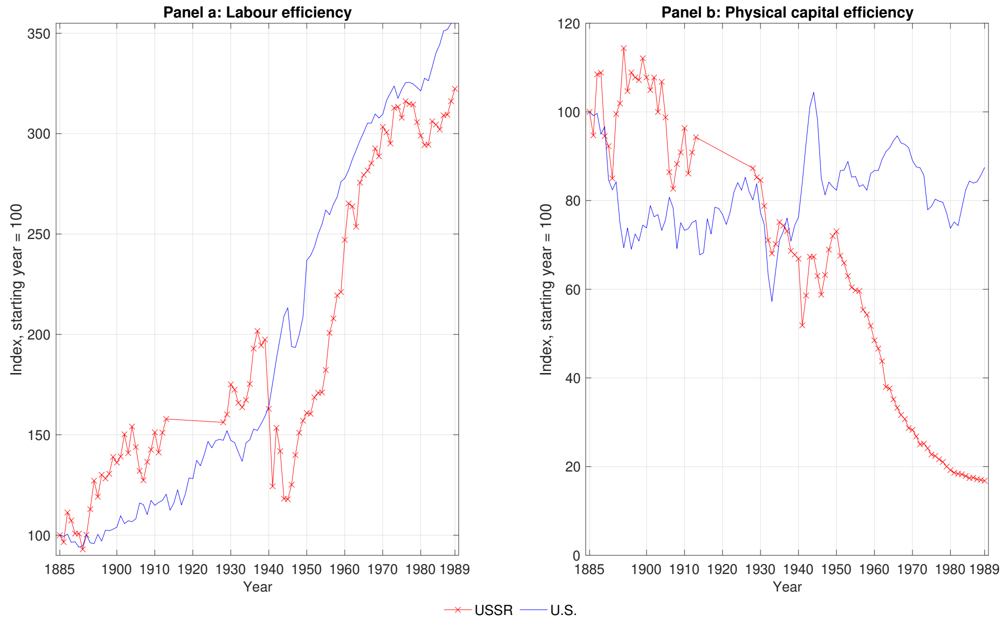


Table 1: Sources of growth, Soviet Union, 1928-1989, average compound annual growth rate (%)

	1928-1989	1928-1939	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989
Labour productivity growth	2.1	2.8	0.3	4.1	2.7	1.4	2.1
Of which:							
Labour efficiency	0.7	1.2	0.6	2.1	0.8	-0.1	0.6
Capital efficiency	-0.8	-1.0	2.1	-1.2	-2.7	-1.3	0.0
Factor accumulation	2.2	2.6	-2.4	3.1	4.6	2.7	1.5
Percentage of labour productivity growth due to:							
Labour efficiency	35	43	188	51	30	-6	31
Capital efficiency	-40	-35	696	-28	-98	-94	-2
Factor accumulation	105	92	-784	77	167	200	71

Notes: Sources of labour productivity growth are based upon the CES equation 2 of section 3. The contribution of each variable is isolated by holding constant the value of all the remaining variables to their initial, 1928, level.
Source: Own calculations based on data in section 4.

growth rate of the Soviet Union. Just like the previous analysis implies, it shows that labour efficiency was an important source of growth, accounting for 35 per cent of labour productivity gains during the overall 1928-1989 period. The contribution of labour efficiency was particularly strong during the 1950s, accounting for 51 per cent of labour productivity gains.

Although labour efficiency growth subsequently slowed down, and severely constrained growth during the 1970s, capital efficiency played a primary role in retarding the Soviet economic performance over the long-run. Capital efficiency decreased labour productivity growth by about 55 per cent during the postwar decades. It had a debilitating effect on growth during the 1960s and the 1970s, decreasing it by more than 90 per cent. During the 1980s, the fall in capital efficiency was less intense, and labour productivity growth, relative to the 1970s, slightly rebounded.

Table 1 additionally shows that factor accumulation was the main source of economic growth throughout the central planning period. For that matter, factor inputs gradually accounted for a larger share of economic growth during the postwar decades. During the 1980s, however, the contribution of factor accumulation decreased. Factor inputs thus played an important role in decreasing growth in the final decade of socialism. This mirrors the results of Vonyó and Klein (2019), who argue that factor inputs were of major importance in causing the deterioration of growth in the other socialist economies in Europe during the 1980s.

Segmenting periods is a useful quantitative summary of results, but can obfuscate the dynamic dimension. I now seek to reinforce the main finding of this paper. Namely, that capital efficiency drove the postwar slowdown in Soviet economic growth.

Figure 6 first charts the contribution of labour efficiency to economic growth. It plots the evolution of labour productivity under the counterfactual scenario where labour efficiency is held constant (the line "without labour efficiency"), while all the other sources of growth are allowed to vary (human capital, physical capital, and capital efficiency). This counterfactual line indicates what labour productivity would have looked like if labour efficiency had not grown at all. The discrepancy between this line and the actual path of labour productivity is thus caused by labour efficiency. If the two lines move in parallel, it means that labour efficiency accounts for a constant share of growth. If they diverge, it means that the share of growth that labour efficiency accounts for has changed.

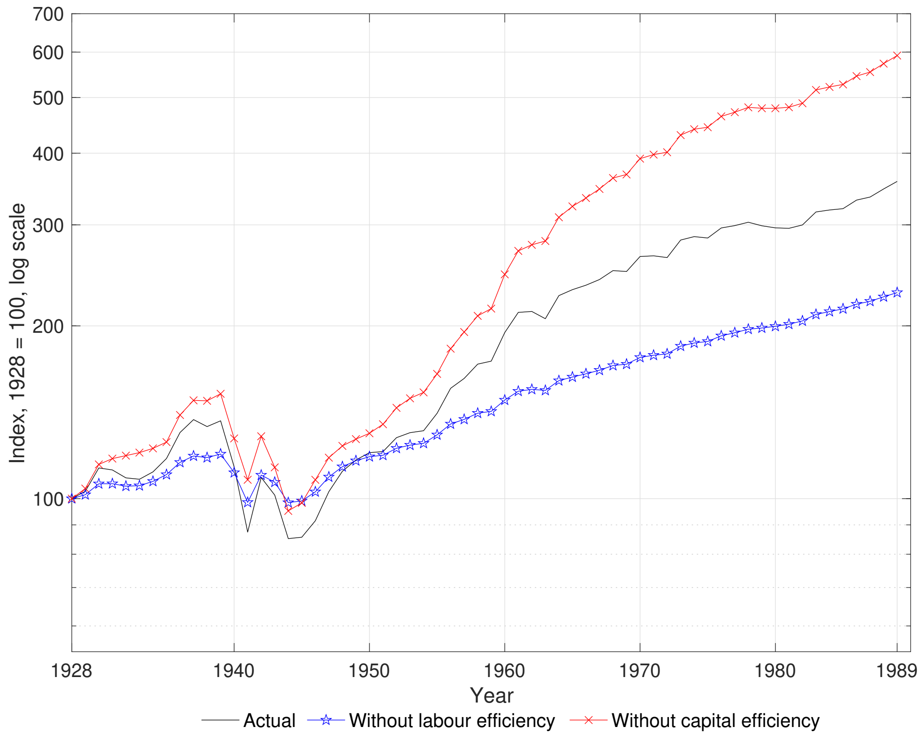
Figure 6 reveals that, in the early stages of growth (approximately until the mid-1950s), the actual path of labour productivity and the counterfactual path in the absence of labour efficiency growth (the line "without labour efficiency) track each other closely. This means that the combined physical capital, human capital, and capital efficiency can replicate most of economic growth. During the 1950s, the gap between the two lines gradually widens, and then stabilises during the remaining postwar decades. This means that labour efficiency gradually accounted for a larger share of growth during the 1950s, and subsequently supported growth in a relatively consistent, although less forceful, manner. At the turn of the 1980s, however, labour efficiency severely constrained growth (the gap between the two lines narrows).

Nevertheless, capital efficiency debilitated growth to a much greater extent, as figure 6 shows. During the 1930s and the 1940s, the actual path of labour productivity is below the counterfactual path where capital efficiency is held constant (the line "without labour efficiency) - it then falls further behind during the postwar decades. This means that capital efficiency constrained growth since 1928, and drove the slowdown of the economy during the postwar period. The results imply that, if capital efficiency was constant, the level of labour productivity by 1989 would been 65 per cent higher than in the actual state. In comparative terms, the Soviet Union would have attained 52 per cent of the US labour productivity level, instead of the 31 per cent it actually attained in 1989.

To gauge further the relative significance of the various sources of growth, figure 7 displays the marginal contribution of each source of growth. It adds to the CES model in equation 2 one at a time the growth rate of factors of production (physical and human capital), the growth rate of capital efficiency, and, finally, the growth rate of labour efficiency.[30] These sources of

[30] When sources of growth are added sequentially, I keep the remaining sources of growth fixed to their initial 1928 level. Thus, for example, when examining the contribution of factor accumulation to economic growth, I keep the labour and capital efficiency fixed to their initial 1928 level.

Figure 6: The actual evolution of labour productivity versus the counterfactual evolution of it (without labour efficiency or without capital efficiency), 1928-1989, Soviet Union



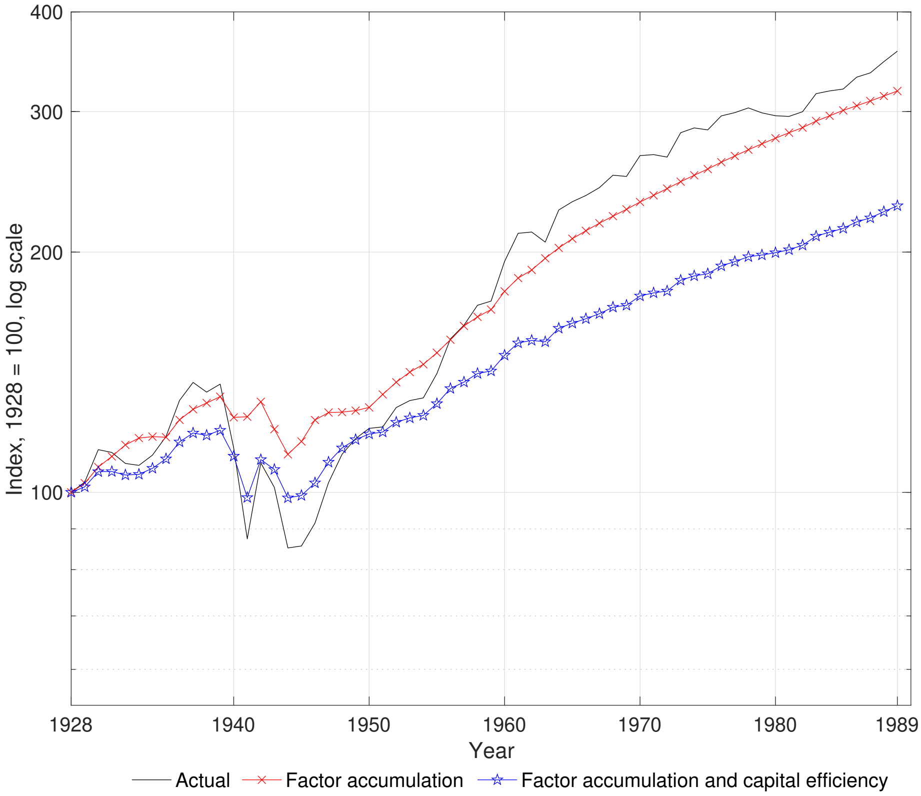
Notes: The line "without labour efficiency" holds constant labour efficiency, while allowing all the other sources of growth to vary (capital efficiency, human and physical capital). It thus indicates what labour productivity would have looked like if labour efficiency had not grown at all. The interpretation of the line "without capital efficiency" is completely synonymous to that of the previous line. The counterfactual output levels are derived from the CES equation 2 in section 3.
Source: Own calculations based on data in section 4.

growth in tandem match the actual evolution of labour productivity (the line "actual"). When the sequential addition of a variable makes the simulated path of economic growth move more in tandem with the actual path of economic growth, the newly added variable is responsible for that movement.

Figure 7 reveals that the path of the actual output and the path of the counterfactual output determined by factor accumulation (the line "factor accumulation") track each other closely over the whole period of analysis. This means that the expansion of physical and human capital can explain most of economic growth that the Soviet Union achieved. When capital efficiency is added to the model containing factor accumulation, the discrepancy between the two lines gradually widens since the 1950s, reconfirming the notion that capital efficiency drove the Soviet growth slowdown. Adding labour efficiency to the model containing factor accumulation and capital efficiency (the line "actual") reconfirms that further (the line of labour productivity is now significantly higher since the 1950s).

In order to gain a deeper understanding of what drove the efficiency of the capital and labour aggregates, figure 8 shows the bias of technical change within each factor of production. Within the labour aggregate, technical change was skill-biased in the Soviet Union since the 1950s. The increase in the relative efficiency of skilled labour was particularly strong during the 1970s and

Figure 7: Simulations of labour productivity versus the actual movement, 1928-1989, Soviet Union



Notes: This exercise adds to the CES model in equation 2 (section 3) one at a time the expansion of factors of production, capital efficiency, and labour efficiency. The three sources of growth in tandem match the data (the line "actual").
Source: Own calculations based on data in section 4.

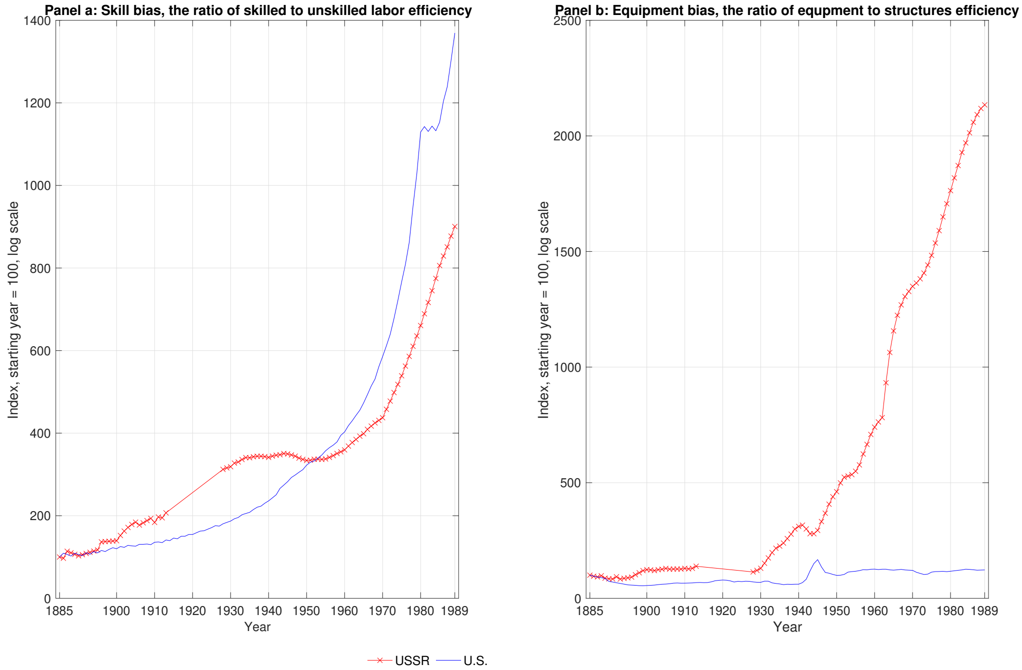
the 1980s. These findings suggest that skilled labour supported the labour efficiency growth rate during the postwar period, and particularly so during the final decades of analysis. Technical change was also skill-biased in the US during the 20th century, which the existing literature widely recognizes (Acemoglu, 1998; Goldin and Katz, 2008).

Concerning the capital aggregate, technical change was biased towards equipment in the Soviet Union (figure 8.b). This implies that the efficiency decline in the capital aggregate was driven by structures, and mitigated by equipment.[31] This conforms to the findings of DeLong and Summers (1991), who argue that equipment embodies technology, and is thus a major driver of TFP. It also conforms to Voskoboynikov (2021), who argues that the over-concentration of investment in structures distorted the TFP growth rate of the Soviet Union.

Although these results on the bias of technical change within each factor of production are informative, they should be, however, taken with caution. They depend on stricter assumptions and some data shortcuts (section 4), and are thus of secondary importance. The results on the overall labour and capital efficiency are more credible, and hence of primary importance.

[31] In the US, however, it seems that there was no strong bias in technical change within the capital aggregate.

Figure 8: The bias in technical change, Soviet Union and the US, 1928-1989



6 Interpretation of results

The existing literature provides many explanations about the Soviet growth slowdown. This section focuses on interpreting the downward trend in Soviet capital efficiency during the postwar period. It also discusses the factors that caused the decrease in labour efficiency at the turn of the 1980s.

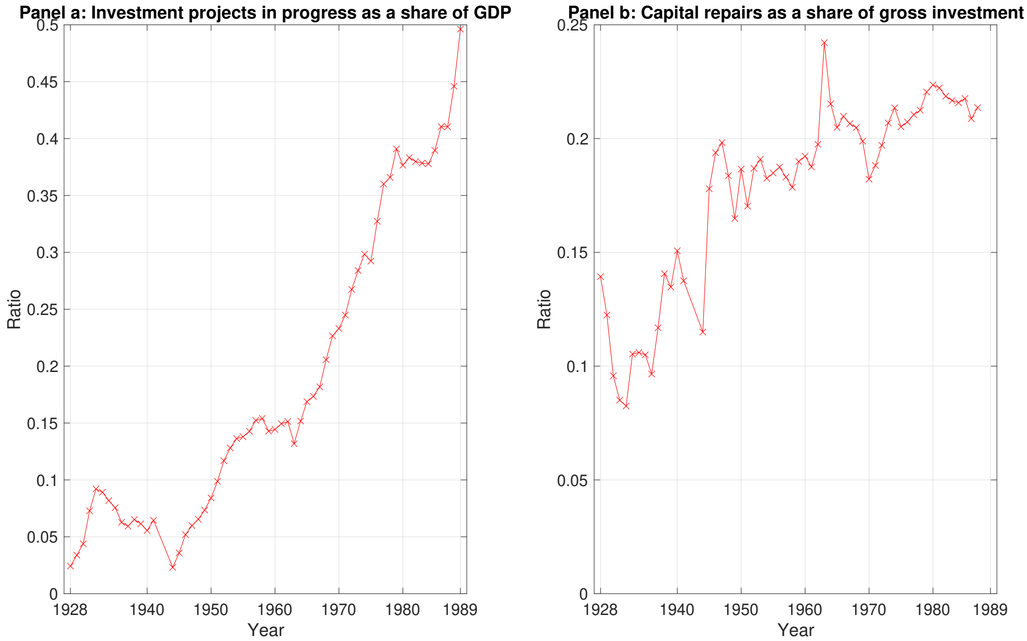
6.1 Capital efficiency

The decrease in Soviet capital efficiency was driven by an inadequate investment policy, combined with increasing labour shortages. A distinctive feature of the Soviet investment policy was the over-concentration of investment in new enterprises, compared with retooling the existing enterprises. This pattern, although natural in the early stages of industrialisation, has prevailed in the Soviet Union throughout the central planning period (Cohn, 1979, 1982; Hanson, 1981). The main reason for this is the relative ease of planning and directing new plants from the center, compared with planning and enforcing investment in the existing plants (Ofer, 1987, p. 1808).[32]

As figure 9.a shows, one corollary of the Soviet investment policy, combined with the general pressure on current production, was the high stock of incomplete investment projects (factories and structures). Such stocks immobilised capital, held up production, and caused a decrease in capital efficiency. A major problem with the Soviet growth, therefore, was that a large fraction

[32] An additional reason for the over-concentration of investment in new plants is that enterprises had strong incentives to expand capacity (Hanson, 1981). Accumulated excess capacity helped firms meet output targets while operating in an environment characterised by frequent shortages (Kornai, 1992). Moreover, under the soft budget constraint, the managers did not have to worry about financing additional plants. Once the investment project was started, the investment finance would follow.

Figure 9: Unfinished investment projects and capital repairs, Soviet Union, 1928-1989



Sources: Investment projects in progress for the 1928-1962 period are taken from Moorsteen and Powell (1966, p. 359), and from Slavic-Eurasian Research Center (Online) for the 1963-1989 period. Capital repairs for the 1928-1949 period are taken from (Moorsteen and Powell, 1966, p. 386), and from CIA (1990, pp. 69-72) for the 1950-1987 period.

of the capital stock was not used in production, indicating a wasteful allocation of resources. Figure 9.a shows that this problem became more intense during the postwar period, particularly since the mid-1960s. The finding of the previous section that the relative efficiency of structures decreased over time suggests that further (figure 8.b).[33]

Beyond immobilising capital, the increasing stock of incomplete projects also delayed the introduction of new technologies. In the Soviet Union, new technologies were typically implemented in the new factories by central directive (Hanson, 1981, pp. 65-71). This allowed the central planners to circumscribe the managers of existing factories, who were extremely reluctant to introduce new technologies. They feared that untested technologies would disrupt the existing production process, jeopardising their objective to satisfy the current output target.

Consequently, the service lives of machinery and equipment in the Soviet Union were extremely long (Cohn, 1979). Such old equipment required an ever-increasing expenditure on maintenance and repair to be kept in use (figure 9.b). As such, production costs increased over time, and capital efficiency decreased further.

Once the stocks of incomplete projects were finally brought to use, however, there were not enough workers to operate the machines and produce high levels of output. The shortage of labor thus compounded the decrease in capital efficiency. These shortages occurred already during the 1930s (Nove, 1992, pp. 197-201).[34] This is indicated by the extremely high labour-

[33]That is, the efficiency of structures, relative to the efficiency of equipment, presumably decreased because an increasing proportion of structures was incomplete.

[34]Despite the rapid inflow of labourers from the countryside, unemployment in the urban areas was eliminated

force participation rate during the interwar period in figure 1.d. These labour shortages were particularly severe among the unskilled labour (Nove, 1992, pp. 197-201), which the mass production process that the Soviet Union adopted relied upon (Davies et al., 1994).

During the postwar period, the labour shortages became more salient (indicated by figures 1.d and 3). The agricultural surplus labour was gradually exhausted, and the female labour-force participation eventually reached its ceiling (Ofer, 1987, pp. 1782-1784). The consistent reduction of the official work week since the 1950s constrained the expansion of the labour supply further. Labour shortages thus intensified over time, decreasing the utilisation rate of equipment, and delaying the construction of new plants.[35] By extension, they reinforced the capital efficiency decline.[36]

Of course, many other countries in postwar Europe during the "Golden Age" of economic growth experienced labour shortages as well. Labour shortages in the Soviet Union, however, were salient for two reasons. First, the soft budget constraint induced an excess demand for inputs, including labour (Kornai, 1992). Second, the Soviet population loses during WWII were immense. Additionally, millions of people perished earlier during the famine of 1932-1933. Allen (2003, pp. 119-120) estimates that, in the absence of collectivisation and WWII, Soviet population at the end of the 1980s would have been 30 per cent higher than in the actual state.

Naturally, there are other factors that may have also constrained the capital efficiency growth. Allen (2003) argues that there was a shift in investment policy during the 1960s and the 1970s. The depletion of old oil fields led to a redirection of investment from Europe to Siberia.[37] This involved huge capital expenditure, but yielded little return, undoubtedly reinforcing the capital efficiency decline during the 1960s and the 1970s. It is unlikely, however, that this shift in investment policy was of primary importance in shaping the overall trajectory of capital efficiency, which started declining since 1928.

Another factor that may have constrained capital efficiency is weak innovation (Berliner, 1976; Amman and Cooper, 1982). One measure of innovation is research and development (R&D) expenditure. Figure 10 shows that R&D expenditure in the Soviet Union has increased during the postwar period, from 1.4 per cent of GDP in 1950, to 3.4 per cent in 1987.[38] The research effort of the Soviets was thus not the main problem with technological growth. The main issue was rather that the diffusion rate of technology was low, and that this diffusion decreased over time (Kontorovich, 1986).[39] The previous discussion implies that technological diffusion was constrained by the increased delays in investment projects, which postponed the introduction of

by the early 1930 (Lane, 1966, pp. 19-35). Under the strains of rapid industrialisation, the demand for labour far outstripped the available supply, causing acute labour shortages.

[35] The increasing stock of incomplete projects was thus at least partly caused by an increase in labour shortages.

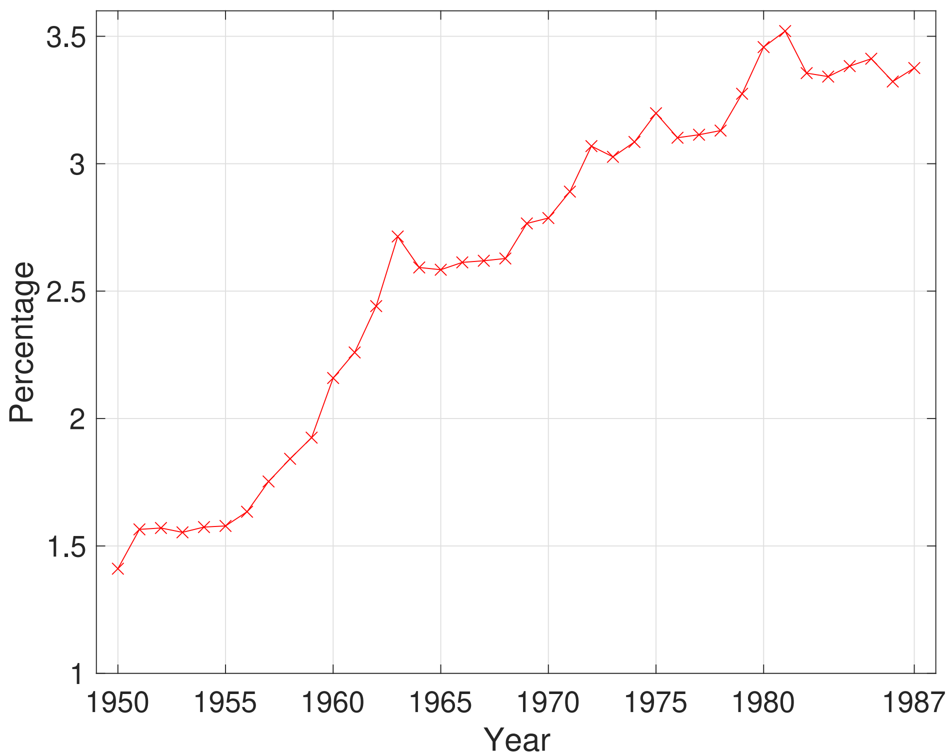
[36] One indicator of increasing labour shortages is the shift coefficient of workers - the ratio of all workers employed during the day to the number of workers in the largest shift. The official sources report that the shift coefficient progressively decreased over time, from 1,54 in 1960, to 1,42, in 1970, 1,37 in 1980, and 1,34 in 1990 (Goskomstat, 1987, 1991). This indicates that labour shortages caused a decrease in the capital utilisation rate.

[37] The redirection of investment is reflected in the renewed increase in the stock of incomplete projects after a temporary lull at the turn of the 1960s in figure 9.

[38] During the same period, R&D share of GDP in the US has increased from 1 per cent to 2.9 per cent (Federal Reserve Bank of ST. Louis, Online).

[39] The diffusion of technology was at least partially handicapped by an increase in defense spending (Ofer, 1987, p. 1815), which redirected R&D expenditure from the civilian sector to the military sector, which was largely insulated from the remainder of the economy. Easterly and Fischer (1995), however, find no clear association between the size of the defense burden and economic growth in the Soviet Union.

Figure 10: Research and development expenditure as percentage of GDP-1989, Soviet Union, 1950-1987



Note: Research and development expenditure prior to 1950 is not available.
Source: CIA (1990, pp. 69-72).

new technologies.

6.2 Labour efficiency

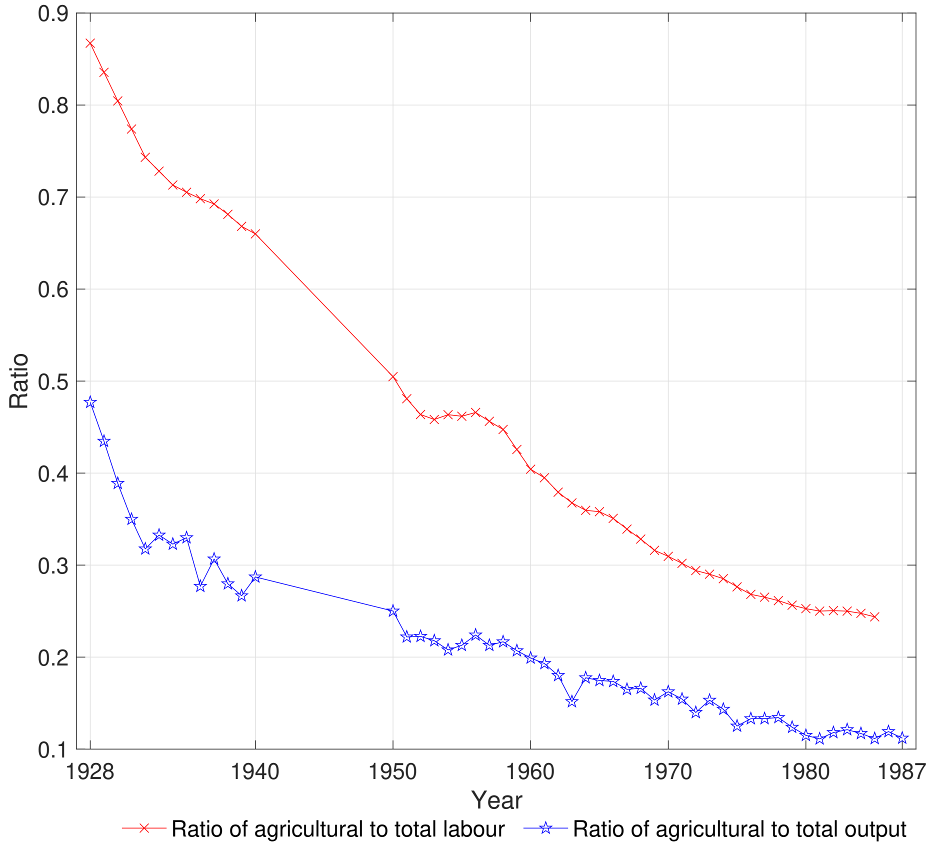
Labour efficiency growth decreased by the early 1960s, driven by the slowdown in structural modernisation (implied by figure 11) and the exhaustion of the potential for postwar recovery (Vonyó, 2017).[40] Subsequently, labour efficiency grew at a roughly stable rate until the turn of the 1980s, when the growth rate became negative.[41]

The decrease in labour efficiency at the turn of the 1980s was driven by a sequence of harvest failures in agriculture, caused by a set of weather shocks in 1975, 1979, 1980, and 1981 (Hanson, 2003, p. 150). The fall in agricultural output was particularly severe between 1978 and 1981, exactly at the time when labour efficiency registered a strong decrease. During this period, grain output - the most important agricultural product of the Soviet Union - fell by about 40 per cent

[40]Structural modernisation is not only about labour. It also involves a sectoral shift of capital. However, agriculture employed a very low share of capital (Moorsteen and Powell, 1966), and it is therefore unlikely that structural modernisation had an important impact on overall capital efficiency.

[41]It is doubtful that the slowdown in structural modernisation and in the postwar recovery can explain the decrease in labour efficiency at the turn of the 1980s. The slowdown in structural modernisation and the exhaustion of the potential for postwar recovery were long and drawn-out processes that can be tracked to at least the 1950s, while the fall in labour efficiency at the turn of the 1980s was sharp and sudden.

Figure 11: Agricultural share of total labour and total output, Soviet Union, 1928-1987



Notes: Output is measured in 1937 rubles.
Sources: Labour for the interwar period is taken from Davies et al. (1994, pp. 278-279), and from Rapawy and Kingkade (1988, pp. 42-43) for the postwar period. Output for the interwar period is from Moorsteen and Powell (1966, pp. 361-362), and from CIA (1990, pp. 54-57) for the postwar period.

(Hanson, 2003, p. 152), decreasing the overall output per efficiency unit of labour.[42]

In general, the Soviet economy was highly sensitive to fluctuations in agricultural output. Despite rapid industrialisation, the Soviet agriculture during the postwar period still employed a large share of labour (figure 11).[43] Fluctuations in agricultural labour efficiency thus loomed large over the labour efficiency of the overall economy.[44]

In 1982, agricultural output started recovering (Hanson, 1981, p, 152), and so did labour efficiency (figure 5). The largely transitory factors in agriculture thus drove the evolution of labour efficiency during the 1970s and the 1980s. This is consistent with the business cycle literature, where booms and boosts of output are typically reflected in the booms and busts of TFP (Basu, 1996).

There are, however, other factors that also decreased the Soviet labour efficiency growth. One of these is the deterioration of population health during the 1970s and the 1980s (Brainerd,

[42]During the same period, overall agricultural output decreased by close to 20 per cent (CIA, 1990, pp. 54-57).
[43]Given the low level of productivity, the agriculture depended on a large labour-force to feed the population of the Soviet Union.
[44]Overall capital efficiency was impacted much less by developments in agriculture, given that agriculture employed a very low share of capital (Moorsteen and Powell, 1966).

Figure 12: Labour efficiency and health, Soviet Union, 1960-1989

Notes: Labour efficiency is adjusted for health following the method of Weil (2007). Namely, as a proxy for health, I use the adult mortality rate, which measures the fraction of current 15-year-old people who are expected to die before age 60. This measure can be interpreted as the probability of dying "young", and is therefore a plausible proxy for overall health condition.
Source: Adult mortality rate is taken from World Bank (Online). Data prior to 1960 is unavailable.

2010). After decades of improvements, infant and adult mortality abruptly increased, and child and adult height deteriorated.[45] I correct labour efficiency for the decrease in population health using the method of Weil (2007)[46] Figure 12 shows that, after adjusting for health, labour efficiency growth during the 1970s and the 1980s is higher. Nevertheless, it still registers a decrease at the turn of the 1980s. This means that, although health played an important role in decreasing labour efficiency growth, it was not of first-order importance in causing that decrease.

Another factor that might have constrained labour efficiency is the shortage of consumer goods, which destimulated labour effort (Kornai, 1992). These shortage were largely stable during most of the postwar period (Kim and Shida, 2017). They have increased, however, during the 1980s, which presumably reinforced the labour efficiency decline at the turn of the 1980s.

The previous explanations focused on the efficiency of the overall labour aggregate, neglecting the possible difference between skilled and unskilled labour. The empirical results of the paper show that the efficiency of skilled labour, relative to unskilled labour, has strongly increased

[45] The deterioration in population health was shaped by many factors, including an increase in alcohol consumption, environmental degradation, and macroeconomic imbalances that caused shortages of consumer goods (Brainerd, 2010, pp. 110-111).

[46] Weil (2007) argues that health is a major driver of TFP growth. As a proxy for health, he uses the adult mortality rate, which measures the fraction of current 15-year-old people who will die before age 60. In practice, this is a measure of the probability of dying "young", and is therefore a plausible proxy for overall health status.

during the 1970s and the 1980s. This implies that the decline in labour efficiency at the turn of the 1980s was driven by unskilled labour, and mitigated by skilled labour. This makes intuitive sense to the extent that skilled labour typically did not work in agriculture (Davies et al., 1994, pp. 122-123), was of better health than unskilled labour (Brainerd, 2010), and had privileged access to consumer goods (Nove, 1992, pp. 211-212). Skilled labour was thus less impacted by the factors that negatively influenced the overall labour efficiency growth.

7 Conclusion

The growth slowdown of the Soviet Union has inspired much research by economists and historians alike. They usually attribute the slowdown to a growing inefficiency of resource allocation under central planning. This paper makes a novel contribution to the literature by studying the direction and bias of technical change in the Soviet Union. It takes a more nuanced approach to efficiency compared to the existing studies, offering novel results.

This paper demonstrates that the Soviet Union registered strong labour efficiency gains until the 1970s, converging towards the labour efficiency level of the global frontier – the US. Labour efficiency growth did decrease over time, but was not of primary importance in causing the Soviet growth retardation. That retardation was instead driven by a decline in capital efficiency. At a fundamental level, I argue that this capital efficiency decline was driven by an inadequate investment policy, combined with increasing labour shortages.

The findings of this paper contain broader implications for our understanding of the growth process. In a subset of OECD countries during the postwar period (1980-2010), Caselli (2017) finds similar results. He finds that the increase in labour efficiency was accompanied by a decrease in capital efficiency in many economies. Kukić (2021) finds similar results for a group of socialist economies in eastern Europe. These findings indicate that there might be an efficiency "trade-off" inherent to the growth process. As countries develop, they seem to trade capital efficiency for labour efficiency.

The fact that Soviet Union experienced a fall in capital efficiency does not seem surprising in this context. However, it seems that the trade-off between capital and labour efficiency was much more intense in the Soviet Union. More research is required to gain a deeper understanding of what drove these efficiency patterns. The analysis in this paper is entirely focused at the country level as the basic unit of analysis. Further progress on understanding non-neutral technical change could come from industry-level, and, even better, firm-level analysis.

A Appendix

A.1 Data for the United States

I take the US GDP from data from (Maddison, Online). For the 1885-1949 period, I take the labour data (total hours worked) from Kendrick (1961, pp. 305-307), and for the 1950-1989 period, I take it from Conference Board (Online). The investment data for the 1885-1914 period I take from Kuznets (1961, p.. 555), and for the 1915-1989 period, I take it from the BEA (Online).

The physical stock data I take from Kendrick (1961, pp. 305-307) for the 1885-1924 period, and from the BEA (Online) for the 1925-1989 period. Data on average years of schooling I take from Lee and Lee (2016), for the working-age population. Their data is provided at five-year intervals. As such, I linearly interpolate the remaining years.

A.2 Robustness checks

This section presents a set of robustness checks. The baseline results are robust to alternative capital share parameters, elasticity of substitution parameters, depreciation rates, returns to education and schooling, and skill thresholds. Changing the data and the assumptions of the model influences the results quantitatively, but not qualitatively. Under a variety of settings, capital efficiency thus remains the primary constraint on Soviet growth.

Before moving further, it is important to note that the capital share, as well as the elasticity of substitution parameters, are constants which affect the levels of capital and labour efficiency (and thus their contribution to growth), but not their trajectory. I therefore do not show the evolution of capital and labour efficiency when changing the capital share and substitution parameters. I show only the contribution of labour and capital efficiency to economic growth.

A.2.1 Alternative capital shares

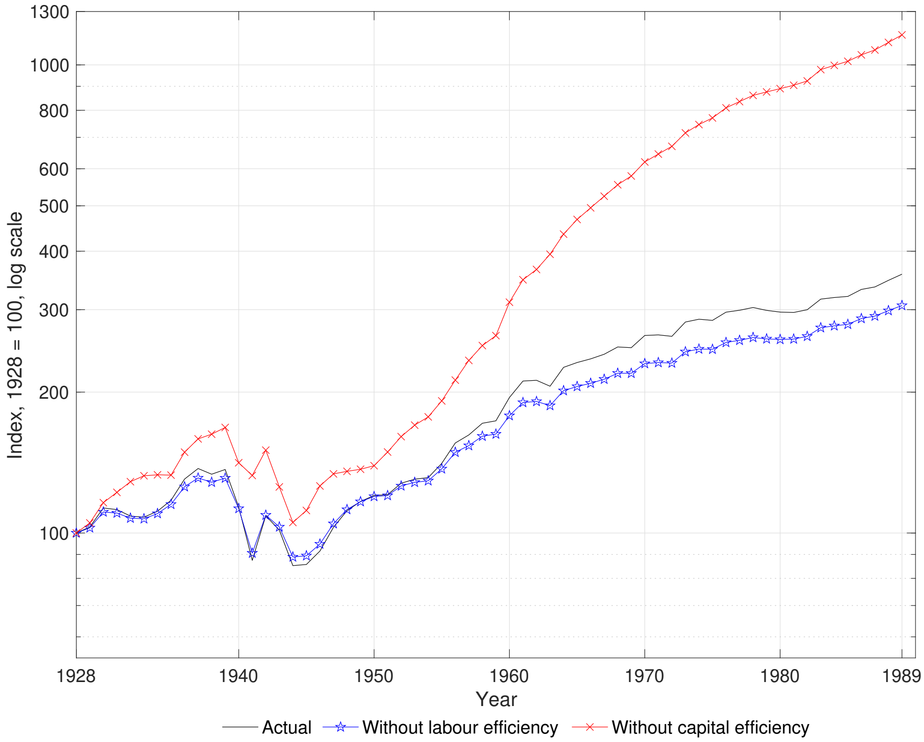
The assumption of perfectly competitive markets is rigid for a socialist economy. The Soviet Union was certainly characterised by markets that were imperfectly competitive. As such, factor shares do not necessarily reflect the elasticity of output with respect to each input. The technological parameters might thus be mis-measured. To the extent that monopoly profits are reflected in capital income, the elasticity of output with respect to capital is overestimated. Concerning labour, to the extent that socialist regimes suppressed wages to fund investment, the elasticity of output with respect to labour is underestimated.

The elasticity of output serves as a weight on the efficiency of input. The larger the elasticity on, say, physical capital, the larger will be the impact of capital efficiency on the growth rate of output. Under constant returns to scale, however, these elasticities sum to one. Increasing the explanatory power of capital also means lowering the explanatory power of labour. With a higher capital share, therefore, the decline in capital efficiency will have a stronger impact on growth, while the increase in labour efficiency will have a weaker impact on growth.

Here, I test the sensitivity of my results to the increase in the elasticity on capital. I find that increasing the capital share by smaller amounts (e.g., by 10 or 20 per cent) impacts the results minimally. I thus prefer to present here a much more aggressive robustness check. I double the baseline capital share parameter from a value of 0.4, to a value of 0.8. The capital share value of 0.8 lies far outside all reasonable bounds found in the literature (Ofer, 1987, pp. 1814-1819). Nevertheless, it remains interesting to the test whether the baseline findings remain robust even under assumptions that are unrealistic.

In figures 13 and 14, I replicate the baseline figures 6 and 7 of the main text, respectively. With a higher capital share, the decline in capital efficiency has a much stronger impact on growth, reinforcing the key finding of the paper. Concerning labour efficiency, its increase has a weaker impact on growth compared to the baseline case, although it remains an important

Figure 13: The actual evolution of labour productivity versus the counterfactual evolution of it (without labour efficiency or without capital efficiency), with capital share of 0.8, 1928-1989, Soviet Union



Notes: The line "without labour efficiency" holds constant labour efficiency, while allowing all the other sources of growth to vary (capital efficiency, human and physical capital). It thus indicates what labour productivity would have looked like if labour efficiency had not grown at all. The interpretation of the line "without capital efficiency" is completely synonymous to that of the previous line. The counterfactual output levels are derived from the CES equation 2 in section 3.

Source: Own calculations based on data in section 4 of the main text.

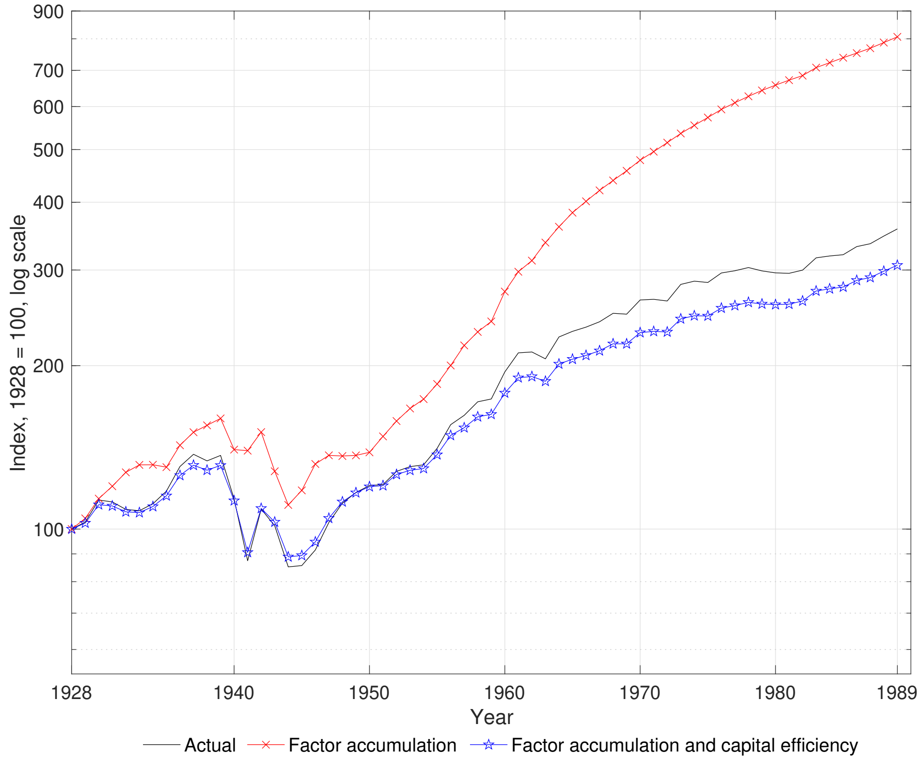
source of growth. The results, therefore, are qualitatively identical to the baseline case - capital efficiency remains the principal determinant of the Soviet growth retardation.

I now decrease the capital share parameter. With a lower capital share, the change in capital efficiency will have a weaker impact on growth, while the change in labour efficiency will have a stronger impact on growth.

Like the previous exercise, I find that decreasing the capital share by a smaller amount (10 and 20 per cent) has a minimal impact on the results. I therefore present here a much more aggressive robustness check. I decrease the baseline capital share parameter from a value of 0.4 to a value of 0.2, which is below any value found in the literature (Ofer, 1987, pp. 1814-1819). Although this capital share parameter is implausible, it is useful to see whether cutting its value aggressively affects the results.

Figures 15 and 16 show the results when using a lower capital share. Now, the decline in capital efficiency has a much weaker impact on growth, while labour efficiency has a much stronger impact on growth. In general, labour efficiency now impacts the general trajectory of growth to a much larger extent, which includes the postwar slowdown in growth. Nevertheless, capital efficiency remains the principal constraint on growth. Using a much lower capital share thus yields results that are quantitatively different, but qualitatively similar, to the baseline case.

Figure 14: Simulations of labour productivity versus the actual movement, with capital share of 0.8, 1928-1989, Soviet Union



Notes: This exercise adds to the CES model in equation 2 (section 3) one at a time the expansion of factors of production, capital efficiency, and labour efficiency. The three sources of growth in tandem match the data (the line "actual").

Source: Own calculations based on data in section 4 of the main text.

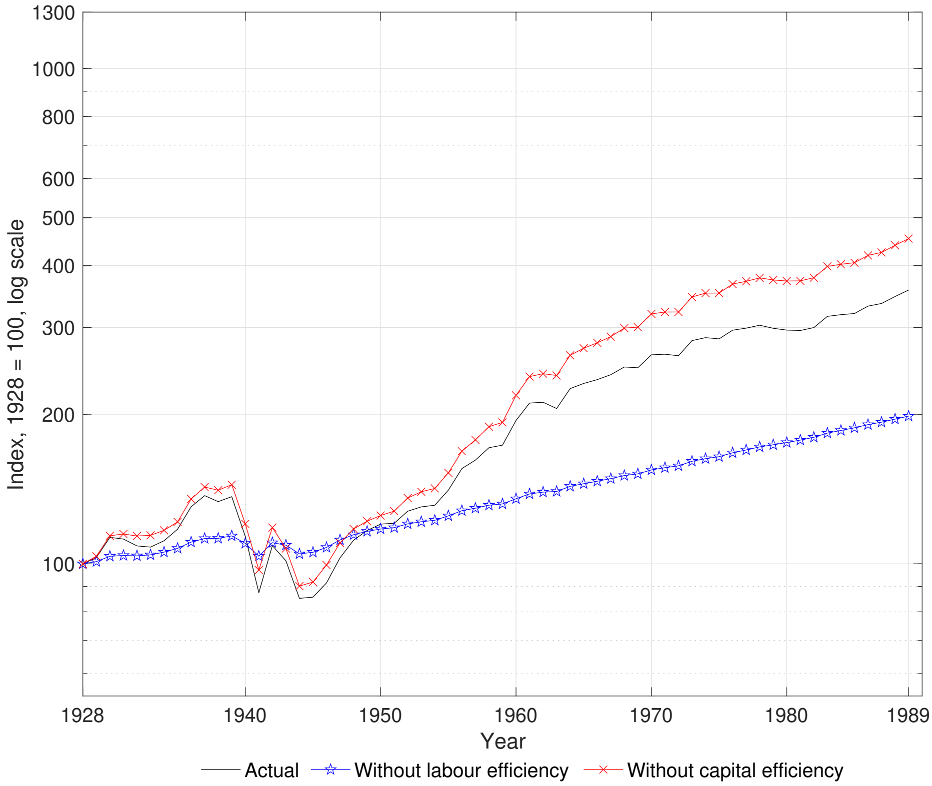
A.2.2 Alternative elasticity of substitution between capital and labour

The parameter σ determines the elasticity of substitution, $1/(1-\sigma)$, with which capital and labor are combined to produce output. In an environment where capital is growing faster than labour, like in the Soviet Union (Easterly and Fischer, 1995), a higher elasticity of substitution effectively puts a greater weight on capital as source of growth. With a higher elasticity of factor substitution, therefore, the decline in capital efficiency will have a stronger impact on growth, while the increase in labour efficiency will have a weaker impact on growth.

In this section, I establish more precisely the sensitivity of my results to the elasticity of substitution between capital and labour. The majority of existing studies find an elasticity value in the range of 0.9/0.99 (see Desai (1986) for an overview). Based on this finding, these studies argue that the Cobb-Douglas production function, with unit factor substitution, provides a good approximation of the production process in the Soviet Union. From the benchmark level of 0.55, I thus increase the elasticity of substitution between capital and labour to a value of 0.99. With this value, the production function is quantitatively almost identical to the Cobb-Douglas form, but qualitatively remains of the CES form. Maintaining the CES form is important, because if the elasticity is exactly equal to one, the CES production function would collapse into the Cobb-Douglas form, and I would not be able to isolate capital and labour efficiency.

In figures 17 and 18, I replicate the baseline simulation exercises of figures 6 and 7 of the main text, respectively. With a higher elasticity of factor substitution, the decline in capital efficiency has a stronger impact on growth compared to the baseline case, reinforcing the finding

Figure 15: The actual evolution of labour productivity versus the counterfactual evolution of it (without labour efficiency or without capital efficiency), with capital share of 0.2, 1928-1989, Soviet Union



Notes: The line "without labour efficiency" holds constant labour efficiency, while allowing all the other sources of growth to vary (capital efficiency, human and physical capital). It thus indicates what labour productivity would have looked like if labour efficiency had not grown at all. The interpretation of the line "without capital efficiency" is completely synonymous to that of the previous line. The counterfactual output levels are derived from the CES equation 2 in section 3.

Source: Own calculations based on data in section 4 of the main text.

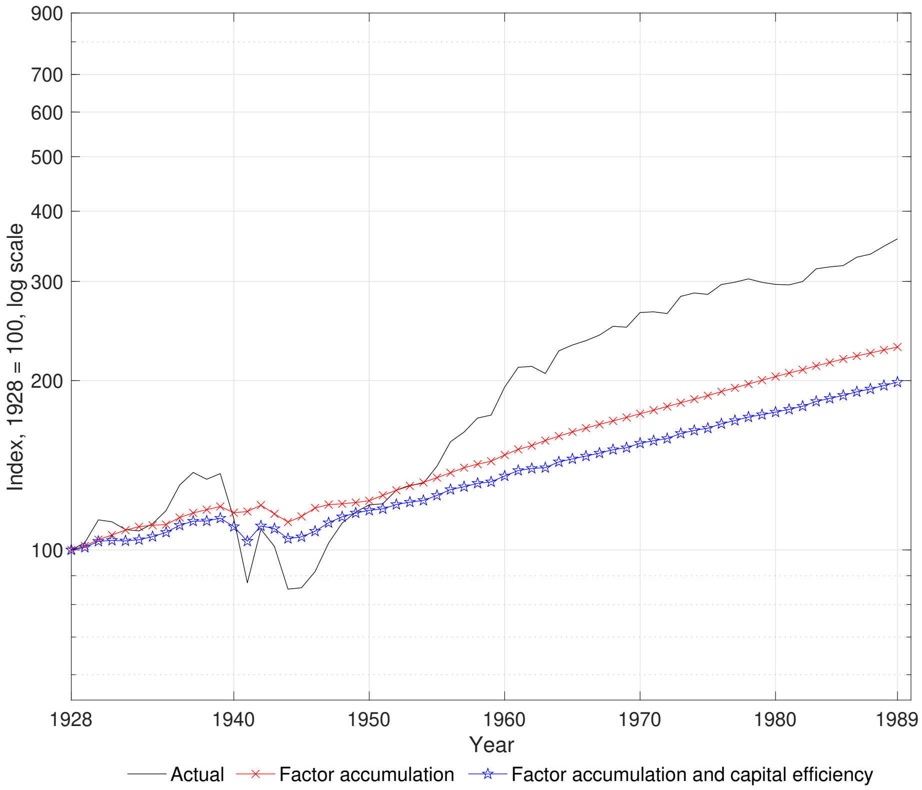
that capital efficiency was of first-order importance in constraining growth. Concerning labour efficiency, its contribution to growth is close to identical to the baseline case, although of slightly smaller magnitude. The results are, therefore, qualitatively identical to the baseline case when using a higher elasticity of factor substitution - capital efficiency remains the principal determinant of the Soviet growth retardation.

A.2.3 Alternative elasticity of substitution for the capital and labour subinputs

This section analyzes the sensitivity of the bias in technical change to the elasticity of substitution parameter for the capital and labour subinputs. A lower elasticity of substitution leads to a steeper relationship between the price premium and the relative supply of an input. This means we need to appeal more to a bias in technical change to rationalize the data. In other words, decreasing the elasticity of substitution would strengthen my results. The skill bias and the equipment bias would be stronger.

I thus show sensitivity tests thatgo strongly against my baseline findings. In figure 19, I increase the baseline value of elasticity of substitution between skilled and unskilled labor to 2, and I double the baseline value of elasticity of substitution between equipment and structures to 1.6. These values fall within the upper bound of plausibility (Temple, 1998; Caselli, 2017).

Figure 16: Simulations of labour productivity versus the actual movement, with capital share of 0.2, 1928-1989, Soviet Union



Notes: This exercise adds to the CES model in equation 2 (section 3) one at a time the expansion of factors of production, capital efficiency, and labour efficiency. The three sources of growth in tandem match the data (the line "actual").

Source: Own calculations based on data in section 4 of the main text.

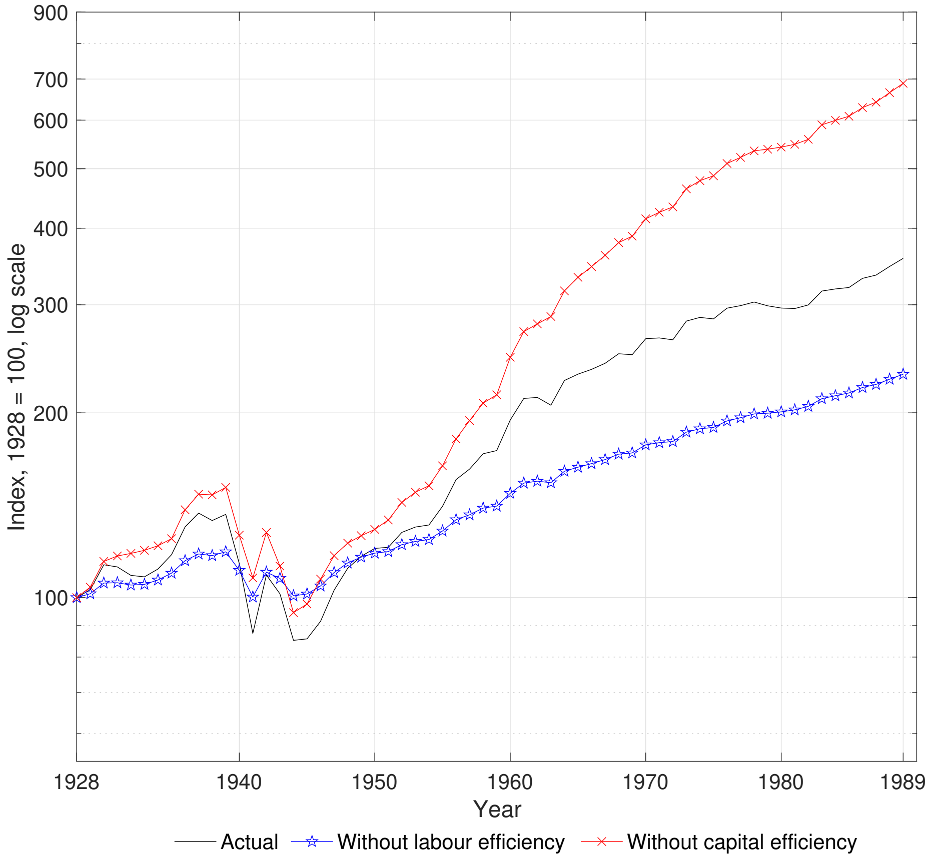
The existing estimates in the literature are typically much smaller, particularly for the elasticity of substitution between skilled and unskilled labor (Caselli, 2017). Figure 19 shows that the results remain qualitatively identical with the higher parameters – skill and equipment bias both remain strong.

In figure 20, I show an even more aggressive robustness check. I increase the two elasticity parameters to 2.5. Even with values that are utterly outside all reasonable bounds estimated in the literature, the results for equipment bias still hold. The bias in skilled labour, however, is now significantly lower over the whole period of analysis. Nevertheless, it still increases during the 1970s and the 1980s.

A.2.4 Alternative depreciation rates

Varying the depreciation rate in the perpetual inventory method changes the relative weight of old and new investment, and hence influences the growth rate of the capital stock. Vonyó and Klein (2019) argue that socialist economies used capital for a long duration, and that capital under central planning depreciated at a lower rate than what is commonly assumed, like in the present paper. In this section, I asses the sensitivity of my results to the depreciation rates that Vonyó and Klein (2019) use. Namely, I assume that the depreciation rate for equipment 6.75, and that the depreciation rate for structures 2.25. These are the average values of the subperiod values that Vonyó and Klein (2019) use, and are substantially lower than what I use in the baseline case (equipment depreciation rate of 12.7 per cent, and structures depreciation

Figure 17: The actual evolution of labour productivity versus the counterfactual evolution of it (without labour efficiency or without capital efficiency), with elasticity of substitution between capital and labour of 0.99, 1928-1989, Soviet Union



Notes: The line "without labour efficiency" holds constant labour efficiency, while allowing all the other sources of growth to vary (capital efficiency, human and physical capital). It thus indicates what labour productivity would have looked like if labour efficiency had not grown at all. The interpretation of the line "without capital efficiency" is completely synonymous to that of the previous line. The counterfactual output levels are derived from the CES equation 2 in section 3.

Source: Own calculations based on data in section 4 of the main text.

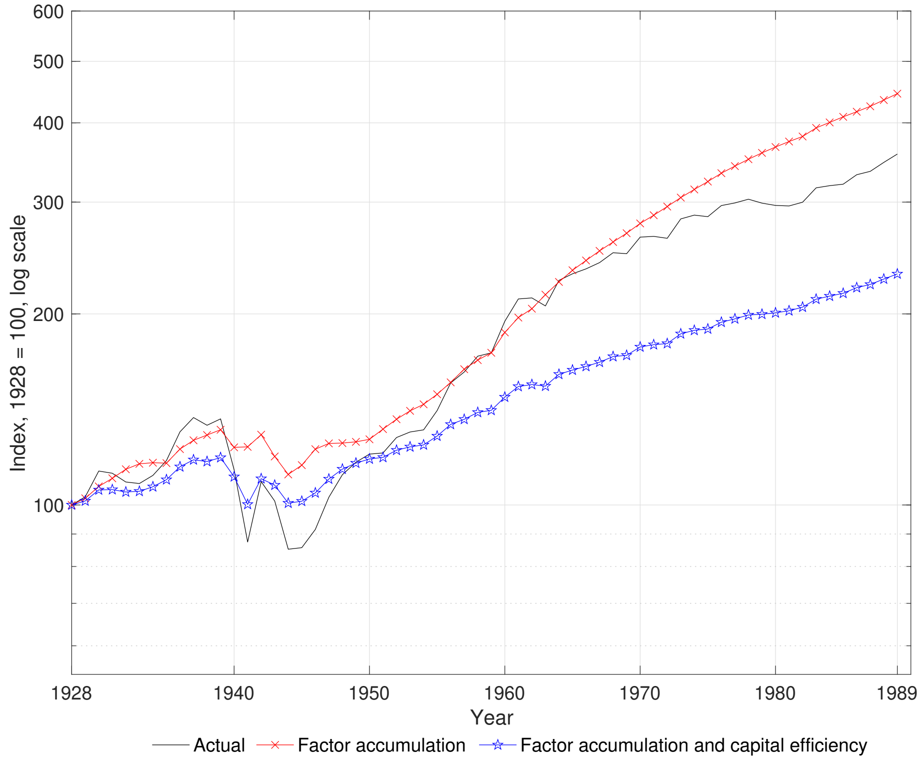
rate of 4.6 per cent).

Figures 21 and 22 show the results when using the lower depreciation rates. With a lower depreciation rate, the growth rate of the capital stock is faster, and the fall in capital efficiency is stronger. Therefore, lower depreciation rates reinforce the finding that capital efficiency drove the postwar slowdown in economic growth.

A.2.5 Alternative returns to years of schooling

In this section, I assess the sensitivity of my results to returns to years of schooling. Returns to years of schooling effectively serve as weights on human capital as a source of output in relation to TFP. For example, by assuming higher returns to years of schooling, I would attach a greater weight to human capital as a source of labour productivity growth at the expense of TFP This would increase the contribution of human capital to growth, and decrease the contribution of labour efficiency. Most of existing studies, however, find lower returns to years of schooling in the Soviet Union than the ones that I use in this paper (6.6 per cent). I therefore assume that returns to schooling are 2.9 per cent, based on the meta-study of Fleisher et al. (2005).

Figure 18: Simulations of labour productivity versus the actual movement, with elasticity of substitution between capital and labour of 0.99, 1928-1989, Soviet Union



Notes: This exercise adds to the CES model in equation 2 (section 3) one at a time the expansion of factors of production, capital efficiency, and labour efficiency. The three sources of growth in tandem match the data (the line "actual").

Source: Own calculations based on data in section 4 of the main text.

Figures 23 and 24 show the results when using lower returns to years of schooling. With a lower return, the growth rate of the human capital stock is slower, and the growth in the labour efficiency is much faster. Therefore, in relative terms, capital efficiency becomes more salient in causing the postwar slowdown in economic growth.

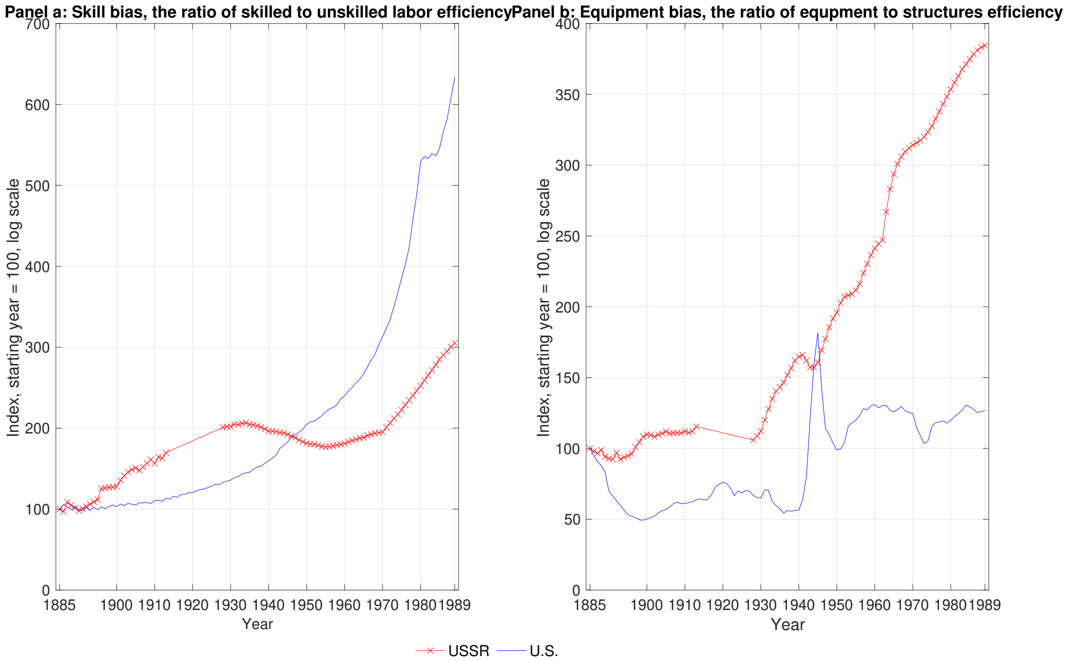
A.2.6 Alternative skill threshold

In the baseline case, I use high-school completed as the threshold for skilled labour. This choice is frequently made in the literature on human capital and development (see Caselli (2017) for an overview). Of course, reality is complex, and drawing an arbitrary line to classify workers into these two categories is a subjective judgment.

Having said that, one may argue that a better threshold for skilled labour is primary school completed. Primary school roughly separates the completely illiterate and innumerate from those who can at least read a text and perform basic arithmetic operations. There are many tasks that no number of completely illiterate agents will be able to perform, and thus the assumption that completed primary schooling marks a fundamental separation between the two groups of workers is possibly more defensible. Moreover, this threshold might be more suitable for developing countries, like the Soviet Union, where basic literacy and numeracy skills are in short supply, and thus highly valued.

Choosing a different threshold for skill also requires re-estimating the wage premium, which is highly data-intensive. Here, I take a slightly different approach compared to the baseline case.

Figure 19: The bias in technical change, with higher elasticity of substitution parameters, Soviet Union and the US, 1950-89



Notes: The bias in technical change is measured with $1/(1-\rho) = 2$ and $1/(1-\eta) = 1.6$.

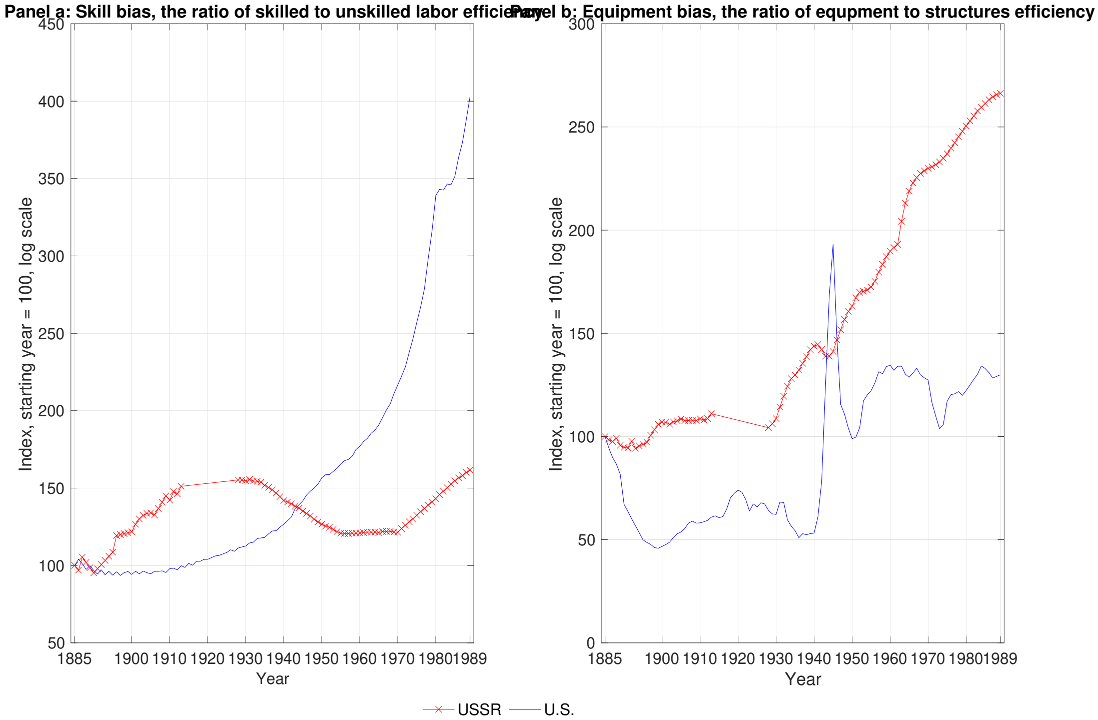
Rather than basing the returns to education for the different categories of workers on the US data, I base the returns on the Soviet data. Namely, I take them from Strumilin (1962), who was an author of the first five-year plan, In 1924, he published a remarkable paper based on a sample of 2602 lathe operators, estimating the relationship between education and productivity. It was intentionally a prewar sample to eliminate the effect of the post-1917 compression of wages that obscured the relationship between education and productivity. Strumilin estimated an equation in which earnings (a measure of productivity) depended on age, job experience, and years of education, preceding the work of Mincer. His results imply that, in the unskilled aggregate, the relative efficiency of workers with some primary schooling is 0.32. In the skilled aggregate, the relative efficiency of workers is 1.56 with some secondary school, 2.01 with secondary school completed, and 2.41 with some university or completed university. These returns are high, but high returns to skill within developing economies are common.

In figure 25, I present the results when changing the skill threshold for the Soviet Union (I keep it the same as in the baseline case for the US). With a lower threshold, the skill bias is much stronger compared to the baseline case. It grows rapidly throughout the Soviet period, and accelerates during the final decades of analysis. Therefore, the baseline finding that technical change was skill biased in the Soviet Union is reinforced when using a lower skill threshold.

A.2.7 Alternative returns to education for skilled and unskilled labour

Beyond the work of Strumilin (1962) (see the above robustness check), there is very little research on the returns to education for the different categories of workers in the Soviet Union. As such, in the baseline case, I based the Soviet returns to education within the skilled and unskilled labour aggregates on the US data that Caselli (2017) uses, and adjusted these returns for the difference between the US and Soviet mincerian coefficient (see section 4 of the main text). In this section, I assess whether the skill bias in the Soviet Union is sensitive to the choice of

Figure 20: The bias in technical change, with very high elasticity of substitution parameters, Soviet Union and the US, 1950-89



Notes: The bias in technical change is measured with $1/(1-\rho) = 2.5$ and $1/(1-\eta) = 2.5$.

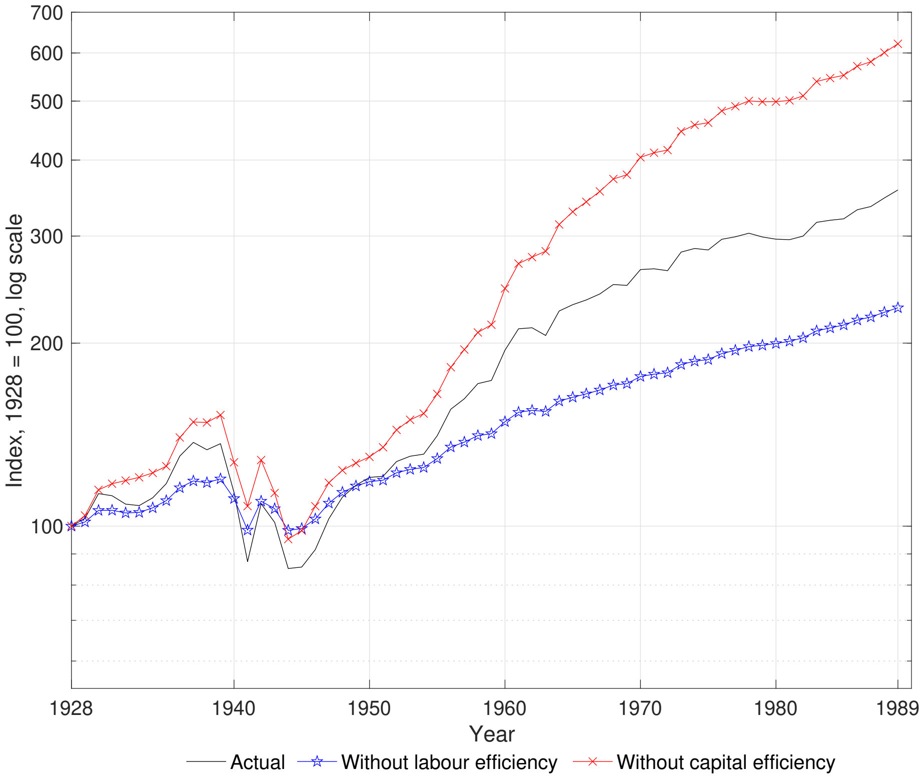
different returns to education.

I find that changing the returns to education by smaller amounts has a minimal impact on the results (e.g., increasing them by 10 or 20 per cent). I thus prefer to present here more aggressive robustness checks. In the first case, I increase the returns to education for each category of workers by 50 per cent relative to the baseline case. In the unskilled aggregate, this makes the relative efficiency of Soviet (US) workers 0.32 (0.48) with some primary schooling; 0.38 (0.57) with primary school completed; and 0.55 (0.84) with some secondary school. In the skilled aggregate, the relative efficiency of Soviet (US) workers is 0.14 (0.21) with some college; and 0.46 (0.69) with at least a college degree.

In the second case, I decrease the returns to education for each category of workers by 50 per cent relative to the baseline case. In the unskilled aggregate, this makes the relative efficiency of Soviet (US) workers 0.11 (0.16) with some primary schooling; 0.13 (0.19) with primary school completed; and 0.18 (0.28) with some secondary school. In the skilled aggregate, the relative efficiency of Soviet (US) workers is 0.05 (0.07) with some college; and 0.15 (0.23) with at least a college degree.

Figure 26 shows that the skill bias, both in the US and the Soviet Union, is stronger when using higher returns to education. When using lower returns to education in figure 27, the bias is weaker. Nevertheless, in both cases, the dynamics of the skill bias are similar to the baseline case. The results are therefore robust to the different returns to education.

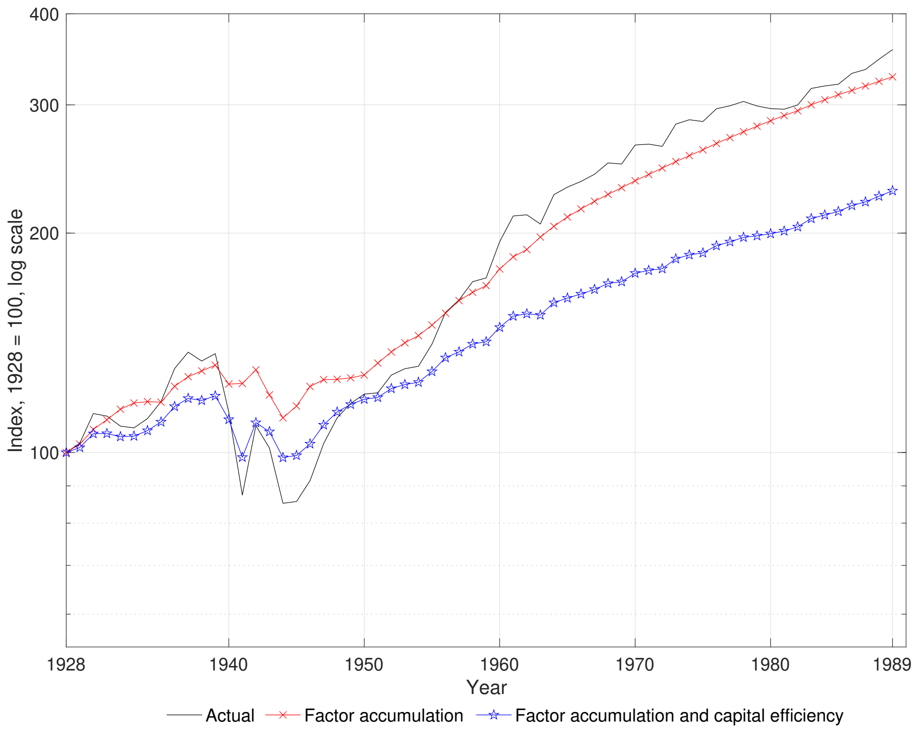
Figure 21: The actual evolution of labour productivity versus the counterfactual evolution of it (without labour efficiency or without capital efficiency), with lower depreciation rates, 1928-1989, Soviet Union



Notes: In this robustness check, I assume that the depreciation rate for equipment 6.75, and that the depreciation rate for structures 2.25, following Vonyó and Klein (2019). The line "without labour efficiency" holds constant labour efficiency, while allowing all the other sources of growth to vary (capital efficiency, human and physical capital). It thus indicates what labour productivity would have looked like if labour efficiency had not grown at all. The interpretation of the line "without capital efficiency" is completely synonymous to that of the previous line. The counterfactual output levels are derived from the CES equation 2 in section 3.

Source: Own calculations based on data in section 4 of the main text.

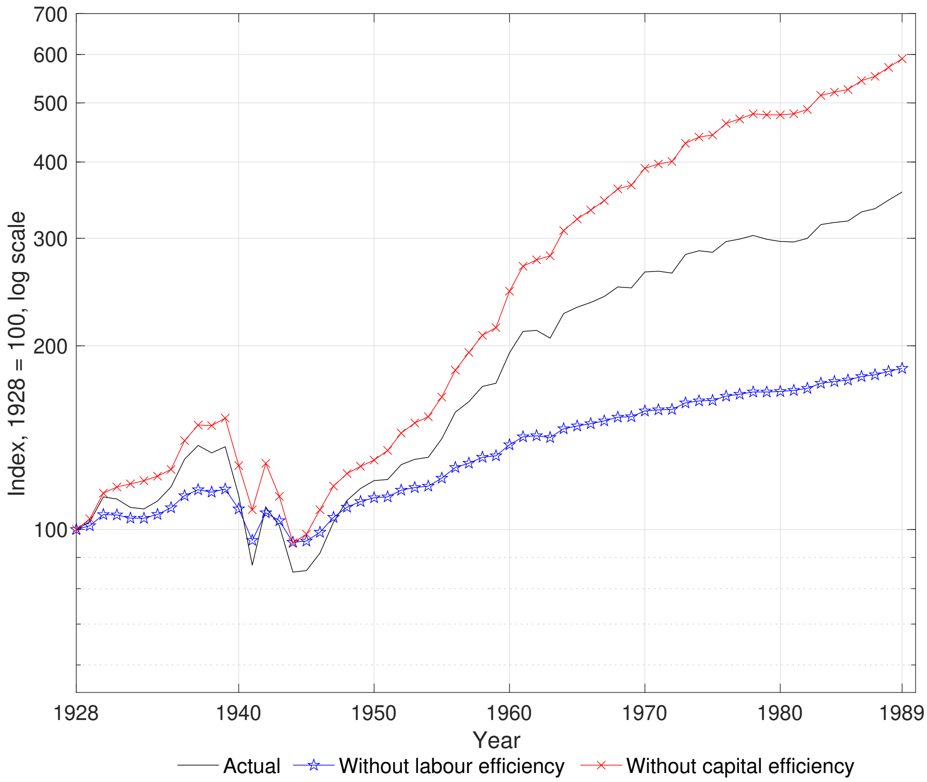
Figure 22: Simulations of labour productivity versus the actual movement, with lower depreciation rates, 1928-1989, Soviet Union



Notes: In this robustness check, I assume that the depreciation rate for equipment 6.75, and that the depreciation rate for structures 2.25, following Vonyó and Klein (2019). This exercise adds to the CES model in equation 2 (section 3) one at a time the expansion of factors of production, capital efficiency, and labour efficiency. The three sources of growth in tandem match the data (the line "actual").

Source: Own calculations based on data in section 4 of the main text.

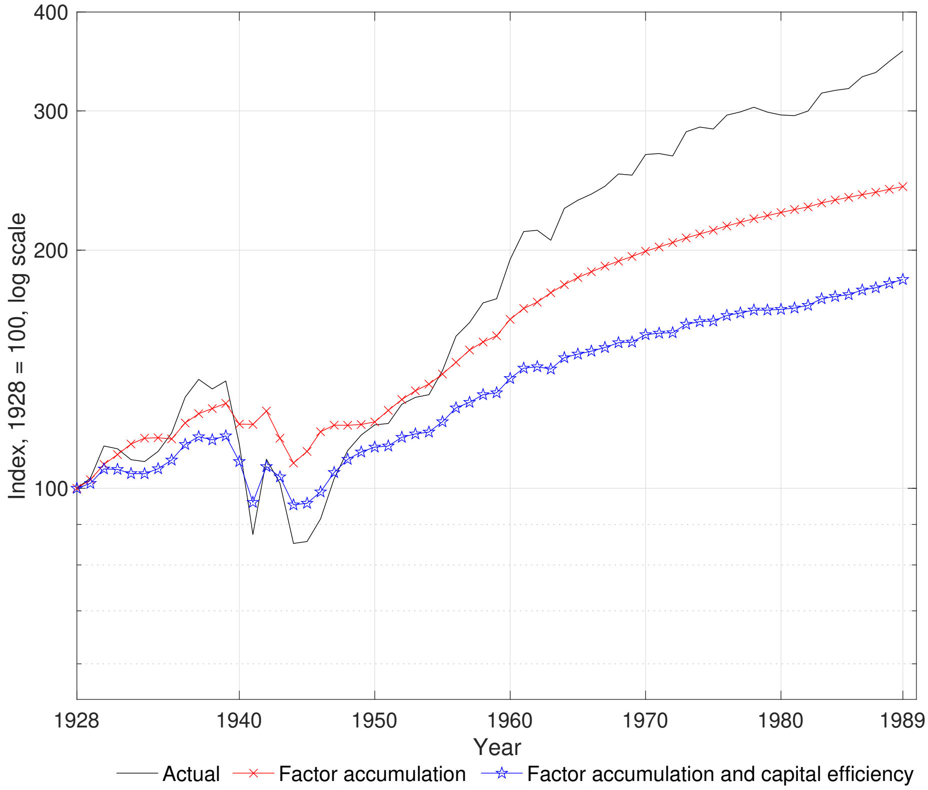
Figure 23: The actual evolution of labour productivity versus the counterfactual evolution of it (without labour efficiency or without capital efficiency), with the return to schooling of 2.9 per cent, 1928-1989, Soviet Union



Notes: The line "without labour efficiency" holds constant labour efficiency, while allowing all the other sources of growth to vary (capital efficiency, human and physical capital). It thus indicates what labour productivity would have looked like if labour efficiency had not grown at all. The interpretation of the line "without capital efficiency" is completely synonymous to that of the previous line. The counterfactual output levels are derived from the CES equation 2 in section 3.

Source: Own calculations based on data in section 4 of the main text.

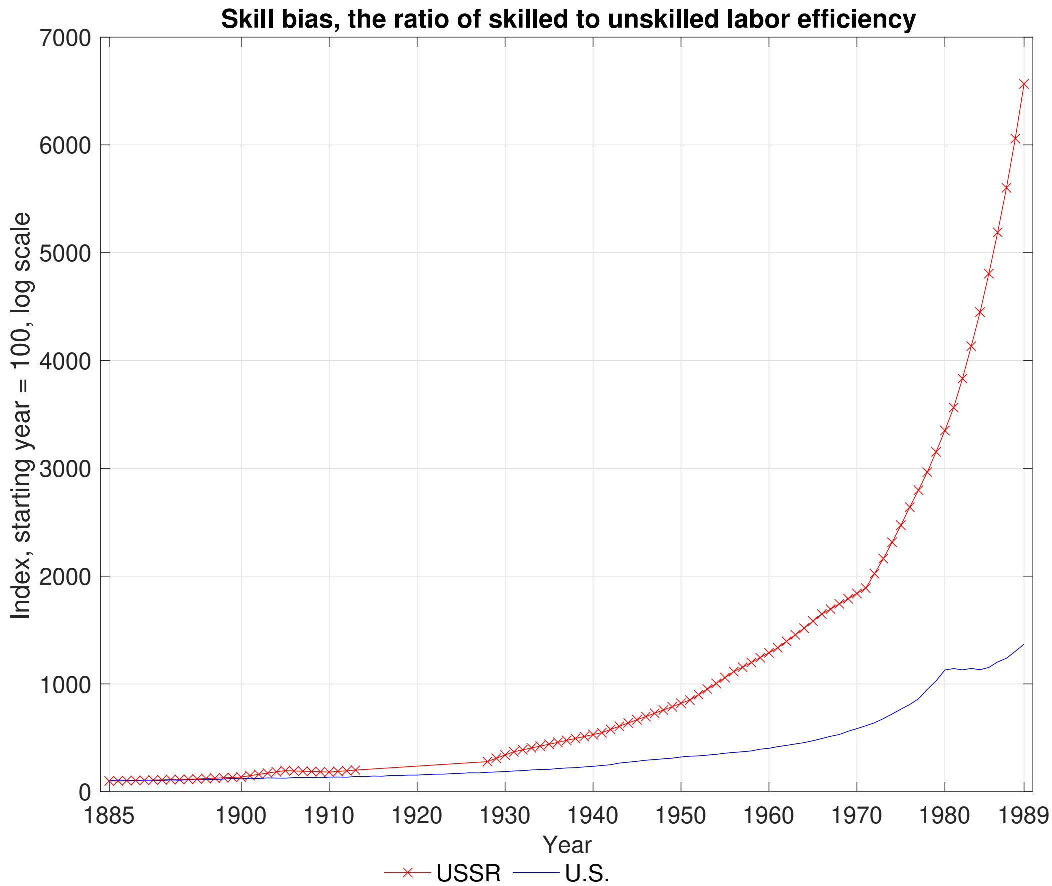
Figure 24: Simulations of labour productivity versus the actual movement, with the return to schooling of 2.9 per cent, 1928-1989, Soviet Union



Notes: This exercise adds to the CES model in equation 2 (section 3) one at a time the expansion of factors of production, capital efficiency, and labour efficiency. The three sources of growth in tandem match the data (the line "actual").

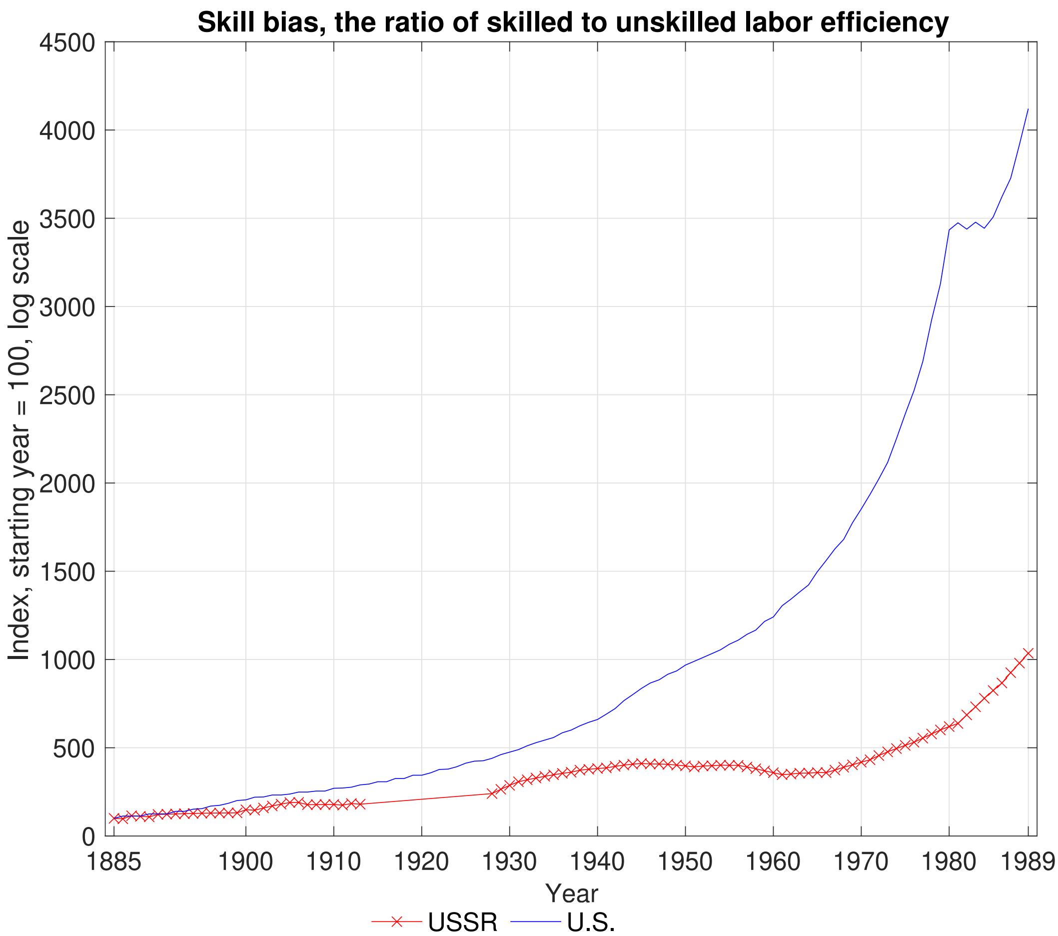
Source: Own calculations based on data in section 4 of the main text.

Figure 25: The bias in technical change, with lower skill threshold, Soviet Union and the US, 1950-89



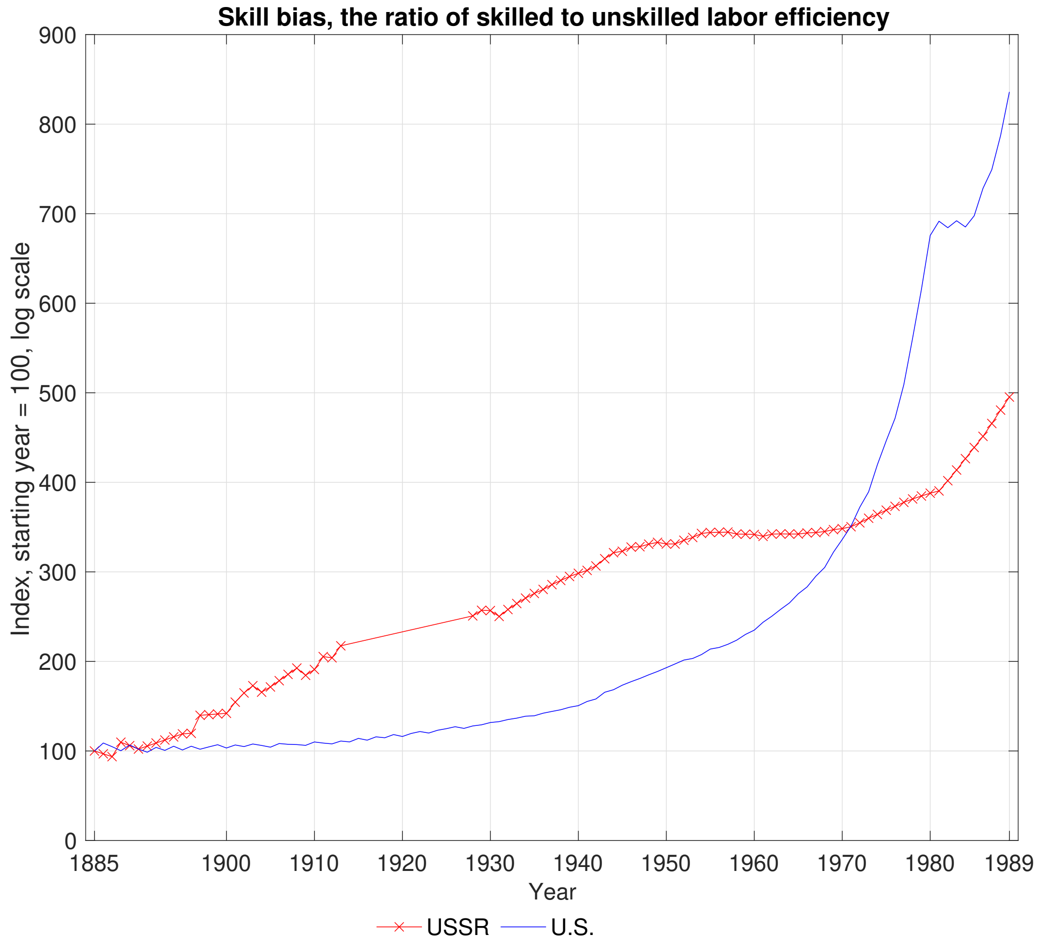
Notes: This graph takes primary school completed as the threshold for skilled labour in the Soviet Union. In the US, the threshold for skill is secondary school completed, just like in the baseline case.

Figure 26: The bias in technical change, with higher returns to skill, Soviet Union and the US, 1950-89



Notes: In this robustness check, I increase the returns to education for each category of workers by 50 per cent relative to the baseline case. In the unskilled aggregate, this makes the relative efficiency of Soviet (US) workers 0.32 (0.48) with some primary schooling; 0.38 (0.57) with primary school completed; and 0.55 (0.84) with some secondary school. In the skilled aggregate, the relative efficiency of Soviet (US) workers is 0.14 (0.21) with some college; and 0.46 (0.69) with at least a college degree.

Figure 27: The bias in technical change, with lower returns to skill, Soviet Union and the US, 1950-89



Notes: In robustness check, I decrease the returns to education for each category of workers by 50 per cent relative to the baseline case. In the unskilled aggregate, this makes the relative efficiency of Soviet (US) workers 0.11 (0.16) with some primary schooling; 0.13 (0.19) with primary school completed; and 0.18 (0.28) with some secondary school. In the skilled aggregate, the relative efficiency of Soviet (US) workers is 0.05 (0.07) with some college; and 0.15 (0.23) with at least a college degree.

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